Self-organisation in non-linear systems: On the triptych of compositions *dripping, windscapes* and *sono taxis*

By Andreas Bick

"If we examine the history of natural science, we discover two diametrically opposed phenomena: on the one hand, simplicity concealed behind apparent complexity; and on the other, apparent simplicity masking extraordinary complexity." Henri Poincaré

The triptych of sound-art compositions *dripping, windscapes* and *sono taxis* focuses on the acoustic phenomena of dripping water, wind sounds, and the songs of frogs and crickets. All three works are based on a new philosophy that has become established in the natural sciences over the past 30 years, causing the cliché-laden sounds of nature, whose potential seemed to have been exhausted, to appear in a new light. This essay aims to give an outline of this new thinking.

Our everyday life is shaped by processes that we can explain intuitively on the basis of simple laws of causality: identical causes have identical effects. This physical worldview dates back to Sir Isaac Newton, whose laws of gravity provided an elegant description for the behaviour of bodies, making the world appear as a giant mechanism functioning like clockwork. This gave rise to the paradigm of determinism, according to which all events could be predicted given sufficient knowledge about the position and speed of all the bodies in the universe ('Laplace's Demon'). This strictly mechanistic approach was not broken with until the 20th century, beginning with the French mathematician Henri Poincaré, who discovered systems whose behaviour could not be predicted despite knowledge of all the physical laws on which they were based. His findings were confirmed by a chance discovery in the 1960s by the American meteorologist Edward Lorenz: during analysis of weather data, he found processes where the tiniest differences in initial conditions sometimes resulted in dramatic changes or even totally irregular system behaviour. Lorenz popularised the idea of the 'Butterfly Effect' – implying that under certain conditions, the beat of the wing of a butterfly could trigger a tornado somewhere else on the planet. This led to a paradigm shift: the deterministic worldview retains its validity for our understanding of everyday phenomena, but on closer examination, many processes in nature can no longer be described using mechanistic models (small causes may have large effects).

Irregular and apparently random movements in nature are referred to as 'deterministic chaos'. The mathematical definition of this term states that the behaviour of a system can be described by differential equations (deterministic), but that it displays irregular, unpredictable temporal behaviour (chaos). Systems whose behaviour is characterized by deterministic chaos are referred to as 'non-linear systems', as distinct from purely regular (periodic) and random (stochastic) processes. Contrary to our mechanistic worldview, in nature, non-linear systems are the norm rather than the exception. Flowing liquids and turbulence, convection currents and circulation systems in the atmosphere, climate models, oscillating chemical reactions, biological ecosystems, neurological systems and social processes can all be explained in terms of non-linear dynamics.

One special field within non-linear dynamics is pattern-building processes in nature, as seen in corals, animal fur patterns or plant growth. These phenomena provide ideal samples for the study of non-linear systems, since a small number of variables are responsible for the formation of complex patterns via feedback effects and processes that amplify each other. The special property of these non-linear systems is that they generate a range of patterns each with its own identity, like a fingerprint, with no two patterns alike. The huge variety of pigment patterns on the shells of tropical snails provide an outstanding model for this kind of pattern-building processes. They are created along the growth axis of the shell as a result of overlapping chemical reactions. Each shell develops its own individual pattern, with each species of snail possessing its own formula which can be described using differential equations and which allows it to be distinguished from other species (cf. Hans Meinhardt, *Algorithmic beauty of sea shells*). Other examples, bringing us back to the compositions referred to above, include the ‘chaotically dripping tap’, the formation of sand dunes and ripples in deserts, and patterns of interaction in frogs and crickets.

The ‘chaotically dripping tap’ is one of the classical experiments in chaos research. It dates back to investigations carried out by Robert Shaw and his colleagues at the University of California in Santa Cruz, who discovered chaotic behaviour in dripping taps at the transition from periodic dripping to a constant flow. With the help of microphones and photoelectric beams, they measured the non-periodic behaviour of the water drops. To their surprise, they were able to represent the data graphically as so-called ‘strange attractors’, which points to deterministic chaos as the cause of this behaviour and means mathematical modulation is possible. For the sound-art composition *dripping*, this test set-up was extended to include several additional drip openings per water source, creating a network of dense rhythms that influenced each other. By combining various resonating bodies under the dripping apparatus, it was possible to gain an acoustic image of these complex rhythmical patterns and render them in sound.

The sound-art composition entitled *windscapes* translates the ripple patterns on desert sand dunes into acoustic rhythm structures. According to Hiraku Nishimori and Noriyuki Ouchi from Ibaraki University in Japan, the formation of ripple marks and of the dunes themselves can be understood as a non-linear system and described in differential equations. In this model, the parameters of wind, sand and gravity form a simple system where the smallest accumulation of sand grains triggers a self-amplifying effect resulting in a ripple mark, in whose wind shadow further ripples will automatically be formed. The same principle applies for the formation of dunes: viewed from above, they can often be seen to form patterns similar to those formed by ripples. Grain of sand for grain of sand, the simple processes at work here create complex patterns of limitless variety at the macroscopic level. In *windscapes*, these patterns were translated into acoustic information by deriving acoustic control signals from photographs of various sand ripple marks, which were then transferred to horizontally suspended sheets of paper with the help of contact loudspeakers. Astonishingly enough, the sand strewn on the sheets of paper immediately formed dune-like patterns and moved across the paper in the same way as wandering dunes. Recordings of these sand movements formed the basis for the rhythmical composition parts of *windscapes*, allowing the formation of sand-ripples to be heard in a single grain of sand, so to speak.

Although this kind of scientific study has yet to be carried out for the patterns of acoustic interaction among frogs and crickets, it is likely that similar non-linear processes are at work here too. Each species of frog and cricket has its own unique acoustic code, defined by the pitch and time structure of the call, primarily for reproductive purposes. In biology, this type of communication is known as ‘phonotaxis’ and is considered the oldest form of acoustic interaction in the animal kingdom. As soon as several individuals of a single species join to form a chorus or are forced to compete by limited habitat, certain collective phenomena occur that represent more than just the sum of their individual voices. The most frequent example of this is synchronization of individual calls, but more complex call patterns may also occur, for example when individual animals try to make their own calls heard in the pauses between the calls of nearby rivals. In addition, attempts to gain a competitive advantage by outdoing each other in volume often results in the song of the chorus getting louder and louder until it stops abruptly, starting again from a lower volume. *sono taxis* explores a wide range of original recordings of such interaction patterns, which formed the basis for the rhythmical parts of the composition. The extraordinarily dense soundscape of the jungle is treated as an acoustic organism, created above all by the competing species of grasshopper, cricket and frog in their struggle for acoustic niches.

The examples used in these three compositions show that in the larger context, processes taking place at the level of the smallest unit combine in fascinating ways to form collective phenomena. Contrary to received wisdom (‘the whole equals the sum of its parts’), pattern-building processes build complex structures based on the apparently chaotic behaviour of individual elements which interact to produce more elaborate structures (‘the whole equals more than the sum of its parts’). This phenomenon is referred to in various fields of natural science as ‘self-organization’ and is considered to be the driving force behind many development processes. Even the evolutionary origins of life on earth in general have been considered as the result of a gigantic process of self-organization of matter, in the course of which life gradually developed out of the primordial soup (cf. Manfred Eigen, *Molecular self-organization of matter and the evolution of biological macromolecules*).

Nature is a highly networked system characterized by an extremely complex interweaving of chaos and order. The pattern-building processes described above are like the tiniest oscillating nodes in a network of interlacing rhythms and time scales that repeatedly apply to each other the laws of development on which they are based. Nature has no fixed unit of time such as those on which we have based our linear notion of time since the invention of mechanical clocks. In nature, time is cyclical, subtly adapting itself to its surroundings with every new cycle. Nature knows no identical processes, only similar ones, with each repetition marked by tiny changes and imperfections. In fact, this ‘fuzziness’ in the rhythms of nature is an essential prerequisite for the flexibility and stability of its systems.

This understanding of rhythm and time forms the shared basis for the sound-art compositions *dripping, windscapes* and *sono taxis.* Instead of following a time signature or fixed meter, the polyrhythmic structures of pattern-building processes consist of several pulses moving on a number of timelines that attract and repel each other as if under the influence of gravitational forces. Rhythms and meters become blurred, with the semantic richness of the material creating a moiré of repeated patterns. These typical properties of pattern-building processes were used to develop a montage technique that has often been described as a 'drifting pattern'. This style of editing was designed to follow the specific dynamics of non-linear processes by repeating passages from the polyrhythmic pattern over and over with a certain degree of fuzziness. This also made it possible to achieve an organic interlocking of recordings made at different times. This editing technique involves a time window moving along a rhythmical pulse of the pattern, steadily shifting by a tiny amount with each cycle, subjecting the material to a sequence of rhythmical reinterpretations. The shifting of the time window can be calculated from the tempo of a basic pulse, with the size of the shift always close to the fusion frequency of the human brain. A suitable image to describe this technique would be cutting a vertical section out of several copies of a single picture, where the section removed shifts by a certain amount each time. If all the various excerpts are laid next to each other, they form a horizontally stretched version of the original picture. In the same way, the 'drifting pattern' editing technique described above allows the rhythmic patterns to be listened to and interpreted in microscopic detail, the material appears to be multiply reflected and fanned out, and the listener experiences how the different pulses move in relation to one another along their timelines in a form of slow motion, as if in a kaleidoscope.

The 'drifting pattern' composition technique is a tool that enables near empirical study of the rhythmical material. Knowledge is acquired by playing out various patterns and combinations, with the composer's subjective influence taking second place to an intuition of natural processes. In all three sound-art compositions, the composer's role is that of one who listens and learns, he submerges himself in the self-generating material and acts as a medium for it to flow through. This is the result of the particular nature of the non-linear processes described above: unlike the sedimentary accumulation of human cultural activity, these processes lack the historical element to which a composer must usually refer. The natural phenomena on which these pieces are based, and their interpretation via non-linear dynamics, exist beyond human efforts towards innovation. In fact, they constitute one of the primal forces of development in what Thomas Mann referred to as "creatively dreaming nature", whose sign language seems so simple but which can never be wholly deciphered. Or to return to the introductory quotation from Henri Poincaré: this apparent simplicity carries within it an extraordinary complexity, which seems strangely familiar to us, but for which we lack the key to final understanding.

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