Performative Science

CHAPTER I

(co-authored by Inge Hinterwaldner)

One of the main research issues of the ZKM | Institute for Basic Research is "Performative Science." By this we understand a specific relationship between art and science, with the focus on the process. A second project, closely related to "Performative Science," is "Operational Hermeneutics". Briefly, this is a possible relationship between philosophy and science, also focusing on the process. An example of a missing relation between art and philosophy has been discussed by the german philosopher Martin Heidegger. Here we will tentatively term it "Performative Philosophy" to complete the "magic triangle" shown in Fig. 1. "Performative Science" is introduced in Chapter I. A review of our research in the fields of complexity, dynamic cognitive systems and perception, follows in Chapter II. Finally, in Chapter III, "Operational Hermeneutics" will be introduced.

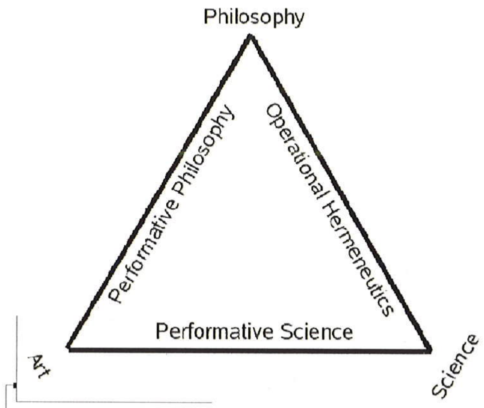


Fig. 1: "Magic triangle," showing the proposed relations between art, science and philosophy.

1. Introduction

Our proposed concept of "Performative Science" should not be confused with "performative studies" which is the "science" of performance. Here we are concerned with the performative element in Science. However, we adopt the notion of "Performativity" meaning a measure for those qualities which cannot be captured and defined in a strict reference system (semiotics). A performance contains more than can be read from pure text (the script, libretto or source code).

As the qualities of live performance are by definition unique, they contradict the scientific dictum of reproducibility. In that complex phenomena cannot be exactly replicated (e.g. weather, earthquakes, cosmology), the performative element plays an additional role in the investigation of complex systems, particularly in dealing with models and data. Interactive manipulation of the parameters during a simulation and the reactions which are evoked, affect the construction of the model.

Firstly, we will give a brief introduction to the notions of performance and performativity. Then discuss two historical examples, in order to explain the basic ideas of "Performative Science." Finally we will present examples from complex systems research. Our aim is to enrich the pool of scientific method and give a better understanding of life processes.

The methods of natural sciences rely, to a large extend, on repeatability. In other words, principles of invariance, stationarity, ergodicity, symmetry etc. are a prerequisite in the laws of physics. Transient behaviour must be excluded. Recently, of course, research into Chaos Theory provides space for a new interpretation of Dynamics. However, even if a specific trajectory is not repeatable in the real world, analysts are at a loss unless the system is, at least temporarily, stationary, i.e., forming an "attractor".

The understanding of complex systems whose behaviour goes beyond stationarity, necessitates flexible methods. Furthermore, the artistic aspect of "Performative Science" tends to imply the process-based structure of Being (which refers to Heidegger's notion of "Dasein") into the canon of scientific methods. Thus, the aim of this chapter, is to promote "Performative Science" as a specific method of investigating complex systems that lack repeatability but also as a general scientific methodological program enriching "classical" fields of research.

According to our observations, some specific practices exist within scientific investigation, which could be described as performances. Thus, we will describe the basic notions of performance and performativity.

There are examples of research being benefited by performance, which provides a motivation for it. We will describe two of these in detail: one taken from social studies (Victor and Edith Turner), the other from humanities (Albert Köster). Then we will look at natural sciences and quote examples from chaotic systems research.

2. Performance and Performativity

Due to many different approaches and divergent developments, the terms "performance" and "performativity" lack conceptual clarity. The notions, of course, derive from various artistic fields and from linguistic, sociological and philosophical discourses, which are rooted in the second half of the 20th century.

They all indicate slightly different concepts, and therefore, no common definition of cultural processes we call "performative," exists.

Although there is a wide range of meanings, a common overlap can be detected. It consists of the focus on "constitution" instead of "ontologically given" or "presence" instead of "representation." The moment of action, its continuity, the inherent temporality, and the relationship to the present, form the basis of the concept [1, p. 11].

Here performativity is meant as a main characteristic of performances that emphasises the moment in which an action is taking place. This moment is not fully controllable. Like theatrical events, also scientific practices have two complementary components. On the one hand it is a kind of text-based knowledge that is implemented intentionally (for example scripts or formulas). Semioticity is the measure of how strong something works as a symbol. On the other hand there are those aspects of performances that cannot be grasped or determined by words: they can be embraced by performativity. One central aspect of the latter touches the relationship between the researcher and the observed object.

3. Characteristics

It fits into our idea of scientific performances that the researcher is actively involved in what he/she is examining. There is something playful in the performative approach. It is primarily intended to open up the space of possibilities, so that the "intention" is secondary at a certain phase. The "actuality" is fundamental, as well as

the process of the researcher acting with his/her tools and topics. This emphasizes its temporality and the perceptible element as important components of the research process. How can one interact with something that does not give any feedback because it is neither visual, audible nor tactile? By integrating interactivity and motor activity, one tries to circle around the object of research, which in the following is called "epistemic thing," according to Hans-Jörg Rheinberger.[1] The researcher tries to provoke a varied manifestation of the examined object, in order to get an insight or an outcome in the end.

4. Performance as a Tool

Here, we are not interested in general performative studies but rather in performance as a method. We concentrate on examples, in which a perceptible scenery is executed by the scientists, in order to explore whatever they are dealing with. To perform his/her model, data or observations enable the researcher to get an alternative approach to the examined processes. Thus, he/she adopts modes of proceeding, which are no longer analytic in a strict mathematical sense. The scientist uses a variety of tools, cooperates for example with other persons, small figures, and computers, in order to create new ideas by means of understanding through embodiment, a practical sense, or action driven knowledge. It follows, that an approach that favours the dichotomy of *logos* and *aisthesis*, as well as the herewith associated idea, that the development of the occidental science is the result of a decreasing reliability in senses, has to be rejected [3, p. 51].
In order to develop further ideas of what could be meant by scientific performances we present two examples, which all began in different periods of the 20th century. The first one is taken from social studies and started in the Sixties.

5. The Turners

Together with his wife Edith, the anthropologist Victor Turner developed the idea to use a performance as a method for capturing aspects that are ignored in ethnological monographs and sometimes also in films. These aspects may be intent, drumming, laughter, the sense of power passing [4, p. 194].
Around 1965 they started a series of performances with their students, first in Cornell, later also in Chicago and at other universities. The seminars were moved into the living room of the Turners, where the discussed rituals and sceneries were "staged."
In order to develop a convincing play, one has to widen ones own horizon, go beyond ethnographic reports and consult literary, historical, biographical and other sources. In collaboration with directors (for example the dramaturge and theoretician Richard Schechner), actors, set-designers and students of anthropology, Victor Turner tried to produce play scripts of rituals from diverse cultures or from special conflicts, that according to Turner followed a certain pattern that he called "social dramas." He then tried to stage these situations.
Anthropological monographs and movies may describe the incentives for action that are characteristic of a certain group. However these genres only rarely give an adequate impression of how participants of a certain culture experience each other. The aim of all performances organized by the Turners was to enrich these theoretical models, so that the students could get a feeling for emotional constitutions, possibilities of expression and logics of actions [5, p. 32]. The performances were always thought as scientific practices.

> "Our aim was not to develop a professional group of trained actors for the purposes of public entertainment. It was, frankly, an attempt to put students more fully inside the cultures they were reading about in anthropological monographs. Reading written words kowtows to the cognitive dominance of written matter and relies upon the arbitrariness of the connection between the penned or printed sign and its meaning. What we were trying to do was to put experimental flesh on these cognitive bones." [5, p. 41]

These words suggest the possibility, that the sensorial executions could provide a critical analysis for the textually fixed claims of scientists. For the Turners the performances may have been a tool for discovering what had not been noticed and for detecting implausible passages in writings. After a precise preparation and after resolving some central problems, this subversive potential can be made accessible. Victor Turner writes:

> "How could we turn ethnography into script, then enact that script, then think about, then go back to fuller ethnography, then make a new script, then act it again? This interpretive circulation between data, praxis, theory, and more data - a kind of hermeneutical Catherine wheel, if you like - provides a merciless critique of ethnography. There is nothing like acting the part of a member of another culture in a crisis situation characteristic of that culture to detect inauthenticity in the reporting usually made by Westerners and to raise problems undiscussed or unresolved in the ethnographic narrative." [6, p. 90]

In the meantime some of the Turners' former students picked up this approach. One of them is Pamela R. Frese. She investigated the cultural, structural and social dynamics of weddings in Central Virginia. In 1981 a corresponding performance was planned that involved the whole Institute of Anthropology at the University of Virginia. Some weeks before the event took place the "genealogies" were fixed on the wall, so that everyone could prepare his/her role mentally. Edith and Victor Turner were playing the bride's parents. Confer Figs. 2a-d.

Fig 2a: The reception line welcoming the "bridal pair." (Frese)

Fig. 2b: Arranging the "bride's" veil. (Frese)

Fig. 2c: The couple feed cake to each other. (Frese)

Fig. 2d: Stealing the "bride's" garter. (Frese)

[1] An "epistemic thing" is an object of research, under the condition, that something is still not understood. Because of this lack of understanding it gets the necessary blurredness, that is needed and exploited in the experiment, in order to widen the horizon of options [2].

6. Albert Köster

Our second example is the work of Albert Köster (1862-1924), professor of German studies in Leipzig and one of the main founders of the theater studies in Germany. Around the year 1907, he started a collection of historical material concerning the matter of theatre "exclusively for scientific purposes" [7, p. 71], as he wrote. He gathered scripts, drawings, sketches in oil, watercolor paintings etc. Köster accepted only objects that "raise and solve problems according to the spirit of science - but this in a far-reaching manner" [7, p. 72]. The core of his collection is a series of self-manufactured small models of stages from different places and epochs. Until his death in 1924 he had produced 22 accurately shaped examples and ten simpler auxiliary models. Köster was proud of them. He took his preoccupation with them seriously because he saw them as a piece of his lifework that had to be regarded as substitutes for not yet written books [7, p. 73].
Köster's ambition was not to create a realistic and detailed copy of a specific performance stage, instead, he wanted to catch the typical basic forms which were realized throughout time. He put the collection as a loan at the university's disposal, so that the unique models were ready to be used in courses or for private studies and experiments [8, p. 128]. It is important to note, that the models were not seen as final products. The auxiliary models were pragmatic variations of the basic forms. However, also the sophisticated models were made to be used. This use of the models was the purpose Köster had in mind:

> "These typical or hypothetical models prove their correctness only because the corresponding play scripts can be performed on them - and possibly exclusively on them - without contradiction." [7, p. 74]

That is the reason why their main value is gained only by following the dramas scene by scene with one's own eyes. In other words, it is not sufficient to explain the empty miniature architecture models.

Fig. 3: View into some rooms of the former theatre museum in Munich (1935). The model on the right is the so called "Hans Sachs" stage of the 16th century in the church St. Martha in Nuremberg. Köster's model is shown here the way it was never intended by the inventor because it's not used as a tool.

A closer look at what Köster was doing with his small stages reveils small coloured figurines with which the stage was inhabited (Fig. 3). On the one hand he puzzled over the constructions of the stages, which may be influenced by certain logistic compulsions. On the other hand, he rehearsed the plays with the figures on them, especially how and when of the actors appear and disappear. Köster named his acting "historische Inszenierungen (historical performances)" of older dramas on the models.
His aim was ambitious: The really important thing from a scientific point of view is to revive a played piece of theatre in the way the poet and his/her contemporaries had it in front of their mental or physical eyes. This has to be done with rich, but at the same time restrained fantasy, as well as by questioning each thesis in the first place [9, p. 22].
Interestingly, Köster, who had quite some problems to justify his sensorial reproductions of the plays in front of colleagues, insisted, that working with the models forces one to be more precise. He wrote:

> "What we decided instinctively or hypothetically in former times, may now be grabbed a bit firmer." [7, p. 75]

He continued:

> "And then it happens like this: one tries out a new direction, one imagines oneself in it, and in doing so one encounters with a lot of small welcome discoveries along this path." [7, p. 75]

Exactly those experiences, for example unnoticed aspects in text sources, are central for developing new theses. Additionally, those models support "vivid thinking" and imagination. Köster finds it very difficult, to remember and to take into account the numerous influential "ingredients" without the help of the "visible means."

7. Advantages of Performances

7.1 Imagination. We now describe some of the advantages, which arise from the performative scientific practice. Köster put it very clear:

> "It is of course possible to imagine the stage of Aristophanes today, tomorrow the one of Hans Sachs, and then those of Richard Wagner or Corneille in a rapid change. Besides the fact, that someone could lack in detailed knowledge somewhere, many persons haven't got the powers of imagination." [7, pp. 72-73]

(that of course is needed.) According to Albert Köster only gifted scholars may be successful in working in a purely mental way.
Sometimes, however, for example in physics, especially in nonlinear dynamics, it is simply impossible to tackle the irregularities. Visualized simulations can often help in these cases. That is why Lambert Wiesing states, that the computer enhances the ability of human imagination [10, p. 235].

7.2 Better Understanding. Those performances may be seen as a new tool for "tinkering" about the epistemic thing. They are useful to understand the own theoretical models or the observed occurrence in a deeper or different way. We quote the Turners, who give an account of their own experiences:

> "Whenever our classes have performed scripts based on our own fieldwork among the Ndembu of Zambia in Central Africa we have undoubtedly learned something about that culture that we failed to understand in the field." [5, p. 46]

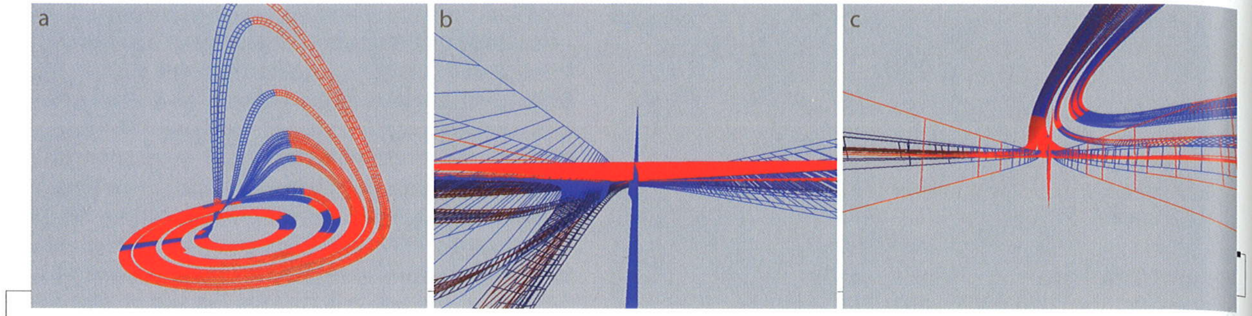
Edith Turner explains furthermore:

> "In another context, our performance of the psychodrama mode of healing and the students' response made me realize that African healing rituals are a combination of a true psychic psychodramas, with all the truth coming out, and the shamanism involved in finding and communicating with the spirit that is making the person ill. I'd never have understood this if we had not had our performances. Books simply don't effect this sort of thing." [11]

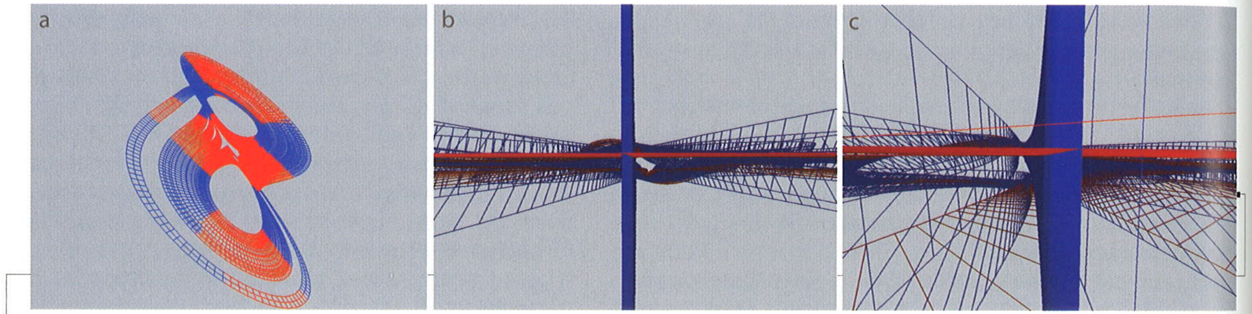
7.3 Critique and Heuristics. In the following we give examples from the fields of complex systems research. Beside all the differences to the historical cases mentioned above, they have in common that visually and/or audibly performing processes may lead to new ideas and hypotheses. We emphasize, that the performance should not be reduced to mere entertainment or decoration, but rather has to be taken seriously as a vehicle for content that has to be interpreted. The performance is not an external event, which could be shifted toward the sociology of science, but an uncircumventable and constituent element of concrete practical investigations, although its importance has often been denied. At least one can say that performances serve as a heuristic tool in basic research. Perhaps it should be emphasized, that performative science is not meant to be applied when it comes to analyse mathematically, to calculate or to evaluate. It is not meant to "construct a bridge" in a concrete sense, however, it may be used as a bridge between disciplines in a metaphorical sense.

8. Endo-Chaos

In this section two chaotic attractors, the Rössler attractor (Figs. 4a-c) and the Lorenz attractor (Figs. 5a-c) in phase space are the objects under performative investigation.



Figs. 4a-c: Three screenshots of an Endo-Chaos-Simulation: One sees an exo view (a) of the Rössler attractor and the flipping behaviour of the endo view (b, c).



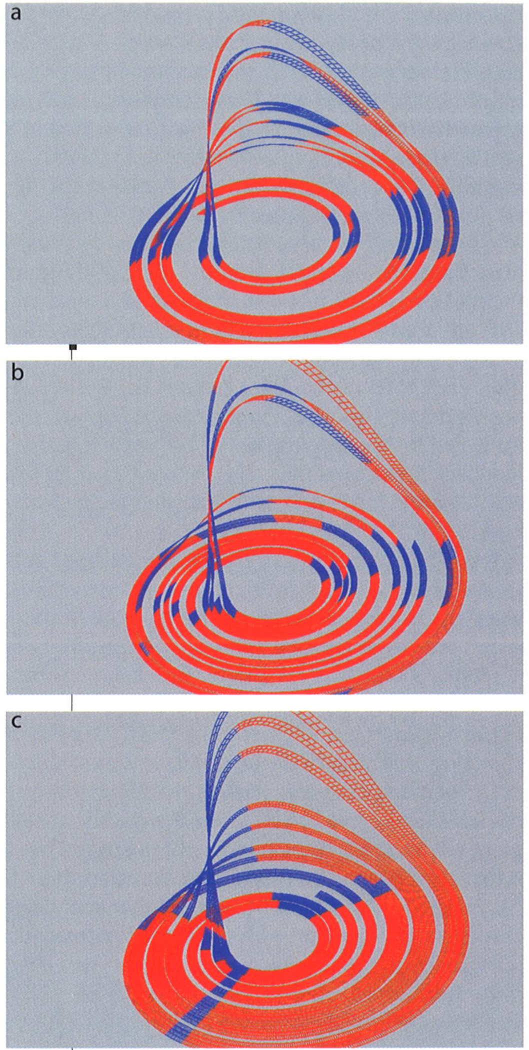
Figs. 5a-c: Three screenshots of an Endo-Chaos-Simulation of the Lorenz attractor. The left part (a) shows an exo-view whereas parts b and c show endo-views.

One can think of the attractor as the path of an object that moves in a force field. The path of a clock's pendulum is an attractor, for example. An attractor deserves its name because a small perturbation of the system away from the attractor will decline soon and the system is driven back to the attractor. A chaotic attractor does not have a closed path like that of a pendulum - which is a periodic attractor. The path of the object spreads over a large surface in a non-periodic way so that it never exactly goes through a point in space where it has already been earlier. Because of this spreading over a larger region a precise prediction is impossible.

In contrast to a periodic attractor, a chaotic one is characterized by a complex topology of attracting and diverging directions. The so called Lyapunov exponents are characteristic measures of this behaviour. These exponents classify chaos. There are, however, still ongoing efforts to compute robust estimates of local contributions to these prominent measures since they promise enormous insight into the behaviour of a chaotic system. In the majority of the cases, the Lyapunov exponents cannot be derived analytically. One has to rely on numerical calculations. The robustness and validity of algorithms for Lyapunov exponents cannot be strictly proven. It is a mixture of the knowledge of experts who regard the output as valid in an instinctive way and a numerical mathematical proof. In any case, the evaluation of the visualization, de facto an interpretation, is an inevitable component. The performative process plays a prominent role within this "video proof."

The complex structure of space can be made visible similar to stream lines of a magnetic field, with the difference, that the latter structure is much more complicated. The visualization (Figs. 4, 5) in our example is done by means of drawing coloured bands along the trajectory where red parts stand for diverging regions and blue parts for attracting ones. These bands, their directions and their colours (indicator for divergence/convergence) are the result of the numerical calculations. Different perspectives as well as different modes of presentation, along with instinct and intuition, contribute to a decision upon the quality of the result.

Figure 6 shows a comparison between the diverging manifolds computed with the traditional Wolf algorithm and our new variant [12], respectively. In Fig. 6a this unstable manifold of the Rössler attractor computed with the Wolf algorithm can be seen. The screenshot has been taken after an arbitrary integration time. In Fig. 6b, which is a screenshot of the same simulation taken some time later, two characteristics can be observed. First, the blue areas change over time. The Wolf algorithm does not calculate time invariant local contributions to the Lyapunov vector. Second, the jagged appearance of the manifold contradicts with



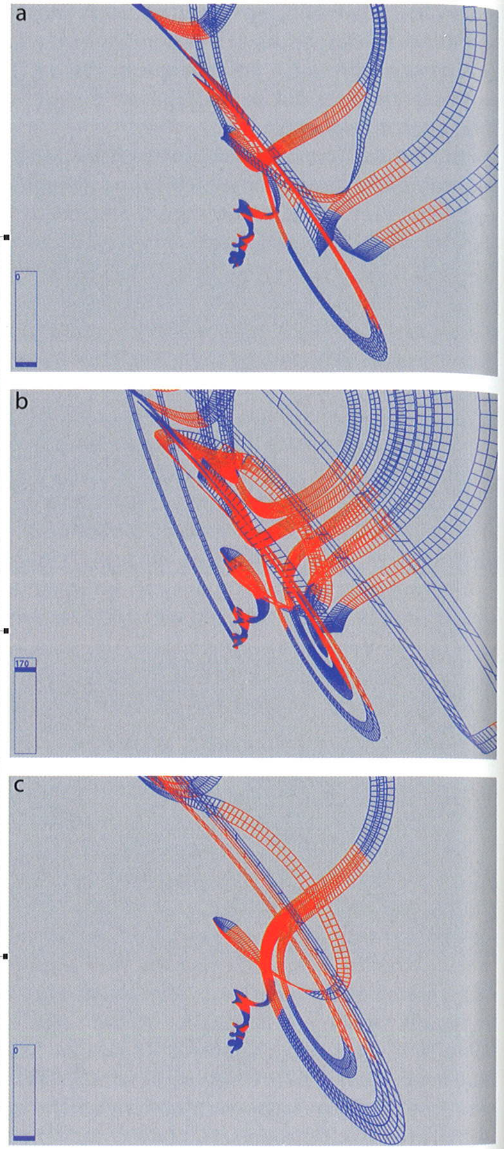
Figs. 6a-c: The unstable manifold of the Rössler attractor computed with the Wolf algorithm (a), again with the Wolf algorithm at a later time (b), with the new algorithm (c).

the assumption of continuity. The appearance of the manifold resulting from the new variant looks smooth (Fig. 6c). Furthermore, it is time invariant. Along with some other appearances as well as dynamical characteristics we finally acquired confidence in our new method. Of course, our decision was supported by concrete figures, too, like the global Lyapunov exponent, which is the same for both methods. The crucial point is, that the local contributions appear to be more reliable using the new variant.

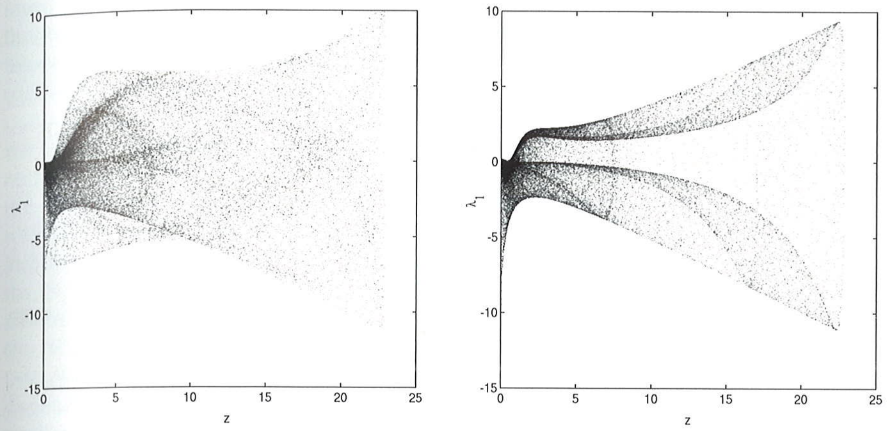
An "endo view" of the attractor is given by virtually sitting on the object and seeing space from the view of this particle. The path of the particle is then seen like the track of a roller coaster from inside. This endo view reveals, for example, a Möbius-strip structure of the attracting and diverging directions. This can be seen because almost after each loop of the roller coaster, the Rössler attractor is flipped upside down (Figs. 4b,c). Figures 5b and 5c show the Lorenz attractor from within. The application of the roller coaster travel to a force feedback Steward-platform (flight simulator) for example, surely will lead to even more profound knowledge. Such an installation is in preparation.

In Figs. 7a-c screenshots of transient transitions in the Lorenz attractor are shown. These transitions are caused by abrupt changes of the value of the control parameter, μ. The value of this parameter determines the shape and characteristics of the attractor. In the lower left corner of the pictures the slider for changing this parameter value can be seen. In Fig. 7a the value is $\mu = 0$, in Fig. 7b it is $\mu = 170$, and in Fig. 7c it is again $\mu = 0$. The screenshots have been made shortly after changing this parameter from one extreme value to another. The attractor in the case of $\mu = 170$ is chaotic and large in size. A value of $\mu = 0$ leads to a fixed point. Both, the chaotic attractor and the fixed point are invariant manifolds in phase space. They are accessible to statistical analyses. The transitions between these invariant structures, however, elude from being captured analytically or statistically. The band structures due to the Lyapunov manifolds, derived from our locally reliable computations, furnish new entropic understanding. Since none of the transitions can be exactly repeated, the advantage of the performative approach becomes visible.

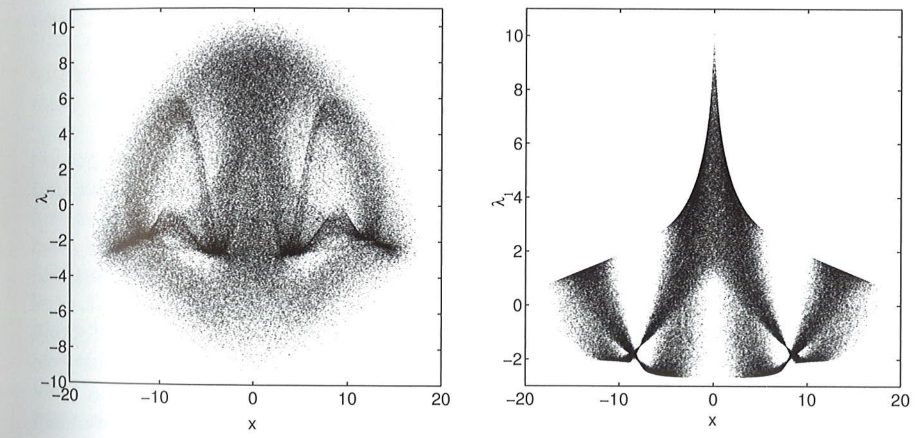
We published new insights that we derived from such a "video proof" in a peer reviewed scientific journal, which shows that there is a gradual opening towards these new methods [13]. In this article we compared different scatter diagrams derived from the Wolf and the new method for Lyapunov exponents. In Figs. 8a,b and 9a,b two of these comparisons are shown. The converging component of the Lyapunov vector is plotted against the *z*-variable of the Rössler attractor (Fig. 8) and the *x*-variable of the Lorenz system (Fig. 9), respectively. The new variant leads to a much stronger correlation although this can hardly be captured by any measure. Moreover, there is no mathematical stringency for the stronger correlation. It is scientific intuition along with some profound arguments on continuity as well as well structured behaviour that brought us to promote the new variant. So far, each interpretation of the investigated dynamical systems, which derived from our method, supported a consistent image. We conclude with the conjecture that artistic intuitions may contribute to find further performative methods to improve understanding.



Figs. 7a-c: Transient behaviour of the Lorenz system after a sudden change of the control parameter.



Figs. 8a-b: Scatter diagram of the diverging component of the Lyapunov vector against the *z*-component of the Rossler attractor. On the left: Computed with the Wolf method. On the right: Computed by our newly derived method. The structural differences are apparent.



Figs. 9a-b: Scatter diagram of the diverging component of the Lyapunov vector against the *x*-component of the Lorenz attractor. On the left: Computed with the Wolf method. On the right: Computed by the newly derived method. Again, the structural differences are apparent.

9. Pattern Formation: Liquid Perceptron

Alan Turing was the first who gave a profound bio-chemical explanation for pattern formation on [14]. However, there are still many open questions concerning morphogenesis. Pattern formation is a topic that challenged us, too. In the year 2000 our research converged into a media art installation of a coupled oscillator system that shows at least some aspects of a network of neurons. "Liquid Perceptron" (described on pages 94ff) is a simulation of a neural network that can be excited by an external stimulus, taken from the live video of the spectator moving in front of the video projection. This installation belongs to an early performative scientific example of our group in the fields of pattern formation. "Liquid Perceptron" has been presented in exhibitions several times. We will present two basic examples of pattern forming systems. This section is devoted to "Liquid Perceptron" and the following one to the μ-neuron model. Pattern formation can be divided into two major areas: evolving into a stationary pattern like those of furs or of shells and snails, and dynamical patterns like those of brain activity. "Liquid Perceptron" is a dynamical pattern forming system in which the simulated neurons are arranged to a two-dimensional array ("Liquid Perceptron," see pages 94ff) or to a three-dimensional cube ("Liquid Perceptron 3D", pages 106ff) and are connected to their neighbours. The activity of the neurons is colour coded (green in "Liquid Perceptron" and blue in "Liquid Perceptron 3D," respectively) whereby the bright areas code a high activity. In a specific parameter setting, which has been chosen to mimic excitability as a result of the "playful" interaction, the network reacts such that if no stimulus evokes the network it will reduce its activity to a small background noise. An external stimulus excites some neurons. The activity of these excited neurons start to spread over the whole network as a result of the neuronal coupling. The activity synchronizes to a coherent dynamical pattern that encodes the perceived stimulus in an abstract representation. Although "Liquid Perceptron" is far from modelling a real brain, it yielded valuable insight in the functioning of neural networks. The differential equation underlying "Liquid Perceptron" reads:

$$
\begin{aligned}
\dot{x}_{i,j} &= a + x_{i,j}y_{i,j} - \frac{c_1 x_{i,j}}{c_2 + x_{i,j}} + D_x \mathrm{Diff}^x_{i,j} - Video_{i,j} \\
\dot{y}_{i,j} &= b - x_{i,j}y_{i,j} + D_y \mathrm{Diff}^y_{i,j},
\end{aligned}
$$

with zero-flux boundary conditions for the diffusion Diff^ξ:

$$
\mathrm{Diff}^\xi_{i,j} = \begin{cases}
\xi_{i+1,j} + \xi_{i-1,j} + \xi_{i,j+1} + \xi_{i,j-1} - 4\xi_{i,j} & : \quad 1 < i < n; \quad 1 < j < m, \\
\xi_{i+1,j} + \xi_{i,j+1} + \xi_{i,j-1} - 3\xi_{i,j} & : \quad i = 1; \quad 1 < j < m, \\
\xi_{i-1,j} + \xi_{i,j+1} + \xi_{i,j-1} - 3\xi_{i,j} & : \quad i = n; \quad 1 < j < m, \\
\xi_{i+1,j} + \xi_{i-1,j} + \xi_{i,j+1} - 3\xi_{i,j} & : \quad 1 < i < n; \quad j = 1, \\
\xi_{i+1,j} + \xi_{i-1,j} + \xi_{i,j-1} - 3\xi_{i,j} & : \quad 1 < i < n; \quad j = m, \\
\xi_{i+1,j} + \xi_{i,j+1} - 2\xi_{i,j} & : \quad i = 1; \quad j = 1, \\
\xi_{i-1,j} + \xi_{i,j-1} - 2\xi_{i,j} & : \quad i = n; \quad j = m, \\
\xi_{i-1,j} + \xi_{i,j+1} - 2\xi_{i,j} & : \quad i = n; \quad j = 1, \\
\xi_{i+1,j} + \xi_{i,j-1} - 2\xi_{i,j} & : \quad i = 1; \quad j = m,
\end{cases}
$$

$$
\xi \in \{x, y\}.
$$

Eqn. 1.

We refrain from writing down the equation for "Liquid Perceptron 3D," since the extension is straight forward. The parameters b = 0.12, $c1$ = 0.502, $c2$ = 0.1, D_x = 0.3, D_y = 0.01 are constants, whereas a plays the role of a control parameter. A value of a = 0.7 leads to a non-selfexcitable network, which means that the oscillations gradually decreases to a small "background" oscillation. Setting a = 0.5 leads to a selfexcitable state where spiral patterns sustain to spread over the whole network. The origin of this equation stems from modelling chemical reaction systems. It has been used, for example, to model calcium oscillations in living cells, which have a close resemblance with oscillations of pottasium ions (K^+), which are the essential substance regarding neuronal activity. Anyway, the representation of the chemical oscillation through two interacting variables x and y is a rather abstract one. In the real reaction-diffusion-system many substances are involved, however, most of them are dynamically negligible.

In a nutshell, the ions that are responsible for measuring a voltage on the scalp, react with an other substance leading to an oscillation. In the abstract representation of Eqn. 1 the concentrations of these substances are named x and y, respectively. In our "model brain" we have $n{\cdot}m$ neurons. Both, n and m are numbers larger than 100, depending on the performance of the available computer. The neurons are arranged to a grid with $n{\cdot}m$ nodes. A given neuron in this grid with the pair of indices (i,j) is coupled with the upper $(i,j+1)$, the lower $(i,j-1)$, the rhs $(i+1,j)$ and the lhs $(i-1,j)$ neighbouring neurons. "Coupled" means, that the concentration of the substances can diffuse to the neighbouring cells, given by the diffusion terms Diff^x and Diff^y. The amount of transferred substance per time unit depends on the characteristics of the medium between the neurons. In the real brain the activity is mediated to the neighboured neurons via axons regulated by the synaptic strenghts. Of course, in the real brain the neurons interact over larger distances with many other neurons leading to a much more complex topology compared to the simple one of "Liquid Perceptron." Additionally, in our model brain a simple homogeneous coupling has been chosen.

Each neuron of the network oscillates autonomously if the diffusion terms as well as the input terms vanish: $\mathrm{Diff}^x_{i,j} = 0$, $\mathrm{Diff}^y_{i,j} = 0$, $Video_{i,j} = 0$ for each index pair (i,j). The vanishing diffusion terms correspond to a zero-strength of the synapses. $Video_{i,j} = 0$ corresponds to a vanishing input signal, i.e. to zero-excitation. In the latter case there is no additional influx of concentration to the oscillators. The fixed influx given by parameter a, is sensitive for the characteristics of the coupled oscillators. In a chemical reaction, the parameter a can be regarded as a continuous intake of a reactant to keep the reaction going. If this influx is either too small or too large, the reaction will stop or become homogeneous, i.e., the oscillations will fade out. There is a certain threshold, above which the oscillation keeps on running. In the excitable state of the network, the value for a is chosen below this threshold. This means, only if the neighboring neurons have high concentrations of x or y that partially are able to diffuse into the given neuron the latter one starts to oscillate. However, somewhere in the network an intake from outside has to appear to start the reaction. This external intake comes from $Video_{i,j} > 0$, which in "Liquid Perceptron" is the signal from a video pixel. It is arranged such, that the size $n{\cdot}m$ of the video matches with the size of the neuronal network. The video signal is interpreted as the signal from the retina of the eyes leading to an activity in the visual cortex. In "Liquid Perceptron" the difference signal of two subsequent frames is used. Thus, only a movement leads to a non-vanishing signal in the live video and thus to an excitation of the network. As explained above, a functions as a control parameter. The video signal adds to this parameter and therefore, shifts the value into the excitable range. $Video_{i,j}$ modulates the control parameter.

On pages 94-105 some examples are shown. As can be seen, an excitation leads to a coherent spiral pattern that spreads over the whole network. After some time (some seconds up to a view minutes, depending on the current activity) the spiral waves fade out and the system returns into a weakly oscillating ground state. The efficacy of excitation depends on the speed and the mode of movement, which has to harmonize with the wave front velocity. A fast movement or high frequent waving, for example, not necessarily excites stronger than a slow but resonant movement. A lasting commitment with "Liquid Perceptron" leads to a deep understanding that is beyond words - an understanding that can be recalled when it comes to specific scientific analyses.

10. Pattern Formation: μ-Neuron

A second example for a pattern forming system is the μ-neuron model. The corresponding differential equation reads:

$$\begin{aligned}\dot{x}_{i,j} &= -y - \mu x^2\left(x - \tfrac{3}{2}\right) + I + D_x \mathrm{Diff}^x_{i,j} - Video_{i,j}\\ \dot{y}_{i,j} &= -y + \mu x^2 + D_y \mathrm{Diff}^y_{i,j}.\end{aligned}$$

Eqn. 2.

The parameters I, D_x, D_y and μ are constant, whereas μ as well as I can function as control parameters. In the case of the "Liquid Perceptron", the diffusion parameters D_x and D_y mainly scale the size of the pattern, the shape of which, however, remains invariant. In the μ-neuron model the diffusion parameters have a qualitative impact on the pattern formation. Therefore, even D_x and D_y can be seen as control parameters.

In general, the μ-neuron model is even harder to grasp than "Liquid Perceptron." It takes time to "play" with the parameters and to explore the huge variety of behaviour. The following static screenshots are far from appropriate to supply full understanding. We recommend a performative approach.

In the screenshots of Figs. 10a,b the video signal was zero. The following parameters have been chosen for the simulation depicted in Fig. 10a: $\mu = 2.25, I = 0.001, D_x = 0.7, D_y = 0.0$. This pair of values of the diffusion parameters along with a positiv but small I leads to a dynamical pattern formation. For a value $I < 0.0$ the rather irregular pattern vanishes after a transient phase. The transient time is shorter the smaller the value for I is chosen. The whole network enters a fixed point attractor. For a larger value, say $I = 0.01$, the network gets very active with a high velocity of pattern propagation.

By decreasing the value for D_x we can direct the system through a number of interestingly dispersed and lively, but still coherent, patterns, until they become totally uncorrelated for $D_x = 0$. In the latter case, each neuron oscillates autonomously. The screenshot of Fig. 10b has been taken for $D_x = 0.1$. A decreasing D_x leads to a decreasing propagation velocity, as expected. When the value for D_x is increased after it has been zero, an interesting hysteresis can be observed. After a change of parameter values, each pattern formation strongly depends on the previously chosen parameter values and the time one stuck with those values.

In the spatially decoupled case ($D_x = 0$ and $D_y = 0$) the

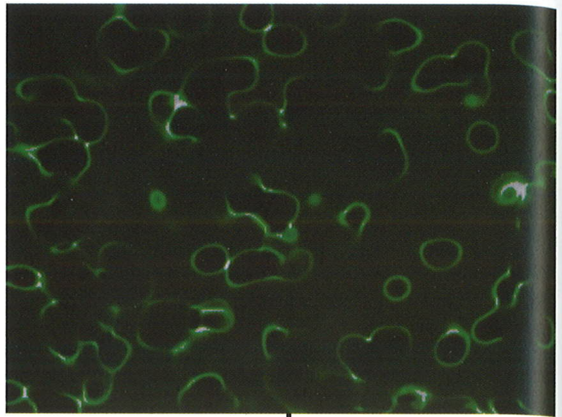
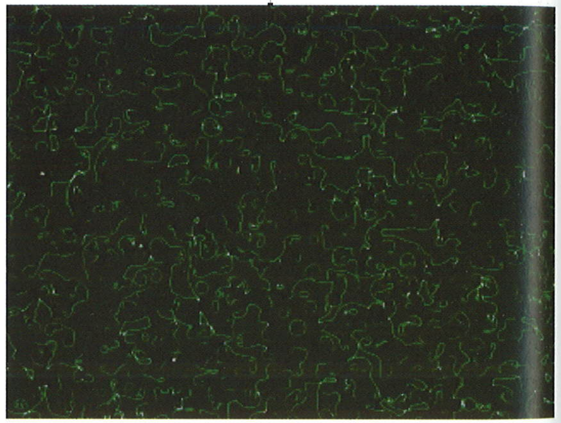


Fig. 10a: Pattern of the μ-neuron array produced for a small influx $I = 0.001$.

Fig. 10b: A "lively" dynamical pattern of the μ-neuron network resulting from a large influx $I = 0.01$.



value of I mainly controls the frequency of the limit cycle oscillation of each neuron. Therefore, it is plausible that the propagation of coherent patterns for $D_x > 0$ is controlled by this parameter. If one fixes $D_x = 0$ and gra-

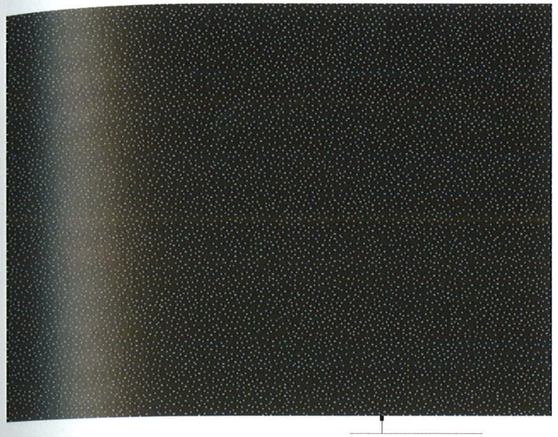
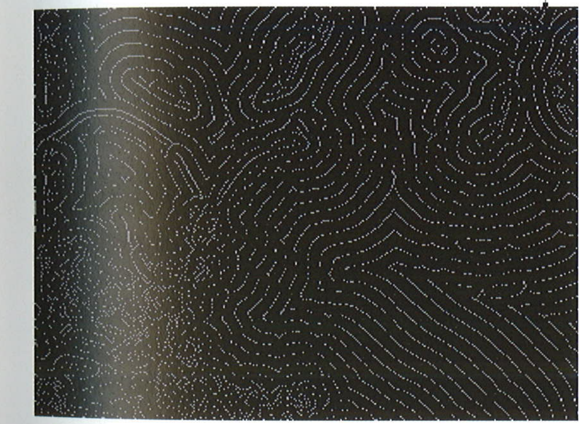


Fig. 10c: A diffusive coupling in the y-component without a coupling in x "freezes" the network to a static pattern.

Fig. 10d: Sudden changes of the coupling parameter can lead to a large variety of static patterns where the previous dynamical pattern is still reflected. One sees the "frozen" wave fronts.

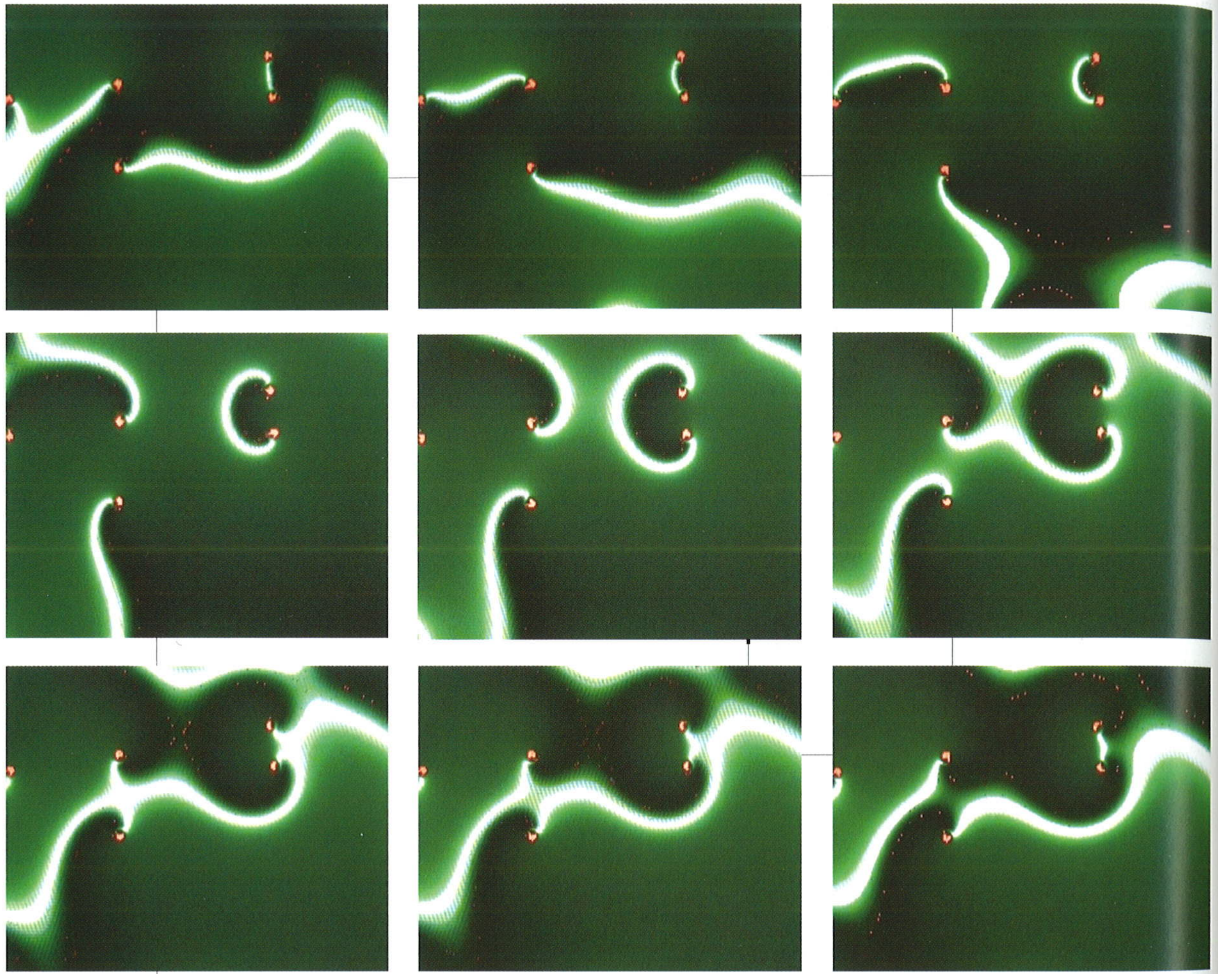


dually increases the value for D_y, one observes that the amplitude of each oscillator shrinks. The average values of these small oscillations, however appear randomly in an equidistributed way. Above a certain threshold, for example for $D_y = 0.2$, the oscillation amplitudes vanish and the concentrations of the neurons "freeze" to a randomly distributed value, leading to a static point pattern. If the increase of D_y is done relatively slowly, so that transient states between the values have time to fade away, the final pattern is homogeneous like in Fig. 10c. If however the D_y changes rapidly, say from 0 to 0.2, say, and if the pattern was coherent before this sudden change, then the pattern "freezes" into a well auto-correlated static shape like depicted in Fig. 10d, where the previous "wave fronts" have been conserved. Depending on the previous dynamical state, many different static patterns can be created.

Perhaps the most fascinating aspect of the μ-neuron model is the capability to bring forth a mixture of the dynamical and the static behaviour. If both, $D_x > 0$ and $D_y > 0$, one observes "standing waves" in the sense, that at some points in space the phase of the corresponding oscillator becomes static. The wave seems to be "pinned" at these positions like an oscillating rope attached to the wall at one end. The spirals in the μ-neuron model meander around these fixed positions. In the screenshot series of Figs. 10e-m, the temporarily invariant points (by means of equality of two subsequent concentrations in the iteration) are coloured in red. The images are details of the whole network. The meandering can be imagined from this image series. The concrete parameter values for this simulation are:

$$\mu = 2.25,\ I = 0.02,\ D_x = 0.16,\ D_y = 0.45.$$

We repeat once more, that this screenshot cannot substitute a performative approach. The number of qualitatively different patterns that can be created by interactively changing parameters is infinite. Even in such an extremely simplified brain model the complexity is overwhelming, but by performing the simulation, one gets at least a rough idea of the underlying dynamics.



Figs. 10e-m: Invariant neuronal activities are coloured red in the simulation underlying this screenshot series. The spiral waves are "pinned" to this static points and form quite complex standing waves.

11. Sonification of Brain Activity

"Performative Science" also tries to elaborate an appropriate mode for representing abstract data and models. For dynamical systems the best representational mode often turns out to be an auditive one. The ear - much more than the eye - is very sensitive for recognizing changes in temporal events. Mathematical analytical tools often can be applied only if a hypothesis has been formulated. Creating hypotheses is perhaps the most important field where sonifications (symbolic auditive representations of the measured data) and audifications (direct auditive representations of the time series) can contribute. We are currently elaborating the application of sonifications to medical diagnostics. We are also trying to work out modes of presentation and the publication of results. For example, the result of an auditive analysis of a complex dynamical system may be given as an acoustic surround installation, which needs a proper forum to be presented. Sonification examples produced in our institute can be found online [15]. Confer also Gerold Bayer's book that contains an audio CD with physiological sonifications [16]. For another example where astrophysical data have been set into music, see the project "SOL" on pages 122ff.

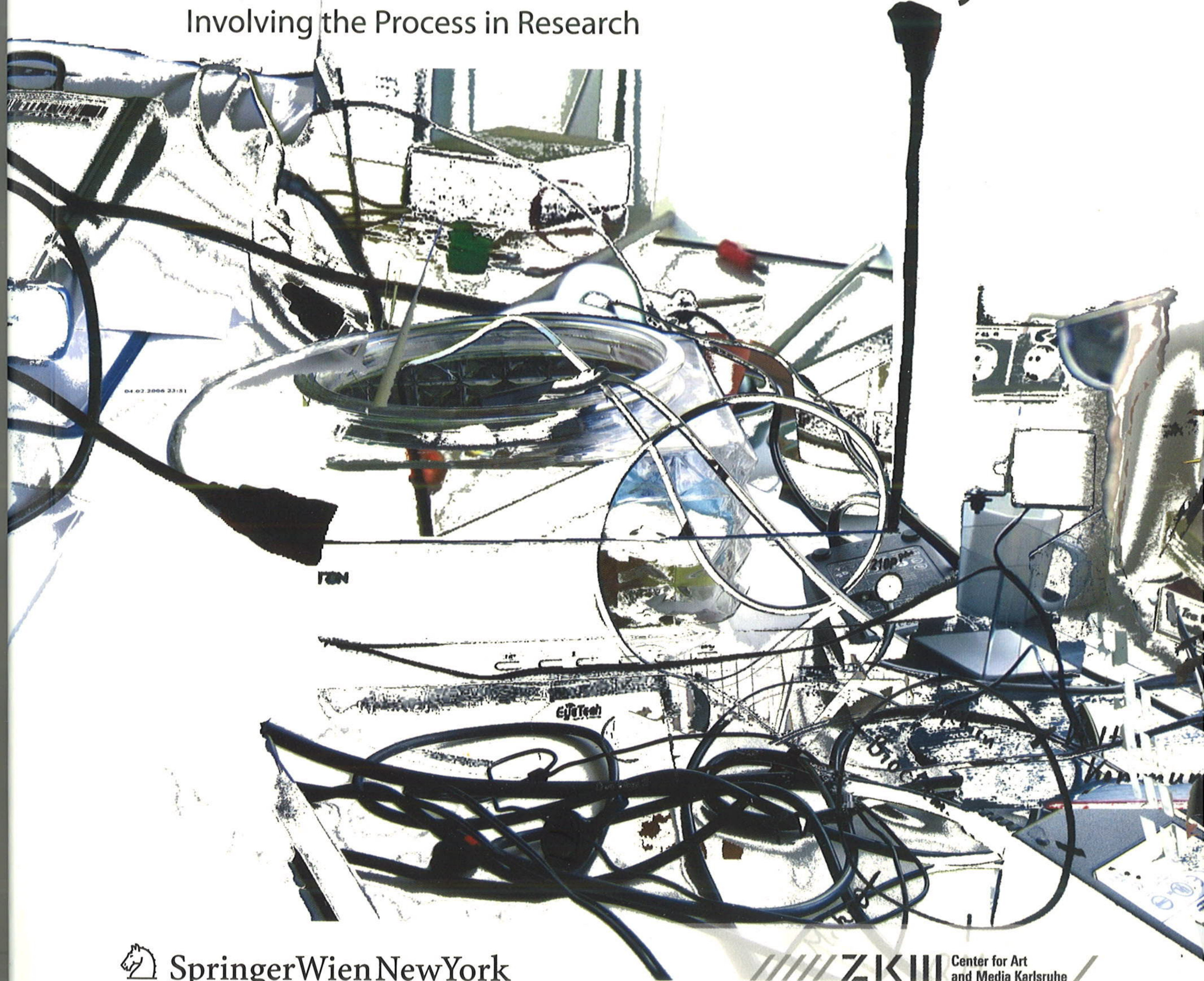
12. Conclusions

"Performative Science" to a large extent means working on concepts within sciences that are open towards methods from arts and humanities and vice versa. In complex system theory mathematics is gradually getting "weak" and meets with hermeneutical principles. Dealing with algorithms and interfaces will enhance humanities at least as a source of new hypotheses. Hermeneutics in turn enhances natural sciences for the same reason particularly through accepting weaker methods of proofs like "video proofs" or "audio proofs," where the latter refers to insight from audification. Sensory impressions are the crucial ingrediences of "Performative Science." A further crucial point in this approach is the attempt to include the public into the research process by providing appropriate interfaces.

Hans H. Diebner

Performative Science and Beyond

Involving the Process in Research



SpringerWienNewYork

ZKM Center for Art and Media Karlsruhe

Hans H. Diebner
Griengasse 4
79540 Lörrach
Germany
email: diebner@inm.de

The presented work has mainly been carried out from 1999 to 2005 in the Institute for Basic Research at the ZKM | Center for Art and Media Karlsruhe. Part of the work is co-authored by the Institute's members as indicated correspondingly.

a ZKM book

ZKM Center for Art and Media Karlsruhe
Lorenzstr. 19
76135 Karlsruhe
Germany
info@zkm.de

Printed in Austria
SpringerWienNewYork is a part of Springer Science + Business Media
springer.com

Graphic Design and Typesetting: Inge Hinterwaldner
Printing and binding: Holzhausen Druck & Medien GmbH, A-1140 Wien
Printed on acid-free and chlorine-free bleached paper
SPIN: 11734536
With numerous figures, mostly in colour
Library of Congress Control Number 2006923238
ISBN-10 3-211-33357-6 SpringerWienNewYork
ISBN-13 978-3-211-33357-0 SpringerWienNewYork