23: Structural and Functional Information—An Evolutionary Approach to Pragmatic Information

FRANK SCHWEITZER

1 EVOLUTION: GENERATION OF POTENTIAL INFORMATION

The discussion about the status of "information" is still continuing. From a physical perspective, information is often considered as an ontological quantity with an unquestionable existence. C. F. v. Weizsäcker, e.g., argues: "Mass is information. Energy is information".[1] This perspective is based on the relation between statistical entropy, S, and information entropy, H: $S = k_B H$, where k_B is the Boltzmann constant.[2]

Entropy is one of the fundamental quantities in physics. Due to the statistical interpretation by Boltzmann, Planck and Gibbs, entropy is related to the thermodynamic probability, W: $S = k_B \ln W$. Here, W is a measure for the number of possible microscopic configurations which may result into a given macroscopic state. This means, that entropy can be considered as a measure for the information needed to clear up the related microscopic state of a given macroscopic state.[3]

One can tempt to get this information by representing an existing state as the result of hierarchical decisions, where every decision generates 1 *bit* (a question is answered either by yes or no). C. F. von Weizsäcker has suggested a theory[4] where every state, every event results from a decision tree consisting of basic alternatives, named urs, ("Ur-Alternativen"; state vector u_r—"ein Ur"). In this sense, the information content of a situation is equal to the number of decided ur-alternatives. Physical mass also is considered as information: it is equal to the number of decisions of ur-alternatives needed to create a particle. Due to v. Weizsäcker, the information invested to create a nucleon is about 10^{40} urs and the information content of the whole universe should be about 10^{120} urs.[5]

This way, on a quantum mechanics level, evolution can be interpreted as a process which permanently decides between ur-alternatives and thus generates information. The entropy is then a measure of the average number of questions needed to clear up the current system state. However, due to the 2nd law of thermodynamics, in closed systems (as the universe is assumed to be) the entropy always increases in the course of time. This basically means that more information is needed to clear up the micro state of a given macro state, hence the number of *questions* increases to clear up a micro state. Thus, we can conclude that the information resulting from decisionable ur-alternatives is not factual information, but virtual (*potential*) information. This dilemma, of course, results from the relation of information in the given sense to the physical entropy, and C. F. v. Weizsäcker notes, too: "Positive entropy is potential (or virtual) information"[6] and "evolution as the increase of potential information".[7]

So, we are left with the problem, how to get *factual* information instead of virtual information. Obviously, the solution could not be found by simply changing the sign of the entropy, to transfer it into negentropy, as suggested by Schrödinger (1951) and Brillouin (1956). Instead, in Section 2 we suggest a dynamical perspective, where information is considered as effective information consecutively generated by an interplay of structural and functional information. In order to elucidate this process, a model of interacting agents is discussed in Section 3.

2 STRUCTURAL, FUNCTIONAL AND PRAGMATIC INFORMATION

2.1 Structural Information

Structural Information denotes the information which is given with the existing material structure of a system at a specific location and time.[8] It is related to the physical nature of the system, hence, the content of structural information could be analysed by means of different physical measures (e.g. conditional or dynamic entropies, transinformation etc.).[9] Thus, structural information represents the *structural determination* of a system state.

Due to the relevance of structural information, several methods[10] have been developed from the perspective of the natural sciences in order to investigate the structural information content. For instance, structural information could be transformed into *symbolic sequences*[11] (strings) which in general have the following linear structure $S_0S_1S_2 \dots S_nS_{n+1} \dots$, with S_i being the generalized "letters". The investigations of these strings, however, cover only the syntactic aspect of information which results from the positions and the structural relations of the different "letters" within the string, whereas the level of meaning is not considered here. A class of strings which is of particular interest, are the so called natural sequences, for instance the DNA as a sequence of nucleotides, a literary text as a sequence of letters, or music as a sequence of tones. Moreover, sequences can be also generated by dynamic processes, e.g. the different heights of the water level in the course of time, or the variations of quotations in the stock exchange market may result in a sequence of numbers, which can be further investigated.

The complex methods of analyzing the structural information of sequences have proved that there exist similarities in information carrying strings as literary texts and music.[12] E.g. the correlations and dynamical entropies which characterize the appearence of "letters" and "words" in these sequences, display similar features indicating the existence of long-range order relations within these strings. It has been shown that these sequences, with respect to the order of "letters", are neither chaotic nor periodic structures. If one tempts to predict the next letter from a known sequence of preceding letters, in chaotic sequences the uncertainity would be on a high and constant level, whereas in periodic sequences due to the existing order the uncertainity shall decrease to zero after the first period. Contrary, natural sequences, such as texts and music, are regarding the arrangement of their "letters" *on the border between order and chaos*. This means that these sequences are neither unpredictable (such as chaotic sequences) nor redundant in their information content (such as periodic sequences after the first period), they rather display a characteristic mixture of the unexpected and the expected in their order of letters.

2.2 Pragmatic Information

The behavior of the structural information of natural sequences can be compared to the concept of pragmatic information,[13] which has been introduced in order to measure the *effect* of information to a recipient. This concept operates with the extremes "novelty" and "confirmation" (cf. Figure 1). Pragmatic information is at its minimum (or zero), if the information is completely novel and therefore cannot be understood, since it does not refer to something already known (novelty 100%, confirmation 0%). On the other hand, pragmatic information is also at its minimum, if the information is completely known and therefore redundant (novelty 0%, confirmation 100%).

E. and C. v. Weizsäcker (1972) have argued that living systems, with respect to the effect of information, always operate between the two extremes novelty and confirmation, hence, near the maximum of pragmatic information. The information which was important in the course of evolution should have been, on one hand, new to a certain degree, but on the other hand interpretable on the base of existing information. This is closely related to the results about the structure of natural sequences. The structure of chaotic sequences always leads to a maximum novelty regarding the prediction of

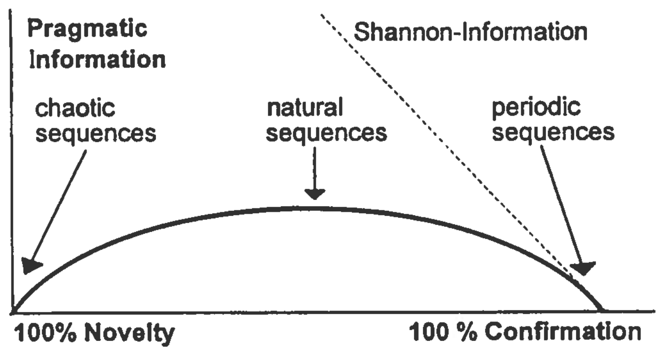

Figure 1 Schematic plot of pragmatic information in dependence on the degree of novelty and confirmation. The information obtained from the Shannon entropy H is indicated by a dashed line. Further, the range of structural information of different types of sequences is indicated.

letters, whereas the structure of periodic sequences eventually results in a maximum confirmation of the order of letters. Natural sequences, however, are between chaos and order, between novelty and confirmation. They have the proper mixture of both novel and redundant elements, and therefore are—regarding their structure—closer to the maximum of pragmatic information (cf. Figure 1).

Hence, the investigations of the structural information of natural sequences have shown that during the evolution of these sequences not the syntactic information is maximized, but the pragmatic information is optimized which is the only effective information. This optimum of pragmatic information could have been an advantage during the evolutionary selection of what we now name "natural" sequences. The most striking part of this insight comes from the fact that the optimal pragmatic information is correlated to a specific structural information which does not consider certain semantic relations. Therefore, we would suggest to use the methods to analyze structural information also for a new way of quantitative measurement of pragmatic information.[14]

2.3 Functional Information

The concept of pragmatic information argues that information to be effective has to be understood. As discussed above, this circumstance is already realized in the structural properties of natural sequences. On the other hand, however, the gain of pragmatic information is always related to some existing information, since the new information has to be understood on the base of something already known. The problem of how the level of meaning appears in information is still under discussion. In order to avoid a logical circle, in the following a second type of information is assumed, which we denote as *functional information*. It is the purpose of functional information to activate and to interpret the existing structural information. Functional information is related to the *semantic aspects* of information; it reflects the contextual relations, since information depends on the situation of the recipient. The distinction between structural and functional information takes into account that complex structures, such as the DNA, contain a mass of (structural) information, which can be selectively activated in dependence on different circumstances. For instance, already cells are able to extract different (pragmatic) information from the genetic code in dependence on the physical and chemical conditions within the cell.

In the sense of the autopoiesis theory, functional information represents the *self-referentiality* and the *operational closure* of the system, whereas structural information represents the structural determination of the system. In order to describe the performance of functional information, a comparison to the process of measurement in quantum mechanics seems to be useful. As we know, during the process of measurement, a micro object (e.g. an electron) is constituted regarding its appearence either as a particle or as a wave packet. Hence, the information about the electron, obtained during the measurement, basically depends on the process of measuring. The (experimental) question is a projection of a specific information out of the information space of all possible information about the object.

Similar relations exist between structural and functional information. The physical nature of the object is represented by the structural information. But it is the act of projection, featured by the functional information, which transforms this structural information to make it effective information. With respect to the term of pragmatic information, we can express this relation as follows: *It is the purpose of functional information to transfer structural into pragmatic information.*[15]

This insight effects also the discussion about the ontological status of information, mentioned in Section 1. Structural information may have such a status, however, in order to understand the character of information as a whole, a kind of a "quantum mechanics revolution" in information theory is needed, which reveals the generation of pragmatic information due to an interplay of structural and functional information.

3 SELF-ORGANIZATION AND THE GENERATION OF INFORMATION IN A MODEL OF INTERACTING ARTIFICIAL AGENTS

The question of whether information could be reduced to mere structural or syntactic aspects has been answered in the previous section in favor of a complementary description of structural and functional information. In order to elucidate the effect of these types of information, an example is discussed now which simulates a process of self-organization based on the generation of local information.

3.1 Generation and Accumulation of Information

In the following, we discuss a simple model of interacting agents which move on a plain surface. These agents do not have a memory to store information, they move without any intentions or aims. However, on every step every agent generates information by locally producing a marking, which is laid down on the surface. All agents shall use the same kind of markings.[16] The marking simply indicates that a site has already been visited. This is an information coded on a material base by means of the markings, and after its release, the information is independent on the agents. The markings stored on the surface, have an eigen dynamics, they can fade out and thus disappear, if they are not steadily renewed. On the other hand, if a site is visited by the same or by different agents several times, the strength of the marking increases, and the information is locally accumulated. The information is also able to spread out by diffusion of the markings. Hence, the surface is characterized by an information density $b(r, t)$, which describes the strength of the markings on a given location r at a given time t. The markings can be detected by an agent if they are in the direct vicinity of the agent's location. In this case, the information affects the further movement of the agent: with a certain probability, the agent moves towards the strongest marking. However, in a probabilistic model, there is also the chance that the agent will move into an arbitrary direction, thus ignoring the marking detected.

With respect to the distiction of the information terms, discussed in Section 2, we note that in this model the structural information is given by the information density $b(r, t)$ which, due to the markings, exists on a material base. The functional information, on the other hand, has the purpose to interpret the structural information with respect to the agent. In the model discussed, this functional information is given by program which the agent consecutively processes, i.e. the set of simple rules which determine the agents behavior:

1. the agent checks *locally* for markings in its direct vicinity,
2. the agent makes a *local* decision about the direction of the next step in dependence on the intensity of the markings,
3. the agent generates a marking on is actual site,
4. the agent moves towards the new site and repeats (1).

The rules (1) to (4) determine what kind of effective information the agents can get out from the existing structural information, i.e. the functional information transforms the structural information into pragmatic information. Noteworthy, structural and functional information both have a different nature: in the example discussed the structural information is a *scalar field*, whereas the functional information is an *algorithm*, which allows to gain pragmatic information from the scalar field. This algorithm can indeed be performed by very simple, memoryless agents, since no *internal* storage of information is needed. The agents rather behave like physical particles which move towards the local gradient of a potential which can be changed by them. Since the agents do not interact directly, but only via the external information density, the model introduced describes an *indirect communication process*, which is further discussed in Section 4. By means of this indirect communication, a process of self-organization occurs which can be visualized in a computer simulation. Figures 2(a–f) show the information density $b(r,t)$ after different time intervals. The initial state of the simulation was given by a surface without any markings, where 100 agents were randomly distributed.

Figure 2(a) shows that the agents first generate information locally by producing markings. At the same time a process of self-amplification occurs (Figures 2(b), (c)), since an agent produces the next marking with a higher probability on those sites where it already found one. However this has to take place consecutively, otherwise the markings fade out or diffuse away. The computer simulation clearly indicates two different dynamic regimes for the evolution of the information density. In the beginning, information is locally generated at *many different places*, indicated by the large

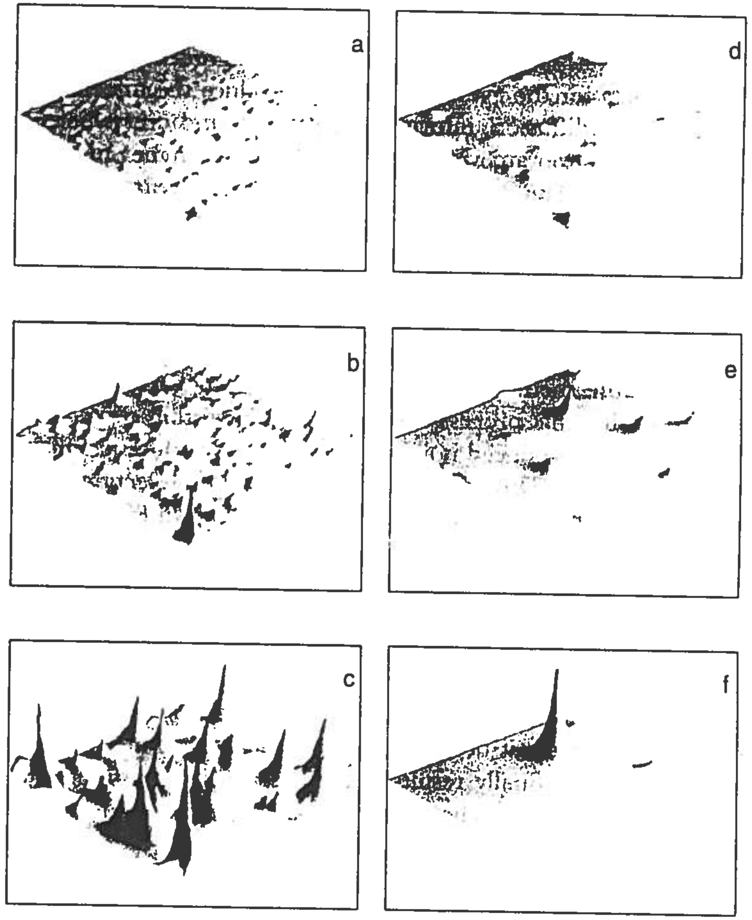

Figure 2 Evolution of the information density $b(r,t)$ after (a) 10, (b) 100, (c) and (d) 1000, (e) 5000, (f) 50.000 simulation steps (number of agents: 100, triangular lattice of size 100×100). In Figures (d)–(f) the scale is reduced by a factor of 10 compared to (a)–(c) in order to cover the further evolution of the information density (Hence, Figure (c) is the same as Figure (d), reduced by a factor of 10).[17]

number of high spikes which represent the maxima of the information density. These spikes can be also looked upon as *information centers*, where most of the information is accumulated.

The initial stage is followed by a second stage (Figures 2(d–f)) where these information centers begin to compete each other, which leads eventually to a decreasing number of spikes, unless one of the centers has succeeded. What are these centers competing for? They compete for the agents which only produce the informationl Caused by the diffusion, information can be found everywhere on the surface; however an overcritical concentration can be only found in the centers. The agents which intend to move towards the direction of the largest local information density, are gradually attracted to the different information centers. Due to the limited number of agents, not all of the information centers are able to grow, therefore, eventually only those centers survive which have the largest attraction to the agents, whereas the other centers gradually loose their supercritical size and disappear. The agents released during that process are drawn to the existing centers; and the information produced is accumulated by less and less centers in the course of time. This process of competition and selection can be described by equations of the same type as the known Eigen–Fisher equations of prebiotic evolution.[18]

The non-linear feedback of the information density $b(r,t)$ to the movement of the agents can be well described by Hakens enslaving principle.[19] By means of the production of markings, the agents commonly create an information level, on which they mutually communicate. Once this level exists and becomes of a supercritical information density, it begins to enslave the further movement of the agents; which finally results in a transition from a free movement of the agents into a bound movement around the information centers established.

3.2 Generation of a Collective Memory

The effect of the enslaving principle should be now discussed with respect to the generation of a collective memory. Therefore, a slight modification of the above model is introduced: the agents still have the same functional information as before, however they are only able to detect markings in the direction of their motion, due to a certain angle of perception assumed. Also, the information should not diffuse now, but the markings can disappear as before. Using these modifications, we obtain from the model a different structure

of the information density $b(r,t)$. Now, instead of information spikes, there are tracks of markings, which resemble pathes created by the agents during their movement (Figure 3). Again, this structure results from competition and selection among the different pathes, where all pathes that are not consecutively renewed disappear again.

The remaining structure is analogous to a collective memory of the agent community: The structure has been created by the common activity of the agents, it has stored all actions of the agents with respect to the information generated during these activities. Of course, this information can partially fade out or disappear, if it is not used any longer, whereas the information used is brushed up again. Thus, for the agents which have no individual memory, the information density $b(r,t)$ represents a kind of a *collective memory*, which contains exactly the information which is available to the agents at a given time and a given location. *Availability* means here,

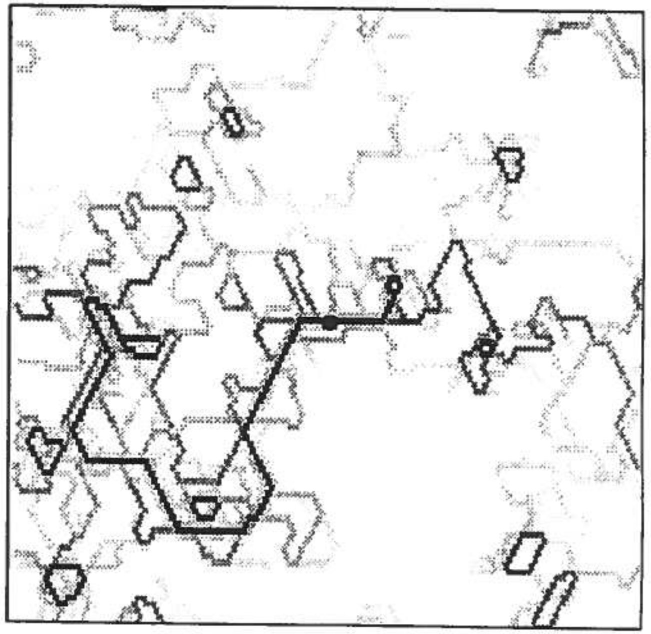

Figure 3 Information density $b(r,t)$, coded in a grey scale, after 5.000 simulation steps (number of agents: 100, triangular lattice of size 100×100).[20]

that this information—which is structural information—can be activated by the functional information of the agents and therefore can be transformed into *effective* or pragmatic information.

The information structure which represents the collective memory is unique due to fluctuations which always affect the formation of the pathes. Of course, the information generated at different times contribute with different weights to the present state of the collective memory. However, this process occurs in a nontrivial way, due to the nonlinear feedback between the existing and the newly produced information. The information generated in the early stages of the system's evolution, is certainly disappeared long ago—but on the other hand, the early information stamps the system because of early symmetry breaks. This early information can be brushed up and reinforced due to usage in the course of evolution. This way, the early information is available also during later stages of the evolution, whereas information not used fades out in the course of time and does not influence the further evolution of the system.

As we see, the term "path", on which Figure 3 may remind, can be used here in a rather general and symbolic manner. It stands not only for the path used for movement, but also for the rather subtle historical path which represents the cultural evolution of man. The path structure discussed here as an example is indeed a collective memory for the agents community. Only those pathes, which are consecutively used and therefore renewed by the agents, survive in the course of evolution. New pathes can be created at any time, the agents are not forced to use the old, confirmed pathes. In a probabilistic model, they have always the chance to discover new ground. The question, however is whether a new path can be established as a new way out of the recent situation, or whether it turns out to be a rather fashion-like phenomenon which fades away after a short time lapse. Here, the enslaving principle of the already existing pathes becomes important: the more these pathes are carved into the collective memory, the more the collective information is confined to specific "areas", the more difficult it would be to establish a new way out. Thus, the collective memory enslaves the agents by forcing them to existing pathes. Since these pathes have been created only by the agents, the agents community is finally enslaved by its own history which partially determines the presence.

4 CONCLUSIONS

In this paper, we have characterized different types of information. The *potential information* which is related to the statistical entropy, can only serve as a measure of the number of questions needed to clear up a given macro state. In this sense, it is virtual rather than factual information. The approach introduced here, is based on a distinction between structural and functional information: *Structural information* is a measure of the information coded in the material structure; *functional information*, on the other hand, activates and interprets the structural information, it *transfers structural into pragmatic information*, which is a measure of the effect of information to the recipient.

This transformation process leads to a new insight into the concept of pragmatic information: From an evolutionary point of view, pragmatic information is not an invariant of evolution, it must be steadily re-generated by an interplay of structural and functional information—otherwise it disappears.

The generation of pragmatic information has been elucidated for a model of self-organizing agents. The interaction of the agents could basically be described as a nonlinear and *indirect communication* process, which consists of three parts:

- *writing*: the local creation of structural information
- *reading*: the local perception of structural information
- *acting*: the transformation of structural into pragmatic information, which the agents use to decide about their further movement.

Noteworthy, the pragmatic information generated, influences the further production of structural informations by the agents, and therefore closes the non-linear feedback of information production.

The local (structural) information generated by the agents is related to a global information, which has been described as an information landscape. This landscape, which is steadily remodeled by the agents, can be interpreted analogous to a collective memory, where the information stored is commonly generated and commonly reinforced, otherwise it would disappear. The emergence of the collective memory on the information level is accompanied with a *structural organization* of the agents on the spatial level, which means a strong correlation between self-organization and the generation of information. As demonstrated, different kinds of information landscapes may lead to different kinds of spatial structures among the agents. This understanding leads to a deeper insight into the *active role* of information in the process of structure formation.

The information system discussed in Section 3 can be characterized by the following features:

1. The information system is an *evolutionary system*, where stages of independent generation of information are followed by stages of selection, in which a competition for the users of information occurs.
2. The information system is a *self-referential system*. This means that the organization of the agents does not result from an external influence of the system, but from an internal differentiation process with respect to the eigen states of the system.
3. In the information system, a non-linear coupling between the level of the agents and the level of the collective information exist; which means that both evolve in the sense of *co-evolution*.

To conclude this discussion, we want to note that the evolutionary approach to information suggested in this paper may help to overcome the discrepancy between different views on information. As we have shown, the emphasis on pragmatic information as the active and effective information does not ignore syntactic and semantic aspects of information, it includes these aspects into an evolutionary view on information as a whole.

Notes

1. C. F. v. Weizsäcker (1974, S. 361).
2. cf. M. W. Wolkenstein (1990).
3. W. Ebeling, R. Feistel (1994, S. 193).
4. C. F. v. Weizsäcker (o. J.), C. F. v. Weizsäcker (1974) (especially: Abschnitt II.5: Die Quantentheorie), C. F. v. Weizsäcker (1994) (especially: 9. Kapitel, 2.b. Uralternativen).
5. C. F. v. Weizsäcker (1974, S. 272).

6. C. F. v. Weizsäcker (1994, S. 167).
7. C. F. v. Weizsäcker (1994, S. 174).
8. In this paper, the term "structural information" is used in a different sense as suggested by T. Stonier (1991, S. 69) who stresses an analogy between structural information and mechanical potential energy.
9. An overview about theses measures and the literature is given in: W. Ebeling, J. Freund, F. Schweitzer (1998).
10. cf. W. Li (1991), H. Atmanspacher, H. Scheingraber (Eds.) (1991).
11. H. Bai-lin (1989), P. Grassberger (1989).
12. W. Ebeling, G. Nicolis (1991), W. Ebeling, T. Pöschel (1994).
13. E. und C. v. Weizsäcker (1972), E. v. Weizsäcker (1974).
14. For other suggestions to quantify pragmatic information, see: D. Gernert (1996).
15. See also F. Schweitzer (1997, 1998).
16. For the case of two different kinds of markings which is related to multivalue information, cf. also F. Schweitzer (1995a, b).
17. F. Schweitzer, L. Schimansky-Geier (1994) L. Schimansky-Geier, F. Schweitzer, M. Mieth (1997).
18. F. Schweitzer, L. Schimansky-Geier (1994) L. Schimansky-Geier, F. Schweitzer, M. Mieth (1997).
19. H. Haken (1978).
20. F. Schweitzer, K. Lao, F. Family (1997).

References

Atmanspacher, H.; Scheingraber, H. (Eds.) (1991) *Information Dynamics*, Plenum Press, New York.

Bai-lin, H. (1989) *Elementary Symbolic Dynamics*, World Scientific, Singapore.

Brillouin, L. (1956) *Science and Information Theory*, Academic Press, New York.

Ebeling, W. and Feistel, R. (1994) *Chaos und Kosmos. Prinzipien der Evolution*, Spektrum Akademischer Verlag, Heidelberg.

Ebeling, W., Freund, J. and Schweitzer, F. (1998) *Komplexe Strukturen – Entropie und Information*, Teubner, Stuttgart.

Ebeling, W. and Nicolis, G. (1991) Entropy of Symbolic Sequences: the Role of Correlations, *Europhys. Lett.* 14, 191.

Ebeling, W. and Pöschel, T. (1994) Long range correlations in literary English, *Europhys. Lett.* 26, 241.

Gernert, D. (1996) Information as a Unifying Concept, in: Kornwachs, K., Jacoby, K. (Eds.): *Information. New Questions to a Multidisciplinary Concept*, Akademie-Verlag, Berlin, pp. 147–162.

Grassberger, P. (1989) Estimation of Information Content of Symbol Sequences and Efficient Codes, *IEEE Trans. Inf. Theory* 35, 669.

Haken, H. (1978) *Synergetics. An Introduction. Nonequilibrium Phase Transitions in Physics, Chemistry and Biology*, 2nd ed., Springer, Berlin.

Li, W. (1991) On the Relationship Between Complexity and Entropy for Markov Chains and Regular Languages, *Complex Systems* 5, 399.

Schrödinger, E. (1951) *Was ist Leben?*, Lehnen, München.

Schimansky-Geier, L., Schweitzer, F. and Mieth, M. (1997) Interactive Structure Formation with Brownian Particles, in: F. Schweitzer (Ed.): *Self-Organization of*

Complex Structures: From Individual to Collective Dynamics, Gordon and Breach, London, pp. 101–118.

Schweitzer, F. (1997) Selbstorganisation und Information, in: H. Krapp, H.; Wägenbaur, Th. (Hrsg.): *Komplexität und Selbstorganisation—Chaos in Natur- und Kulturwissenschaften*, Fink, München, pp. 99–129.

Schweitzer, F. (1998) Strukturelle, Funktionale und Pragmatische Information—zur Kontextabhängigkeit und Evolution der Information, in: Fenzl, N.; Hofkirchner, W.; Stockinger, G (Hrsg.): *Information und Selbstorganisation. Annäherungen an eine allgemeine Theorie der Information*, Wien, in press.

Schweitzer, F., Lao, K. and Family, F. (1997) Active Random Walkers Simulate Trunk Trail Formation by Ants, *BioSystems* 41, 153–166.

Schweitzer, F. and Schimansky-Geier, L. (1994): Clustering of active walkers in a two-component reaction-diffusion system, *Physica A* 206, 359–379.

Stonier, T. (1991) *Information und die innere Struktur des Universums*, Springer, Berlin.

Weizsäcker, C. F. v. (o. J.) Quantentheorie elementarer Objekte, *Nova Acta Leopoldina*, N. F. Nummer 230, Band 49.

Weizsäcker, C. F. v. (1974) *Die Einheit der Natur*, dtv, München.

Weizsäcker, C. F. v. (1994) *Aufbau der Physik*, 3. Aufl., dtv, München.

Weizsäcker, E. v. (1974) Erstmaligkeit und Bestätigung als Komponenten der pragmatischen Information, in: Weizsäcker, E. v. (Hrsg.): *Offene Systeme*, Bd. I, Stuttgart, S. 82–113.

Weizsäcker, E. v.; Weizsäcker, C. v. (1972) Wiederaufnahme der begrifflichen Frage: Was ist Information, *Nova Acta Leopoldina*, N. F. Nummer 206, Band 37, S. 535–555.

Wolkenstein, M. W. (1990) *Entropie und Information*, Deutsch, Thun.

WORLD FUTURES GENERAL EVOLUTION STUDIES
A series edited by Ervin Laszlo
The General Evolution Research Group
The Club of Budapest

VOLUME 1
NATURE AND HISTORY: THE EVOLUTIONARY APPROACH FOR SOCIAL SCIENTISTS
Ignazio Masulli

VOLUME 2—KEYNOTE VOLUME
THE NEW EVOLUTIONARY PARADIGM
Edited by Ervin Laszlo

VOLUME 3
THE AGE OF BIFURCATION: UNDERSTANDING THE CHANGING WORLD
Ervin Laszlo

VOLUME 4
COOPERATION: BEYOND THE AGE OF COMPETITION
Edited by Allan Combs

VOLUME 5
THE EVOLUTION OF COGNITIVE MAPS: NEW PARADIGMS FOR THE TWENTY-FIRST CENTURY
Edited by Ervin Laszlo and Ignazio Masulli with Robert Artigiani and Vilmos Csányi

VOLUME 6
THE EVOLVING MIND
Ben Goertzel

VOLUME 7
CHAOS AND THE EVOLVING ECOLOGICAL UNIVERSE
Sally J. Goerner

VOLUME 8
CONSTRAINTS AND POSSIBILITIES: THE EVOLUTION OF KNOWLEDGE AND THE KNOWLEDGE OF EVOLUTION
Mauro Ceruti

VOLUME 9
EVOLUTIONARY CHANGE: TOWARD A SYSTEMIC THEORY OF DEVELOPMENT AND MALDEVELOPMENT
Aron Katsenelinboigen

VOLUME 10
INSTINCT AND REVELATION: REFLECTIONS ON THE ORIGINS OF NUMINOUS PERCEPTION
Alondra Yvette Oubré

VOLUME 11
THE EVOLUTIONARY TRAJECTORY: THE GROWTH OF INFORMATION IN THE HISTORY AND FUTURE OF EARTH
Richard L. Coren

VOLUME 12
THE MIND OF SOCIETY: FROM A FRUITFUL ANALOGY OF MINSKY TO A PRODIGIOUS IDEA OF TEILHARD DE CHARDIN
Yvon Provençal

See the back of this book for other titles in World Futures General Evolution Studies.

The Quest for a Unified Theory of Information

Proceedings of the Second International Conference on the Foundations of Information Science

Edited by

Wolfgang Hofkirchner
Vienna University of Technology, Austria

with a Foreword by Klaus Haefner

Gordon and Breach Publishers
Australia • Canada • China • France • Germany • India • Japan • Luxembourg • Malaysia • The Netherlands • Russia • Singapore • Switzerland
1999

Amsteldijk 166
1st Floor
1079 LH Amsterdam
The Netherlands

Cover Figure: Schweitzer, F.; Schimansky-Geier, L.: Clustering of Active Walkers in a Two-Component System, Physica A 206, 323 (1994).

The chapters in this book originally appeared as a special issue of *World Futures: The Journal of General Evolution*, volume 49, numbers 3–4 and volume 50, numbers 1–4.

British Library Cataloguing in Publication Data

The quest for a unified theory of information : proceedings of the Second International Conference on the Foundations of Information Science. – (The world futures general evolution studies series ; v. 13 – ISSN 1043-9331)
1. Information science – Philosophy – Congresses
2. Information theory – Philosophy – Congresses
I. Hofkirchner, Wolfgang II. International Conference on the Foundations of Information Science (2nd : 1996 : Vienna, Austria)
020.1

ISBN 90-5700-531-X

Contents

CONCEPTS OF INFORMATION

SELF-ORGANIZING SYSTEMS

LIFE AND CONSCIOUSNESS