Optimal Structures for Social Systems

Markus Schwaninger[1]

October 21, 2004

Contribution to: Complexity Theory and Philosophy Workshop,
Rio de Janeiro, Brazil, 2004

1. Introduction

The search of optimal structures for social systems has been an ongoing concern of the social sciences, but reliable answers have not been given. Optimization theory has provided solutions, but these have always addressed very specific organizational problems, not the issue of overall optimality in terms of the fitness of the organization as a whole. In this paper, a new approach, grounded in system theory, is suggested for assessing and ultimately also for pursuing such a general optimality of organizational designs.

2. The Question and Established Modes of Dealing with it

The question “Are there optimal structures for organizations?” has recurrently been posed in this general form. The answers have varied, but to date the tenor has been: “No, there is no generally optimal structure. Probably there is an optimal structure for each organization. But we are still looking for a solid theory to ascertain that.”

In the past, the question of organizational optimality has been considered discussible only in very specific and therefore limited contexts. The more famous examples are linked with the optimization of *organizational processes*, e.g. routing problems, resource allocation problems, and control problems. Applications of this type have resulted in substantial improvements as far as the economic use of scarce resources is concerned. The types of problems of *enduring structures*, which have been studied in terms of optimization, are different:

- *Single-objective optimization:* Under this title the classical types of optimization can be subsumed. A typical case is the question of the optimal span of control in a hierarchy of agents with largely uniform tasks (e.g., the optimal number of salespersons in service centres for a market).
- *Multi-objective, multi-parameter and multi-level optimization:* Large and complex logistic systems may call for “multiple-issue” solutions which allow for an overall optimum, taking into account different objectives at the same time (e.g., a postal system where cost, time and ecological performance may be the pre-eminent criteria, and where a structure of distributive centres with several levels may be considered). Solutions for this type of problem involve multi-objective, as well as multi-parameter and multi-level optimization in a combined mode.

It must be noted that only a subset of the optimization techniques can provide “optimal solutions” in the strict sense of the word. Most of the more complex solutions

---

[1] Professor of Management at the University of St. Gallen, Switzerland.

mentioned are numerical and only approximate optimality. In other words, it is known that these solutions are close, often very close to the theoretical optimum, although that theoretical optimum remains unknown. The exact boundary between the cases with "optimum" solutions and those with "close to optimum" solutions is given by the theoretical limit of feasible computation, which establishes the physical limits of analysis. Essentially, the use of heuristic methods is motivated by the question as to whether the decision problems which are part of these optimization problems are "NP-complete"[2]. This means, to put it in a nutshell, that an exact solution of a given optimization problem is possible if one can construct a polynomial algorithm which can solve all the decision problems of the complexity class in focus (cf. Garey/ Johnson 1979, Wegener 1993).

Another approach to the search for optimality has been multidimensional structuring. In principle, optimization can be applied to multi-dimensional problems, as has been said: Multi-objective optimization is a case in point. When we talk about "multidimensional organization" we mean something different: We indicate the simultaneous structuring of an organization according to different structuring criteria. Even though multidimensionality has contributed substantially to absorbing complexity, the question of an optimal degree of dimensionality remains open. In fact, it has barely been addressed.

3. Idea for an Innovative Approach and Hypothesis

If we ask "What dimensionality is optimal?", organization theory itself cannot provide us with satisfactory answers. We have to take recourse to the natural sciences, as General Systems Theory and Cybernetics have done more often[3]. Once more biology appears to be a reliable source of knowledge.

This approach is based on the following idea: If the *fractal dimensionality* (known as the „Hausdorff-dimension", in acknowledgement to its originator. Cf. Hausdorff 1918) of living organisms is optimal (as proposed by biology; cf. M. Sernetz 2000), and if optimal structures are invariant across different domains of reality (as claimed by systems theory; cf. J.G. Miller 1978 and S. Beer 1981, 1985) then the *benchmark* for the optimality should be the size of that dimensionality.

Recent biological studies teach us that living organisms (plants, animals, humans) are structured in a fractal mode: Their metabolism, breathing, blood circulation and other vital functions are optimized by these fractal structures.

The dimension of a fractal can be ascertained by determining its conventional measures with the help of increasingly fine yardsticks, and by ascertaining how much the measures grow as a function of this refinement. Real biological objects can be measured in this way, whereby their fractal dimension can be determined. Biometric studies have ascertained that the metabolic activity of living organisms follow a law of power, expressed by the following formula, which has been derived from empirical evidence (after Sernetz/ Justen/ Jestczemski 1996, Jestczemski/ Bolterauer/ Sernetz 1997, Sernetz 1994):

$$M = L^D, \text{ where } 2{,}2 > D > 2{,}3. \qquad (1)$$

---

[2] NP stands for *nondeterministic polynomial time*.

[3] Cases in point are Anatol Rapoport's exemplars of mathematical modeling in biology and the social sciences, as well as James Grier Miller's *Living Systems Theory* and Stafford Beer's *Viable System Model*.

M is the metabolic activity, measured as the organism's throughput in Joule per second, and L is the length of the organism. D is the fractal dimensionality of the organism. On the basis of measures of multiple species, Sernetz and his team at the University of Giessen ascertained an allometric exponent of b=0,74, measuring the progression of throughput in Joule per second, as a function of body volume in litres. Expressed by the length instead of the volume, the applicable exponent is $D=3b=2{,}22$, which denotes the growth of the metabolic rate as a function of the length of an organism. On the assumption that the extant living organisms are optimally structured, Sernetz concludes: An optimally built organism must be 2,22-dimensional (Sernetz 2000). In other words, according to this theory, for optimally built organisms the law of power must be:

$$M = L^{2{,}22}. \qquad (2)$$

If the structural laws governing the behavior of social organizations and living organisms are the same, and there is a large body of evidence indicating that they are, then we can make use of a powerful isomorphy (i.e., structural invariance):

Similarly to an optimally built organism, an optimally conceived organization should exhibit a dimensionality of about 2,2 to 2,3. Then, the hypothesis to be tested is:

An optimally conceived organization shows a dimensionality between 2,2 and 2,3.

4. Test of the Hypothesis

The first approach taken has been to test whether a structural arrangement already proven or at least considered optimal is in accordance with the hypothesis.

The organizational model chosen for this purpose is Beer's *Team Syntegrity* model, a structural framework for an optimal structuring of interactions and communications in large groups (Beer 1994). At this stage, Team Syntegrity has been extensively tested; about 200 applications have been realized, several of which have been explored scientifically (Cf. inter alia: Beer 1994, Hechenblaickner et al 1995, Espejo/ Schwaninger 1998, Schwaninger 2003). By and large, the theoretical claim that the Team Syntegrity architecture is prone to optimize interactions and communications in large groups (cf. Jalali 1994) appears to hold also on empirical grounds.

3.1. Setup

The *Team Syntegrity* model *(TSM)* provides a theory for an optimal structuring of interactive and communicative processes in large groups, i.e. groups that exceed the size of face-to-face groups, which are, in principle, limited to seven plus or minus two members. It is a structural framework to foster cohesion and synergy in larger groups of individuals, or to encourage the transformation of mere aggregates of individuals with similar interests into organizations with their own identities. Invented by Stafford Beer (1994), TSM is a progressive design for democratic management in the sense of the heterarchical-participative type of organization (cf. Schwaninger 1996, 2000a). The TSM is a holographic model for organizing processes of communication in a non-hierarchical fashion that can be shown to be mathematically optimal for the (self-) management of social systems. Based on the *structure of polyhedra,* it is especially suitable for realizing team-oriented structures, and for supporting processes of planning, knowledge generation and innovation in turbulent environments. In the following, I shall illustrate the architecture of the model by using the geometry of an *icosahedron*, which is one of the structures commonly used to organize syntegration events, - in this case with 30 participants.

The formation of networks by persons who are connected by mutual interests is a manifestation of the information/knowledge society and a structural answer to challenges of our time. An *infoset* is a set of individuals who share a common concern and who are in possession of pertinent information or knowledge connected with the issues of concern, and who have the will (and most likely also the enthusiasm) to tackle these. The *Team Syntegrity model* supplies the structural framework for the synergetic interaction of an infoset which is intended to lead to an integration of multiple topics and perspectives towards a shared body of knowledge. The term *Syntegrity* results from a combination of *synergy* and *tensile integrity*. We speak of synergy when the interaction or co-operation of two or more agents produces a combined effect greater than the sum of their individual efforts. Tensile integrity is the structural strength provided by tension, as opposed to compression (Fuller/Applewhite 1982).

3.2. The Architecture of Team Syntegrity

An infoset of 30 persons, for example, can organize itself according to the structure of an icosahedron, the most complex of the regular, convex polyhedra (Figure 1[4]), whereas for smaller gatherings, structures based on other polyhedra are possible. Each member of the a 30 member infoset is represented by one edge on the icosahedron. Each vertex stands for a team of five players (-> five edges) working on one topic; in an icosahedron there are 12 vertices that would be marked by different colors in a Syntegration. Therefore, given the geometry, each participant as a player/actor is connected by his/her edge to two different teams. Ms*. Red-Yellow*, for instance, belongs to the teams (vertices) *Red* and *Yellow*. At the same time, she acts as a critic to two other teams (for example, *Black* and *Silver*, which are her immediate neighbors). This means that each team consists of 5 players and 5 critics. Altogether, the thirty agents perform a total of 120 roles (30 times 2 roles as a player and 2 as a critic). In addition, there is the observer role, which will be explained in a moment.

---

[4] Kindly made available by TSI – Team Syntegrity Inc., Toronto, Canada.

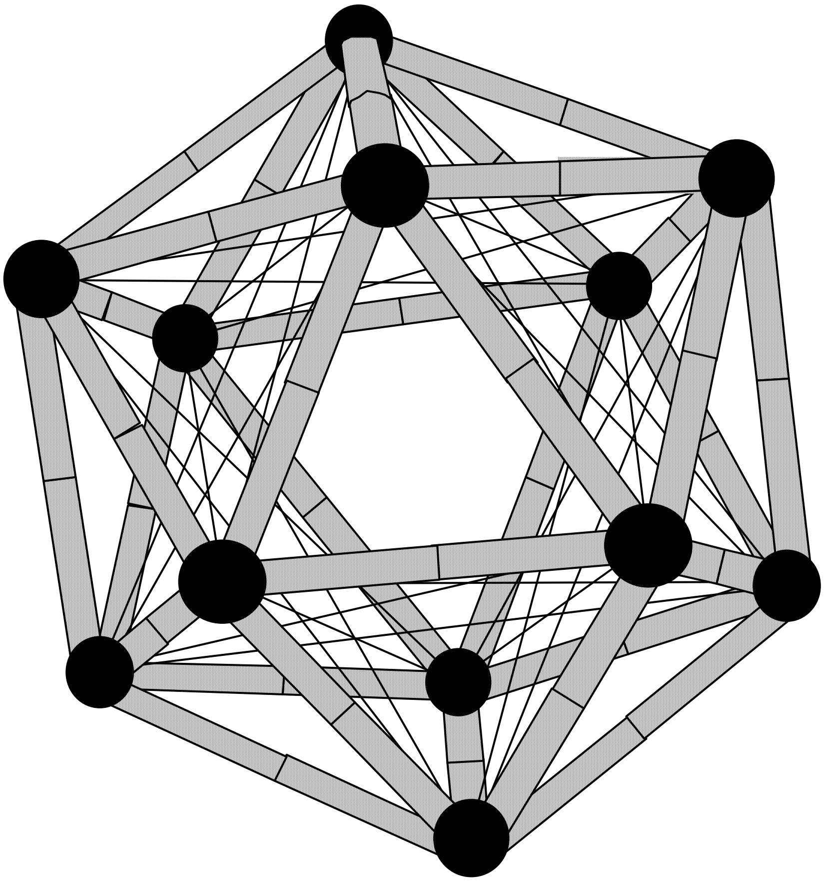

Figure 1: Icosahedral structure of the Team Syntegrity model

This structure resolves the paradox of peripherality versus centrality of actors in an organization (as formalized by Bavelas (1952): While peripherality leads to communication pathologies, alienation and low morale, centrality is needed for effective action. However, as a group grows, centrality can only be „purchased" at the cost of increasing peripherality (Leonard 1994). Team Syntegrity enables an Infoset to acquire „centrality" via a reverberative process (each team will meet more than once), although the peripherality of each one of its members equals zero, i.e., there is no peripherality at all.

Typically, the structure of Team Syntegrity is applied in the context of processes by which ill-defined issues have to be tackled and for which contributions of multiple agents with different backgrounds are required. This is the case e.g. in strategy making, knowledge generation and organizational development. A Syntegration process has the following phases: After the phases of initialization and joint design of the agenda around the common subject of interest, the 12 individual teams (consisting of 5 players and 5 critics each) explore their respective topic. Each team meets several (usually three) times and writes up a summary of its results to share with the whole infoset. Discussions evolve as follows: The sessions are developed in a parallel mode with two teams working at a time. This means that 20 of the 30 members of the infoset are involved in these discussions. The remaining 10 can attend any one of the meetings as observers, in order to complement the views derived from their activities as players and critics in their respective, individual set of 4 teams. They may also use some of that time for lateral conversations with other "idle" members or simply relax.

The fact that the same issue with its different but interconnected aspects is continually processed by the same set of people, who gather in alternating compositions (topic-oriented teams) implies strong reverberation and leads to a self-organizing process with high levels of knowledge integration. There is no center required to integrate the individual efforts; integration just occurs of its own accord. It can be shown mathematically that this is a geometrically ergodic process, in which the eigenvalue[5] of the process converges to a minimum: Ninety percent of the information in the system will be shared after three iterations, and ninety-six after four iterations (Jalali 1994).

3.3. Calculus of the Dimensionality of the Team Syntegrity Architecture

In the following, a rough calculus of the dimensionality of an infoset as structured by the icosahedral architecture of Team Syntegrity ensues:

$$R_I = R_T + R_C \,, \qquad (1)$$

where R_I denotes the total set of actual relationships of the members of the infoset. Its components are R_T, - the relationships at the team level, and R_C , - the complementary relationships of the observers.

R_T is the composite of the relationships within the teams (*t*), 12 in the ideal case. n_i expresses the number of team members of team *i,* the ideal number of members being five players (*p*) plus five critics (*c*) for all teams. The number of relationships between a pair of members is denoted by (*m*).

$$R_T = \sum_{i=1}^{t} \frac{m \cdot n_i (n_i - 1)}{2} \,,\; n_i = p_i + c_i \,. \qquad (2)$$

For this ideal case, with reciprocal relationships between each pair of members, i.e. (m=2), R_T amounts to:

R_T =12•2•10•9•1/2=1’080

R_C is the composite of the relationships between the members of the discussing teams (*b*) and the members of the team they observe. The arrangement is that, while team discussions are going on, some of the observers relax[6] whereas others switch from team to team, visiting both sessions going on at the time. Switches can also be made between the iterations of the team discussions, i.e., an observer could distribute his activities between the three iterations: For example, in the three iterations of the parallel discussions of teams A and B he or she could observe team A in the first iteration, relax in the second, and observe team B in the third iteration. To take account of these aspects, some assumptions must be made explicit to arrive at a first, rough calculation. We establish a parameter *f* denoting the average percentage of the total number of observers *b* (ideally 10) which are actively observing teams during a given pair of sessions. Furthermore, we introduce a parameter *s* which expresses the average fraction of those active observers who switch between teams. Based on the many Syntegration events realized to date, including those accompanied by the author[7], the assumption of *f*=1/2 and *s*=1/3 appears to be realistic for a rough approximation of an idealized Syntegration[8].

---

[5] The formula to calculate the eigenvalue is: y=($1/\sqrt{5}$)^n, with n denoting the number of iterations.

[6] Such relaxation is essential to keep the vigor, concentration and involvement of participants high.

[7] To date approximately 200 Syntegrations have been realized, despite the relative recency of the model. The author has directed or co-directed several, among them the first worldwide electronic Syntegration (cf.

Consequently, the following formula can be applied:

$$R_C = \sum_{i=1}^{t} b \cdot n \cdot f \cdot (1+s) \;. \qquad (3)$$

For this ideal-type we get:

$$R_C = 12 \bullet 10 \bullet 10 \bullet 1/2(1+1/3) = 800$$

Adding up R_T and R_C leads to:

$$R_I = 1'080 + 800 = 1'880$$

In other words, the set of relationships of the icosahedral infoset, as specified above, totals 1’880. At this point, the dimensionality of the structure (x) can be calculated as a function of R_I and the total number of the members of the infoset (N)[9]:

$$R_I = N^x \,. \qquad (4)$$

To solve this equation the following transformations are necessary:

$$\log R_I = x \log N \,,$$

$$x = \frac{\log R_I}{\log N} \;. \qquad (5)$$

With a total set of relationship (R_I) of 1'880 and a total number of infoset members (N) of 30, the result is:

$$x = \frac{\log 1'880}{\log 30} = 2{,}21658 \,.$$

In other words, the dimensionality of the icosahedral architecture of Team Syntegrity is 2,21658. In sum, the working hypothesis formulated above is strongly corroborated.

The surprising fact is that this size of x is very close to the optimal dimensionality observed in biological organisms. It is actually closer to 2,22 than originally expected (cf. hypothesis above).

3.4. The Revised Theorem

In the light of these results, the hypothesis formulated above can be slightly revised, in the sense of proposing the following *Theorem for an Optimal Structure of Organizations*:

An optimal organization structure shows a dimensionality of approximately 2,22.

Espejo/Schwaninger 1998) and accompanied many more, within the framework of a research association with Stafford Beer, the creator of the model, and TSI-Team Syntegrity Inc., Toronto, the organization which makes Team Syntegrity available to organizations.

[8] The assumptions made explicit here try to capture a structure which enables an „optimal“ flow of information, taking into account the psycho-physically limited resilience of participants. Variations of the parameters f and s as a function of the situation at hand should also be considered (see below).

[9] Equation (4) is isomorphic with equation (1) in section 2. Therefore, N is formally identical with the L, and R_I with the M, in the latter. In other words, an isomorphic correspondence between *Length* and *Number of members of an Infoset*, as well as between *Metabolic Rate* and *Number of Actual Relation- ships between Infoset Members* is assumed.

3.5. Discussion

I am aware that this proposition is bold, but it conforms to Popper's principle of falsifiability. In principle, this *Theorem for an Optimal Structure of Organizations* provides a powerful conceptual instrument to establish whether the dimensionality of a structure is too high or too low. The benefit lies in avoiding potentially huge costs and a host of disfunctionalities, - not only economic but also social and ecological ones.

However, the theorem also prompts questions. One major question that emerges is, how general this theorem is. Does not contingency theory postulate that organizational structures are and should be a function of the contexts they face? According to contingency theory, placid environments require and induce less complex structures than turbulent ones (cf. Lawrence/Lorsch 1967, Thompson 1967). The answer is straightforward: The theorem proposed here defines optimality in terms of contexts similar to those faced by living biological organisms. These are always confronted with complex, turbulent environments, at least potentially. Also, in the social domain potential high-level complexity and turbulence are ubiquitous.

Team Syntegrity, the reference model used for the test above, is definitely a model to be recommended for dealing with complex issues, but it would not be advisable for the structuring of a mere routine task. In addition, coping with that kind of task would most probably not require an organization of a dimensionality of 2,22. However, routine tasks are usually part of more encompassing organizations, which in the end strive for viability and development (Schwaninger 2000b, 2001). As a whole, these organizations are in principle exposed to high complexity, at least potentially.

Further research should explore the possible limits of this theorem. Admittedly, a limitation of this paper is one of extension: Therefore, not all the practical implications, which are already discernible at this point, can be treated in detail.

For example, this first test has been confined to one organizational model, albeit under consideration of multiple modalities of its use. Other models for organizational structuring, which cannot be examined here, should be studied in the light of this *Theorem for an Optimal Structure of Organizations.* Also, the test applied here, has essentially been realized in a deductive mode. In addition, empirical tests of the type mentioned at the beginning of Section 3 should be carried out in the future.

Furthermore, variants of the assumptions underlying formula (3) of the calculus should be considered[10]. For example, possible trade-offs between parameters f and s should be studied; see also the sensitivity analysis in the following section. Finally, a great deal could be gained by improving and fine-tuning organizational models and methodologies, - Team Syntegrity being one of them -, in the light of this theorem.

---

[10] Empirical studies will – ceteris paribus (all other factors being equal) - show different values for f and s depending on the circumstances of the respective Syntegration event: For example, a Syntegration with obligatory participation and limited commitment of participants tends to exhibit lower values for f and for s, than the ones chosen in the calculus above. The opposite - higher values for f and for s - will tendentially be the case in a Syntegration of a group of people tackling a difficult issue all of them are highly committed to.

4. Sensitivity Analysis

Following up on the discussions of the calibration of parameters, a number of scenarios were calculated in order to test the sensitivity of the TSM structure's dimensionality to changes in these parameters. A summary is presented in Table 1.

Scenarios	No. Relationships betw. Pairs	No. Players	No. Critics	No. Members/ Team	No. Teams	No. Relationships Team Level	No. Observers	Active Observers	Share Switchers	No. Compl. Rel. Ships (Observers)	Total No. Relationships	Dimensionality	Difference from ideal	Deviation %
	m	p	c	n	i	RT	b	f	s	RC	RI	D	D = 2,22	
Base	2	5	5	10	12	1080	10	0.500	0.333	800	1880	2.21658	-0.00342	***-0.15***
Incomplete Teams	2	3	3	6	12	360	6	0.500	0.333	288	648	2.23981	0.01981	0.89
Less Teams	2	5	5	10	9	810	7.5	0.500	0.333	450	1260	2.29286	0.07286	3.28
"Non"-communicators	1.5	5	5	10	12	810	10	0.500	0.333	800	1610	2.17100	-0.04900	-2.21
Workaholics	2	5	5	10	12	1080	10	0.800	0.800	1728	2808	2.33454	0.11454	5.16
Lazybones	2	5	5	10	12	1080	10	0.200	0.200	288	1368	2.12311	-0.09689	-4.36

Table 1: Sensitivity Analysis - Summary

The scenarios are:

1. *Base:* This scenario corresponds to the "ideal case" as in the calculations above.
2. *Incomplete Teams:* Parameters *p* and *c*, which denote the numbers of players and critics per team are set to 3 respectively, instead of 5, as in the base scenario.
3. *Less Teams:* Parameter *i* which represents the number of teams is reduced from 12 to 9.
4. *"Non"-communicators:* The average number of relationships between each pair of members of the infoset – captured by parameter *m* - is reduced from 2 to 1,5.
5. *Workaholics:* The share of active observers – denoted by parameter *f* - and the share of those who switch teams in a given session – *s* – are drastically increased.
6. *Lazybones: :* The share of active observers - *f* - and the share of those who switch teams in a given session – *s* – are drastically reduced.

The results show deviations between 0,15% and 5,16% from the ideal of D=2,22. The Team Syntegrity structure appears to be very robust against incompleteness of teams, weak communicators and even reduced team numbers. While the deviation of plus 5,16% in the case of the "Workaholics" scenario probably does not imply more than some unproductive work due to excessive activism, the deviation of minus 4,36% indicates that a low level of commitment may lead to some, albeit not even very strong decrease in the shared information. Altogether, it appears that it is difficult to be unproductive in the context of the Team Syntegrity structure.

5. Synopsis and Outlook

This paper has addressed the question of the optimality of organizational structures. Biological research into organic structures has empirically ascertained the fractal dimensionality of living organisms, which can be assumed to be optimal. Building on this body of knowledge, *a new theorem for the design of optimal organizations* has been proposed here. Also, a first test of the main proposition has been undertaken. The results suggest that the theorem is surprisingly accurate.

In addition to further testing of the proposition, follow-up research should address several important questions, two of which shall be pointed out here. The first question is: “What are operational measures of fractal dimensionalities, and how can they be achieved?” The second question is: “To what degree can the optimal dimensionality vary as a function of the properties of an organization, such as the cohesiveness or diversity of goals, values and preferences of its members?”

In sum, this *Theorem for an Optimal Structure of Organizations* is applicable to all kinds of social organisms, be they private firms, public organizations or social initiatives, etc. It opens up new prospects of a more rigorous assessment of models of structure proposed by theories of organization. But it also enables a better-founded evaluation of concrete structuring options, as well as a theory-based design and implementation of structural models in practice. The implications for the methodology of organizational structuring could be substantial: this theorem offers a benchmark by means of which obsolete fads and fashions can be exposed and disfunctional propositions refuted. In sum, the better variants can be sorted out.

Finally, it must be emphasized that this theorem sheds new light on structural issues of the design of the structures by which a society governs itself: The political system, the “state”, i.e., government and the public sector in general can benefit from it.

Acknowledgements

The author extends his thanks to Professor Anatol Rapoport and to Mr. Peter Vrhovec for reading drafts of this paper as well as for their valuable and encouraging comments. He is also very grateful to Mr. Heiko Eckert for making him aware of Sernetz’ work and to Dr. Andreas Klose for reading parts of this paper and giving helpful technical advice. Finally, he thanks Professor Roberto Moreno-Díaz for providing an ideal working environment at the Institute of Cybernetics, University of Las Palmas de Gran Canaria, where most of this paper was written during a visiting professorship.

References

Bavelas, A.: Communication Patterns in Problem Groups. In: Cybernetics: Transactions of the Eighth Conference, New York: Josiah Macy Jr. Foundation (1952)

Beer, S.: Brain of the Firm, 2nd ed., Chichester etc.: Wiley (1981)

Beer, S.: Diagnosing the System for Organizations, Chichester etc.: Wiley (1985)

Beer, S.: Beyond Dispute. The Invention of Team Syntegrity, Chichester etc.: Wiley (1994)

Espejo, R./ Schwaninger, M., eds.: To Be and Not to Be that is the System, Festschrift für Stafford Beer, CD-ROM, Wiesbaden: Carl Auer Systeme Verlag (1998)

Fuller, R.B./ Applewhite, E.J.: Synergetics: Explorations in the Geometry of Thinking, New York/London: Macmillan/Collier (1982)

Garey, M. R./ Johnson, D. S.: Computers and Intractibility: A Guide to the Theory of NP-Completeness. New York: Freeman (1979)

Hausdorff, F.: Dimension und äusseres Mass. Mathematische Annalen 79 (1918) 157-179

Hechenblaickner, P./Krafft, A./Steiner, S.: Kingview Syntegration, Toronto, Canada, Research Report, St. Gallen, Switzerland: University of St. Gallen (1995)

Jalali, A.: Reverberating Networks. Modelling Information Propagation in Syntegration by Spectral Analysis. In: Beer, S., Beyond Dispute. The Invention of Team Syntegrity, Chichester etc.: Wiley (1994) 263-281

Jestczemski, F./ Bolterauer, H. / Sernetz, M.: Comparison of the Surface Dimension and the Mass Dimension of Blood Vessel Systems. In: Miyazima, S., ed.: The Future of Fractals, Singapore etc.: World Scientific (1997) 11-20

Lawrence, P.R./ Lorsch, J.W.: Organization and Environment: Managing Differentiation and Integration, Boston: Harvard University Press (1967)

Leonard, A.: Team Syntegrity: Planning for Action in the Next Century. In: Brady, B./ Peeno, L., eds., Proceedings, Conference of the International Society for the Systems Sciences, Louisville, Kentucky (1994) 1065-1072

Miller, J.G.: Living Systems, Niwot, Colorado: University Press of Colorado (1978; 1995 reprint)

Schwaninger, M.: Structures for Intelligent Organizations, Discussion Papers, Institute of Management, University of St. Gallen, Switzerland, No. 20 (1996)

Schwaninger, M.: Distributed Control in Social Systems. In: Parra-Luna, F., ed.: The Performance of Social Systems, New York etc.: Kluwer Academic/Plenum Publishers (2000a) 147-173

Schwaninger, M.: Managing Complexity - The Path Toward Intelligent Organizations. Systemic Practice and Action Research, Vol. 13, No. 2 (2000b) 207-241

Schwaninger, M.: Intelligent Organizations: An Integrative Framework. Systems Research and Behavioral Science, Vol. 18, Issue 2 (2001) 137-158

Sernetz, M.: Organisms as Open Systems. In: Nonnenmacher, T.F./ Losa, G.A./ Weibel, E.R., eds.: Fractals in Biology and Medicine, Basel etc.: Birkhäuser (1994) 232-239

Sernetz, M.: Die fraktale Geometrie des Lebendigen. Spektrum der Wissenschaft, July 2000, 72-79

Sernetz, M./ Justen, M./ Jestczemski, F.: Dispersive Fractal Characterization of Kidney Arteries by Three-Dimensional Mass-Radius-Analysis. In: Evertsz, C.J.G./ Peitgen, H.-O./ Voss, R.F., eds.: Fractal Geometry and Analysis. The Mandelbrot Festschrift, Curaçao 1995, Singapore etc.: World Scientific (1996) 475-487

Thompson, J.D.: Organizations in Action, New York etc.: McGraw-Hill (1967)

Wegener, I.: Theoretische Informatik. Eine algorithmenorientierte Einführung, Stuttgart: Teubner (1993)