International Twin-Conference
on Complexity and Self-Organization

International Conference:

Self-Organization of Complex Structures:

From Individual to Collective Dynamics

24-28 September 1995.

Berlin, Germany

Welcome

Welcome to Berlin, welcome to the International Conference "Self-Organization of Complex Structures: From Individual to Collective Dynamics".

The investigation of complex systems is one of the primary topics of recent scientific interest. During the past 15 to 20 years, in physics, chemistry and molecular biology a broad spectrum of theories and methods has been developed to explain structure formation in complex systems. The conference should show how these methods could be transfered into different fields of application, and therefore has an *intrinsic interdisciplinary outline.*

The topics of the conference, ranging from fundamental questions regarding the evolution of complexity, to biological and ecological dynamics, to socio-economic problems and urban structure formation, gain not only scientific interest. They also attract a broad public attention in order to manage the challenges and problems of our common future.

Therefore, we would like to see the conference providing a forum of broad-minded and intensive discussions. A personal atmosphere at the conference should allow exchange of ideas, with ample possibilities to establish contacts and to organize future collaboration.

Our conference center, the Berlin Congress Center (BCC), should provide the best prerequisites. Located in the heart of the city, directly on the Spree River, the BCC offers modern facilities for the conference and also includes convenient restaurants for lunch and dinner as well as cafes to relax and discuss sessions.

For entertainment in the evenings, the BCC has a ticket counter to buy tickets for theaters and operas. The historic district of Berlin, the "Nicolai Viertel", known for its stylish restaurants and shops, is a mere 10 minutes walk along the river. Similary, Alexanderplatz, the "Mitte" of the city, is situated only one subway stop away. Taking the same subway a second stop will bring you to the old "Scheunenviertel" renowned for its night life.

So, in addition to a presumably interesting conference, Berlin will offer you its very best immediately after the afternoon sessions. There will be ample time to enjoy it, as Berlin never closes.

Best wishes for an interesting and stimulating conference and a pleasant stay in Berlin.

On behalf of the Scientific Committee (W. Ebeling, A. Hübler, L. Schimansky-Geier, F. Schweitzer) and the organizers

Frank Schweitzer

About the Conference

The International Conference *Self-Organization of Complex Structures: From Individual to Collective Dynamics* is part of the *International Twin-Conference on Complexity and Self-Organization* which also includes the conference *Managing Complexity: Applications of Self-Organization* (Stuttgart, Germany, 20-22 September 1995) organized by the Sonderforschungsbereich 230 "Natural Constructions" (Stuttgart / Tübingen), which finishes its research activities by the end of 1995.

Both conferences are dedicated to a broad presentation of recent developments in the application of complex systems theory and self-organization, with possibilities to establish contacts and future collaboration.

The Berlin conference focuses on the emergence of collective phenomena from individual or microscopic intereactions. Emphasis is on dynamic models of self-organization in the following fields of applications:

1. *Biological and Ecological Dynamics*, including co-evoultion, emergence of functionality, collective phenomena in biological systems

2. *Evolution of Complexity and Evolutionary Optimization*, including molecular self-assembly and selection, multi-agent systems, thermodynamic and biological ensemble search strategies

3. *Dynamics of Socio-Economic Processes*, including emergence of collective strategies, interacting spatial economies, innovation processes

4. *Urban Structure Formation and Transportation Dynamics*, including settlement formation, fractal city growth, traffic flow models, transportation networks

The Scientific Committee of the Berlin Conference includes A. Hübler from the Center of Complex Systems Research of the University of Illinois, Urbana, and W. Ebeling, L. Schimansky-Geier, and F. Schweitzer from the Institute of Physics of the Humboldt University, Berlin. The local organization is carried out by F. Schweitzer, with the assistence of B. Tilch.

Regarding the scientific outline, the Berlin conference continues conference series as "Irreversible Processes and Self-Organization" (IPSO 1-4, Rostock, 1977, Berlin, 1982, Kühlungsborn, 1985, Rostock, 1989) and "Models of Self-Organization in Complex Systems" (MOSES, Gosen near Berlin, 1990). The 1995 conference attracts about 150 participants. During the five days meeting, 18 plenary talks, 34 talks in parallel sessions and 40 poster contributions are presented.

We acknowledge gratefully financial support from the "Deutsche Forschungsgemeinschaft" (Bonn) and the "Senat für Wissenschaft und Forschung" (Berlin).

Sunday, 24th of September

12.00	Begin of Registration for the Conference Berlin Congress Center (BCC): Room A 529 - 5th floor Märkisches Ufer 54, 10179 Berlin, Germany
Plenary session Room A 529 - 5th floor	
14.00	Opening of the conference
14.15	Varela, F.J. (Paris) Cognition and Self-Organization in the Brain
15.00	Fontana, Walter (Vienna) "The Arrival of the Fittest" - On the Origin of Functional Organization
15.45	Ben-Jacob, Eshel (Tel Aviv) Adaptive Self-Organization in Complex Bacterial Patterns
16.30	*Coffee Break*
17.00	Mosekilde, Erik (Lyngby) E. Mosekilde, O. Jensen, G. Dewel, P. Borckmans Complex Patterns in Reaction-Diffusion Systems
17.45	MacCaskill, John S. (Jena) Evolving Molecular Cooperation
18.30	Crutchfield, James P. (Berkeley) James P. Crutchfield, Melanie Mitchell The Evolution of Emergent Computation
19.15	*Break*
19.30	*Welcome Party* *Restaurant Wintergarten, BCC*

Monday, 25th of September

Plenary session Room A 529 - 5th floor	
09.00	Arrechi, F. Tito (Firenze) How sciences approaches the world: risky truths versus misleading certitudes
09.45	Latane, Bibb (Boca Raton) Dynamic Social Impact and the Clustering and Bundling of Cultural Elements
10.30	*Coffee Break*
11.00	Ebeling, Werner (Berlin) W. Ebeling, M. A. Jimenez-Montano, Karmeshu Dynamics of Innovations in Technology and Science - Including Individual Development
11.45	Silverberg, G. (Maastricht) Is there Evolution after Economics ? - On the Origin of Functional Organization
12.30	*Lunch*
14.00	Andresen, Bjarne (Copenhagen) Global Optimization using Ensembles
14.45	Weidlich, W. (Stuttgart) From Fast to Slow Processes in the evolution of Urban and Regional Settlements Structures
15.30	*Coffee Break*
16.00	White, Roger (St. Johns) Roger White, Guy Engelen Self-Organization and Complexity in the Evolution of Urban Structures
16.45	Schweitzer, Frank (Berlin) Frank Schweitzer, Jens Steinbrink Urban Cluster Growth: Analysis and Computer Simulations of Urbban Aggregations
17.30	*Break*

Tuesday, 26th of September

Parallel Sessions		
	Room A 529 5th floor URBAN STRUCTURE FORMATION AND TRANSPORTATION DYNAMICS	Bankett Hall 1st floor EVOLUTION OF COMPLEXITY
09.00	Helbing, Dirk (Stuttgart) Microscopic Foundation of Macroscopic Traffic Models	Baas, Nils (Trondheim) Self-Organization and Higher Order Entropies
09.30	Nagel, Kai (Los Alamos) Kai Nagel, Steen Rasmussen Chris Barrett Which is my fastest Route to Work ?	Nguyen, Duy (Los Angeles) D.H Nguyen, P.K.C. Wang F.H. Hadaegh Self-Organization of a Multi-Agent System in Pattern Formation
10.00	Hilliges, Martin (Stuttgart) Martin Hilliges, Norbert Koch A simulation model for dynamic traffic flow in freeway networks	Deco, Gustavo (Munich) Gustavo Deco, Bernd Schürmann Information Flow in Chaotic Systems
10.30	*Coffe Break*	
11.00	Schuler, Richard (Ithaca) Richard Schuler, Jose Lobo Urban Hierachies and Fitness Landscape Criteria	Fussy, Siegfried (Vienna) S. Fussy, G. Grössing, H. Schwabl Fractal Evolution in Discretized Systems
11.30	Rosé, Helge (Berlin) F. Schweitzer, W. Ebeling Helge Rosé, Olaf Weiss Optimizations of Road Networks using Evolutionary Strategies	Atmanspacher, Harald (Garching) Meta-Statistical Measures of Complexity
12.00	Molnar, Peter (Stuttgart) Optimiazation of the shape of pedestrians facilities by evolution programs	Yu.L. Klimontovich (Moscow) Statistical Theory of Open Systems
12.30	*Lunch*	

14.00 - 17.30 Poster Session - Bankett Hall 1st floor
15.30 - 16.00 Coffe Break

BIOLOGICAL AND ECOLOGICAL DYNAMICS

1 Beyhl, Friedrich (Kelkheim)
Ontogenesis as a Self-Organizing Process
2 Büssenschütt, Martin (Dübendorf)
Temporal Self-Organization in Abstract Ecosystems
3 Czerlinski, Jean (Chicago)
A Critical Review of Definitions and Conditions for Emergence
4 Dieckmann, Ulf (Jülich)
The dynamical theory of coevolution: an unifying perspective
5 Eckhardt, Irina (Berlin)
Challenging Complexity. Conceptual Issue in an Approach to New Diseases
6 Herbig, Astrid (Stuttgart)
Astrid Herbig, Ulrich Kull
The Generation of Leaf Venation
7 von Hertzen, Raimo (Espoo)
O. Kongas, R. von Hertzen, J. Engelbrecht
Response Characteristics of a cardiac nerve pulse equation stimulated periodically by dirac's delta spikes
8 Janosi, Imre M. (Jülich)
Imre M. Janosi, Istvan Scheuring
Absence of Collective Chaos in a Metapopulational Model
9 Klonowski, Wlodzimierz (Krakow)
Emergence of Functionality and Biological Clock in 'Fast' Proteins
10 Schweitzer, Frank (Berlin)
Frank Schweitzer, Lutz Schimansky-Geier
Aggregation in Cellular Swarms Described by an Active Walker Model
11 Wirtz , Kai (Kassel)
Effective Modelling of Adaptation in Ecosystems

14.00 - 17.30 Poster Session - Bankett Hall 1st floor
15.30 - 16.00 Coffe Break

EVOLUTION OF COMPLEXITY

12 Hempel, Harald (Berlin)
A stochastic cellular automaton of an excitable media with long ranging inhibitor

13 Hofkirchner, Wolfgang (Vienna)
Wolfgang Hofkirchner, Norbert Fenzl
An evolutionary systems model of information - A philosophical framework

14 Medvinsky, Alexander B. (Pushchino)
A.B. Medvinsky, I.V. Lysochenko, D.A. Tikhonov,M.A. Tsyganov, V.V. Kravchenko,G.R. Ivanitsky
A model of spontaneous aperiodic pattern formation: emergence of stationary non-Turing structures

15 Papoyan, Vladimir (Dubna)
D.V. Ktitarev, V.V. Papoyan
On Self-organized criticality in chemical reactions

16 Wiedemann, Gerda (Garching)
G. Wiedemann and H. Scheingraber
Pattern Formation in Coupled Maps

EVOLUTIONARY OPTIMIZATION

17 Bornberg-Bauer, Erich (Vienna)
The Course of Evolution of Biopolymer Structure Formation

18 Chechkin, Alexander V. (Moscow)
Self-Organization and Self-Teaching in Ultra Media

19 Göbel, Ulrike (Jena)
Ulrike Goebel, Christian V. Forst, Christian Reidys
Breaking Neutrality into Pieces

20 Kopp, Stephan (Jena)
Stephan Kopp, Christian Reidys
Exploration of Artificial Landscapes Base on Random Graphs

21 Kschischo, Maik (Berlin)
Torsten Asselmeyer, Werner Ebeling, Helge Rose'
Smoothing representation of fitness landscapes and the density of states

22 Molgedey, Lutz (Berlin)
Evolution Strategies in flat and rugged fitness landscapes

23 Starke, Jens (Stuttgart)
Combinatorial optimization based on the principles of selection and competing processees

14.00 - 17.30 Poster Session - Bankett Hall 1st floor
15.30 - 16.00 Coffe Break

Dynamics of Socio-Economic Processes

24 Adjali, Iqbal (Ipswich)
Critical fluctuations and phase transitions in decentralised agent-resource

25 Brenner, Thomas (Freiburg)
Decision Making Under Uncertainty and the Evolution of Risk Aversion

26 Grothe, Martin (Vallendar)
Complexity and Self-Organization in Socio-Economic Systems: A Structural Approach

27 Watson, Tim (Leicester)
Kin Selection and Cooperating Agents

Urban Structure Formation and Transportation Dynamics

28 Brandt, Kai (Stuttgart)
Modelling and Simulation of Regional Dynamic Processes in the Economy

29 Freund, Jan (Berlin)
Jan Freund, Thorsten Pöschel
A Statistical Approach To Vehicular Traffic

30 Kropp, Jürgen (Potsdam)
J. Kropp, G. Petschel-Held
Topological analysis of micro-statistical data sets of German Cities

31 Tilch, Benno (Berlin)
Frank Schweitzer, Benno Tilch
Self-Organization of Trail Networks with Active Brownian Particles

32 Zamparelli, Michele (Berlin)
Hierarchic Network Optimization

Wednesday, 27th of September

Parallel Sessions		
	Room A 529 5th floor BIOLOGICAL AND ECOLOGICAL DYNAMICS	Bankett Hall 1st floor DYNAMICSS OF SOCIO-ECONOMIC PROCESSES
09.00	Lange, Holger (Bayreuth) H. Lange, C. Romahn, M. Hauhs Classification of Terrestrial Eco-systems with Complexity Measures	Peklenik, Janez (Ljunljana) Coplexity in manufactoring systems, in search for a new paradigm
09.30	Malchow, Horst (Geesthacht) Spatio-temporal Self-organiaztion in Population Dynamics	Ahrens, Volker (Hannover) V. Ahrens, H.-P. Wiendahl Planning and Control in Self-Organized Production Systems
10.00	Stevens, Angela (Heidelberg) Individual Gliding, Collective Movement and Aggregation of Bacteria	Eisenberg, L. K. (New York) Connectivity and Finacial Network Shutdown
10.30	*Coffee Break*	
11.00	Phipps, Michel (Ottawa) Tissue homeostasis: A collective behavior emerging from individual interaction ?	Shakhova, Margarita (Moscow) S. Guriev, M. Shakhova Self-Organization of Trade Networks in a Transition Economy
11.30	Drasdo, Dirk (Teltow) Drowing Tissue Cells Populations: A Stochastic Model based on the Monte Carlo Method	Dandridge, Tom (Albany) T. Dandridge, B. Johannisson Self-Organization among Business Establishment
12.00	Yagil, Gad (Rehovot) Complexity Analysis of Self-organizing and Template Directed Structures	Benenson, Itzhak (Tel-Aviv) J. Portugali, B. Itzhak Trade off Between Global Socio-Spatial Structures and Local Individual's Behavior in a Self-Organizing City
12.30	*Lunch*	

	Room A 529 5th floor BIOLOGICAL AND ECOLOGICAL DYNAMICS	Bankett Hall 1st floor DYNAMICSS OF SOCIO-ECONOMIC PROCESSES
14.00	Bersini, Hugues (Bruxelles) H. Bersini, V. Calenbuhr Frustration in biological networks: a source of diversity and instability	de Vree, Johan (Utrecht) The process of Integration
14.30	Carmesin, Hans-Otto (Bremen) Cortical Functionality Emergence: General Theory & Quantative Results	Liebl, Franz (Witten) Strategic Issue Managment in Complex Socio-Political Environments
15.00	Hearst, John (Berkeley) J. E. Hearst, Y. Shi Elastic Rod Models for the Shape of DNA in Interphased Chromatin	Holyst, Janusz (Warsaw) K. Kaperski, J.A. Holyst Leaders and Clusters in Social Impact Model of Opinion Formation
15.30	*Coffee Break*	
16.00	Reidys, Chrstian (Jena) J. Weber, C. Reidys, P. Schuster Peter Schuster Neutral Evolution on RNA Secondary Structures	Dittes, Frank-Michael (Dresden) How Egotism helps to solve global problems
16.30	Asselmeyer, Torsten (Berlin) T. Asselmeyer, W. Ebeling Mixing of Thermodynamical and Biological Strategies in Optimization	Kirman, Alan (San Domenico di Fiesole) G. Weissbuch, A. Kirman D. Herreine Market Organization
17.00	*Break*	
19.00	**Special Lecture** Hübler, Alfred (Urbana, U.S.A.) Application of Self-Organization Location: Humboldt Universität zu Berlin, Institut für Physik Hörsaal 10, Invalidenstraß, Hofgebäude	

Thursday, 28th of September

Plenary session Room A 529 - 5th floor	
09.00	Nicolis, G. (Bruxelles) Probalistic Approach an Complex Systems
09.45	Shiner, J.S. (Bern) Self-Organization, Entropy and Order
10.30	Coffee Break
11.00	Rasmussen, Steen (Los Alamos) Dynamical Hierachies
11.45	Schimansky-Geier, Lutz (Berlin) Lutz Schimansky-Geier, Frank Schweitzer, Michaela Mieth Interactive Structure Formation with Active Brownian Particle
12.30	Closure of the Conference
12.45	*Lunch*

Biological and Ecological Dynamics

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Mixing of Thermodynamical and Biological Strategies in Optimization

Torsten Asselmeyer, Werner Ebeling
Institut für Physik, Humboldt Universität Berlin, Germany

Several standard processes for searching minima of potential functions, such as thermodynamical strategies (simulated annealing) and biologically motivated selfreproduction strategies, are reduced to Schrödinger problems. The properties of the landscape are encoded in the spectrum of the Hamiltonian. We investigate this relation between landscape and spectrum by means of topological methods which lead to a possible classification of landscapes in the framework of the operator theory. The influence of the dimension d of the search space is discussed.

The connection between thermodynamical strategies and biologically motivated selfreproduction strategies is analyzed and interpreted in the above context. Mixing of both strategies is introduced as a new powerful tool of optimization.

Adaptive Self-Organization in Complex Bacterial Pattering

Eshel Ben-Jacob
School of Physics and Astronomy, Tel Aviv University, Israel

Bacterial colonies exhibit a far richer behaviour than patterning of non-living systems, reflecting the additional levels of complexity involved. The building blocks of the colonies are themselves living systems, each having its own autonomous self interest and internal degrees of freedom. At the same time, efficient adaptation of the colony to adverse growth conditions requires self-organization on all levels - which can only be achieved via cooperative behaviour of the individual bacteria. It may be viewed as the action of singular interplay between the micro-level (the individual bacterium) and the macro-level (colony) in the determination of the emerging pattern. In general, as growth conditions worsen, more complex global structures are observed together with more sophisticated strategies of cooperation. To achieve this, the bacteria have developed communication channels (which they utilise when growth conditions are more stringent) on all levels from direct (by contact) bacterium-bacterium physical and chemical interactions via marks left on the agar surface and chemical (chemotactic) signalling, to genetic communication via exchange of genetic material. The bacteria have developed sort of a particle-field duality: each is localised (moving) particle which can produce a chemical and physical field around itself, and sense fields produced by the other bacteria. Looking at the colonies, it becomes evident that we should view them as adaptive cybernetic systems or multi-cellular organisms which posses fantastic capabilities to cope with hostile environmental conditions and survive them (in passive "particles"). We then discuss the issues of genome adaptation vs. genome learning and horizontal genetic variations (in analogy with Kuhn's "normal science") vs. vertical genetic variations (in analogy with scientific revolutions). the assumption that the genome is a cybernetic unit (i.e. it can process information, has a problem solving capacity and can perform self-changes and reorganizations according to the solutions to the problems) can explain the horizontal variations. It is not sufficient to explain the vertical variations (paradox solving). The highlight of this lecture is our proposal that to solve a paradox (vertical variation) the bacteria form a genetic network employing communication cybernetics, a network which can design (creativity) and can perform vertical variations. This proposal is motivated by the fact that a network of computes can design a new computer which is more advanced than the network elements. The lecture ends with comments about future directions.

Frustration in Biological Networks: A Source of Diversity and Instability

Hugues Bersini and Vera Calenbuhr
IRIDIA - CP 194/6 Universite Libre de Bruxelles, Belgium

The behaviour of several types of biological network is investigated: Boolean net, Hopfield net, network of oscillators and immune idiotypic network, mainly the effect on the dynamics induced by connecting the network in a frustrated way. Frustration occurs when the connectivity is such, in general a loop containing an odd number of inhibitory coupling, that no global configuration with all couples of units equally satisfied turns out to be possible. Each couple mutually competes to impose its natural complementary configuration. Frustration has two consequences: in some cases it enlarges the repertoire of possible stable configurations, but in general it de-stabilizes the network and provokes "wavering" among these configurations. The immune idiotypic network in which the prevailing behaviour is oscillatory will be studied in more details. It will be shown that connecting the network in a frustrated way transforms the oscillatory regime into a chaotic one. This chaotic regime will be investigated in some depth: Poincare map, Fourrier analysis and symbolic dynamics. The main originality of this chaotic regime lies in the behavioural equivalence of the variables involved due to the homogeneity of the structure and the closed chain connectivity. To our knowledge no other system displaying chaotic behaviour shows this variable homogeneity and we suspect "frustration" to be a new way of generating chaotic regimes. Additionally, we will show that frustrated idiotypic networks show tolerant response towards auto-antigen without the need for ad hoc mechanisms that prevent the immune response.

Ontogenesis as a Self-Organizing Process

Friedrich E. Beyhl
Kelkheim, Germany

Ontogenesis, i.e. the ordered development of an organism from the starting cell (spore, zygote, together with its morphogenetic substeps, was not understood for long times until studies showed that it is mediated by biologically active tripper compounds (morphogens, induces, activator, etc.). Only recent molecular-biological methods clarified the way these compounds work. So ontogenesis turns out to be a very complicated but highly ordered and therefore rationally comprehensible self-organizing process which is regulated by a vast multiplicity of tripper compounds (set free by gene expression) acting at certain times, at certain places, an in certain cascades of events. By diffusion from the spot of their origin, they form concentration gradients and, at specific concentrations (which are localized at certain positions of the body) react with further, specific trigger substances in order to form new substances triggering again new morphogenetic event, etc. So self-ordered, steadily changing spatial and temporal patterns of gene activations by such compounds guide and organize ontogenesis. Mutations in this sphisticated morphogenetic process cause either absorption or malformations or evolution , according to internal and external selection processes.

Temporal Self-Organization in Abstract Ecosystems

Martin Büssenschütt
Swiss Federal Institute for Environmental Science and Technology (EAWAG), Dübendorf, Switzerland

The main idea of this project is to investigate the functional significance of temporal self-organization for ecosystem performance and species coexistence. For this aim an abstract ecosystem model was constructed that traces the nutrient flows through the system. Based on allometric relationships for the physiological rates of the organisms, the model is discrete with respect to body weight and to time. In a first step the model is applied to a typical lake plankton community, comparing its behavior with the successional patterns described by plankton ecologists. The results consolidate the argument that the observed dynamics are created endogenously rather than by physical factors. Furtheron the model is used to investigate competition situations in more abstract ecosystems, like sequences of predator-prey-pairs and multiple food-chains. The effect of internal and external parameters on the organizational structure is tested. Particularly the transition from stable equilibrium through periodic niching to chaotic dynamics is examined. It can be shown how an increase in diversity reduces variability on the global scale by increasing it locally. Eventually experiments with a dynamically changing system are performed, demonstrating under what conditions new species can successfully invade an evolving ecosystem.

Cortical Functionality Emergence: General Theory & Quantitative Results

Hans-Otto Carmesin
Institut für theoretische Physik, Universität Bremen, Germany

The human genotype represents roughly ten billion binary informations, whereas the human brain contains more than a million times a billion synapses. So a differentiated brain structure is essentially due to self- organization. Such self-organization is relevant for areas ranging from medicine to the design of intelligent complex systems. Many brain structures emerge as collective phenomena of a microscopic neurosynaptic dynamics: a stochastic dynamics mimics the neuronal action potentials, while the synaptic dynamics is modeled by the Hebb-rule, that is, a synaptic efficiency increases after coincident firing of the pre- and postsynaptic neuron. The microscopic dynamics is transformed to a collective dynamics reminescent of hydrodynamics. The theory models empirical findings quantitatively: Topology preserving neuronal maps were suggested by Descartes in 1664; their self- organization was suggested by Weiss in 1928; they were found empirically by Marshall in 1941; it is shown that they are neurosynaptically stable due to ubiquitous infinitesimal short range electrical or chemical leakage. In the visual cortex, neuronal stimulus orientation preference emerges; empirically measured orientation patterns are determined by the Poisson equation of electrostatics; this Poisson equation orientation pattern is derived here. Altogether a general theory for the emergence of functionality in neurobiological systems via a synaptic growth dynamics is presented and used for quantitative modeling of empirical observations via transformation to collective dynamics.

A Critical Review of Definitions and Conditions for Emergence

Jean Czerlinski
Department of Sociology, University of Chicago, U.S.A.

I. Criteria for a good definition. First, we must distinguish between conditions for our definition and conditions that we empirically observe to be correlated with what we want to call emergence. We will want our definition to agree with some of our intuitions yet provide new insights. Furthermore, we'll want our definition to be useful for our research, so that knowing a system exhibits "emergence" gives us information about how we should proceed in studying the system. I will suggest that we might want to identify several different kinds of emergence. II. Review of definitions and empirical conditions. Candidate definitions for emergence include 1. organization not forced from above, 2. properties not directly generatable from below, 3. a higher-level pattern one can use to place winning bets, and 4. a change to a higher level of intrinsic computation. I then review some proposed conditions for emergence, including 1. natural-selection-style competition, 2. being at the "edge of chaos", 3. non-substitutability of system parts, 4. qualitative dissimilarities under size scaling, 5. variance of system properties upon RmixingS, 6. non-linearity, 7. competition among micro-level states, 8. competition between forces of change and stasis, and 9. elusiveness from full prediction. (This section focuses on work by Haken, Baas, Dennett, Crutchfield, Wimsatt, and Cariani.) III. Critique. The critique begins with the criteria outlined above. I test research usefulness with the heavily-studied case of cellular automata and with a few social examples. Some definitions will clearly be in need of modification. One conclusion will be that emergence must be defined relative to given system properties and different evaluative discriminations (e.g. accuracy) and computational devices; different sets of these (which sets are in the same equivalence class?) can lead to different definitions.

The Dynamical Theory of Coevolution - A Unifying Perspective

Ulf Dieckmann
Institute for Ecological and Evolutionary Sciences, University of Leiden, Netherlands
and
Theoretical Ecology Group, Research Centre Jülich, Germany

A unifying framework is presented for describing the phenotypic coevolutionary dynamics of a general ecological community. We start from an individual-based approach allowing for interactions among an arbitrary number of species. By providing the mathematical links from the individual level via the population level up to the community level we derive the adaptive dynamics of species' trait values from the underlying population dynamics within the community – in consequence, the evolutionary process is driven by ecological change.

We present a hierarchy of four dynamical models for the investigation of coevolutionary systems. The necessity of stochastic treatment is demonstrated and deterministic approximations are derived where appropriate. The mathematical framework advanced here to our knowledge is the first one to combine the individual-based, stochastic perspective with a fully dynamical analysis of the phenotypic coevolutionary process.

Deductions are given to identify various well-known equations from the literature of (co)evolutionary modelling as special cases of our approach. In particular, equations central to the fields of evolutionary game theory, adaptive dynamics, replicator dynamics and selection-diffusion systems are recovered. In doing so, various ad-hoc assumptions can be removed and the different domains of validity for these models can be delineated.

Growing Tissue Cell Populations: A Stochastic Model based on the Monte Carlo Method

Dirk Drasdo
Max-Planck-Institut for Colloid and Interfacial Science, Teltow, Germany

Different approaches to morphogenesis in growing cell biological populations have been intensively studied in the last years accompanied by a fast increase of information from experiments to understand the underlying mechanism in developmental biolological processes (e.g. [TURING, 1952] - [LINDENMAYER, 1968]).

In the present Monte Carlo approach to tissue cell formation, a cell is described in an off-lattice model as single unit with average shape. A stochastic dynamics is assumed for cell movement, growth and division applying the Metropolis algorithm [METROPOLIS, 1953]. An interaction potential between neighbour cells is defined consisting of a repulsive part, which takes into account the confined compressibility of a cell, and a cell type-dependent attractive part due to adhesive interaction of cell adhesion molecules in the membranes of the cells. In the presented version, the model is specially suitable to describe cell types with approximately spherical shapes as found in epithelia and often in cells of the connective tissue.

The Monte Carlo approach seems to be very flexible and allows the study of very different biological systems, such as growing populations in cell cultures, wound healing of a skin cut and blastocoel formation [DRASDO, 1994].

For two dimensional monoclones in cell cultures, two simple models, one, which explicitely considers the excluded volume effect of interacting cells and one, which base on an autocatalytic reaction-diffusion scheme can be shown to contain the main features of the Monte Carlo approach. Some results obtained be numerical simulations as by analytical investigations are compared with experiments, additional predictions may be confronted with experimental results in the future.

References:

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MEINHARD, H.[1982]: *Models of Biological Pattern Formations.* Academic Press Inc., London.

EDEN, M.[1961]: in: *Proc. of the 4th. Berkeley Symposium on Mathematics and Probability.* **Vol. IV**. ed. by J. Neyman, University of California Press.

LINDENMAYER, A.[1968]: *J. theor. Biol.***18**, 280-315.

METROPOLIS, N., ROSENBLUTH, A.W. AND M.N., TELLER, A.H.[1953]: *J. Chem. Phys.* **Vol. 21**, No. 6, 1087-1092.

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Challenging Complexity. Conceptual Issues in an Approach to New Diseases

Irina Eckhardt
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Despite all modern and advanced technologies, drugs, pesticides, health surveillance systems, and the various international activities of different health organizations, it is currently not possible to predict and anticipate the emergence of new pathogens and their virulence.

A new conceptual framework for the research on 'disease in evolution' has been demanded in several publications and workshops during the last few years. In this paper we will explore the most important assumption for the design of a new conceptual framework - that the emergence of new and known infectious disease is a complex evolutionary process in which several natural and social processes are interacting.

We will assume that the development of new models of complex evolutionary processes and the theoretical premises of these models enables us to combine the systematic approach with an evolutionary basis. The development of such epistemological "tools" like pattern recognition, causal analysis, and statistical and mathematical modeling will be used in that enterprise. The biological concept of 'co-evolution' (Levins and Lewontin) will guide us in modeling the complex interactions of social and natural processes involved in disease emergence.

"The Arrival of the Fittest" - On the Origin of Functional Organization

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The modern formal theory of evolution explains how changes in the gene frequencies of reproducing organisms are linked to a local measure of performance called "fitness". By focussing on a purely dynamical phenomenon, the theory can afford to be silent about what an organism actually is: it simply specifies at the outset how organisms behave. This, however, makes it impossible to formally reason about how organisms come into being and to formalize the interaction between evolution and development or the limits to variation - problems which are central to organismal and molecular biology alike.

To understand what evolution is actually doing requires a theory which is at least capable of expressing the construction of self-maintaining organizations and their change ; a theory of the phenotype, as it were.

In this lecture I will sketch past and current work with Leo Buss (Biology Dept., Yale) which is aimed at this problem. The thinking goes basically like this: The primitive "objects" we must start with are molecules. As a first step, therefore, we need an abstract view of chemistry together with a theory of that view. We begin by taking a molecule to be the symbolic expression of an operator. Interaction, then, is viewed as the functional application of an operator (the function) to another operator (the argument) which results in the construction of a new operator (the value). In this metaphor chemistry becomes a calculus, and the choice of calculus is arguably unique. I will review the phenomena which arise if thousands of such operators interact under the conditions of a flow reactor, as well as the (obvious!) definition of organization which is suggested by these phenomena. I will then briefly sketch work in progress which is aimed at taking care of what we swept under the carpet: selective interactions (an abstract notion of "shape"), symmetry and proper mass action. Possible solutions to these issues flow naturally from the chosen formalism. This will lead us to type theory and from there right into logic, yielding a refinement of our abstract view of chemistry.

A meta-message of this lecture is to exemplify that computer science is among the most powerful allies in extending the foundations of theoretical biology.

Elastic Rod Models for the Shape of DNA in Interphase Chromatin

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The mechanical properties of DNA can be likened to those of an isotropic elastic rod. The laws of rod elasticity exert limitations on the geometries that the DNA must have when condensed into highly coiled fiber structures. We have determined the geometric forms of the stationary states of such an elastic rod. By limiting the histone-DNA interactions to normal and binormal forces, we are able to present solutions and graphics of DNA in the 11 nm fiber (helix) and the 30 nm fiber (superhelix). In stationary states, when the 11 nm fiber is a left-handed helix, the superhelix of the 30 nm fiber must be right-handed, and vice versa. The mathematics suggests that much of the cell cycle and gene regulation can be associated with dramatic local phase changes in DNA structure.

The Generation of Leaf Venation

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Summary The generation of the leaf venation is a continous process in ontogeny and in phylogeny, as is demonstrated by a quantitative analysis (scaling exponent). The effectivity of different venation patterns is discussed.

Abstract In phylogeny leaf venation starts with one vein, which first split dichotomous, later in a lateral way and producing a net. In ontogeny the dichotomous process often is reduced. In the development of leaf and venation the main principles are iteration an self-organization. The definition of a scaling exponent allows to quantify the continuity of this process. To test the effectivity of the supply, we compare the vein nets of different species with different mathematical patterns. The theoretical selection factor is to save the expensive material-vein (lignin) in relation to the distance of the point which is to supply. Other functions of the veins as stiffness of the leaf or the evolution of the veins led to the immense number of different patterns which exist.

Absence of Collective Chaos from a Metapopulational Model

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Although for more than twenty years is known that populations may exhibit complex dynamics, including chaos, the evidence for chaotic behavior in natural populations is scarce. There may be (at least) three reasons of this discrepancy. First, it is difficult to distinguish low dimensional deterministic chaos from colored noise originated from stochastic environmental effects. Second, it is possible that natural selection keeps populations away from chaos. The third possible hypothesis states that spatial and dynamical complexity of natural habitats and populations prevents the emergence of chaos.

In this work we present a new metapopulational model, which is built up by local sub-populations. Nearest neighboring local populations interact via migrations. Migration begins from a habitat only if the local population is overcrowded, i.e. the population density exceeds a threshold level. The elementary migrations are supposed to be much faster than the reproduction rate, thus a timescale separation is also introduced. The local populations are allowed to evolve in a chaotic way. Depending on the threshold level, the metapopulation density shows noiselike dynamics of many degrees of freedom, periodical evolution, or tends to a fixed point. Low dimensional collective chaos has not been detected. This demonstrates that spatial complexity and a biologically motivated interaction are able to prevent chaotic time evolutions of natural populations.

Emergence of Functionality and Biological Clock in "Fast" Proteins

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We have put forward hypotheses concerning functionality and timing in "fast" proteins, i.e. those showing short half-time (1 to 30 min.). We think that functionality in these proteins emerges as a consequence of the intrinsic physical instability. The instability arises due to conformational strains resulting from the "competition" between chain proliferation during protein biosynthesis on ribosomes and chain folding. One can consider this instability to be a kind of conformon (so called Klonowski-Klonowska conformon [Ji, 1991]) which serves as a biological clock determining the lifetime of "fast" proteins and the associated time evolution of cellular functions. We discuss experimental results on which these hypotheses are based. If the hypotheses are true, it is impossible to engineer in a laboratory a biologically active exact copy of a "fast" protein, neither it is possible to renaturate a "fast" protein after its denaturation (very unfortunately, renaturation experiments which turned out to be "unsuccessful" usually have not been reported in scientific literature). The instability characteristic for a "fast" protein may arise only if both time and space organization of its biosynthesis are strictly reproduced. We also notice that another powerful mechanism of functional regulation of subcellular structure and function may be that of sol-gel dissipative structures [Klonowski, 1979].

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Classification of Terrestrial Ecosystems with Complexity Measures

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To understand ecosystem behavior and function on the whole system's scale, it is necessary to characterize the way an ecosystem transforms a given input data stream from its abiotic environment into corresponding output. As experience with large amounts of data, especially from forested catchments, show, one may argue that ecosystems act as *filters*; this includes the feature "redundant smoothing" for the input/output relationship. The concurrent information loss of the signal induced by this transformation serves as a measure for the efficiency of the ecosystem or its computational capabilities. An important question is to which degree the system is able to discover regularities of the input data stream and how it can differentiate between complex structured signals and pure noise. This leads to the internal representation or model the system has for its environment. To reconstruct or simulate this internal representation, systemtheoretic tools can be investigated, which up to now mainly have been used for artificial or highly-controlled systems. We use ϵ-machines for the analysis of typical time series of input and output variables. Associated with the number and connectedness of the states of these machines are complexity measures, such as the statistical complexity or the metric entropy. Comparing their values for input (e.g. rainfall) and output (e.g. runoff) data from ecosystems finally leads to a quantitative measure for the information reduction process ecosystems perform. The results for this measure are, however, biased by the need to choose a phase space partition for the process analysed, whose dynamics is unknown; to find a *generating* partition seems not to be feasible. The consequences of different partitioning prescriptions are demonstrated, as well as the dependence of the machine's architecture from its parameters (tree and morph length). The noise/signal distinction is also affected by these choices. We show typical examples from natural ecosystems.

Spatio-Temporal Self-Organization in Population Dynamics

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The dynamics of temporal, spatial and spatio-temporal self-organization in nonlinear systems far from equilibrium is of continuous interest. Local and spatial steady-state multiplicity, regular and irregular oscillations, excitability, propagating fronts, target patterns and spiral waves, pulses as well as stationary spatial patterns have been described. In the current paper, a number of these phenomena are presented for predator-prey dynamics with varying predation characteristics. Furthermore, different scenarios of spatial pattern formation after diffusive as well as advective instability of the uniform population distribution will be described, using population-dynamical sub-models of aquatic ecosystems.

Tissue Homeostasis : A Collective Behavior Emerging from Individual Cell Interaction ?

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Tissue homeostasis implies the existence of some control loop between cell loss and gain. Empirical evidence of a link between cell proliferation and cell-cell interaction through gap junctional intercellular communication (GJIC) suggests a putative role of GJIC in cell growth control. The neighborhood coherence principle (NCP) offers a framework to understand this role. This rule based on cell-cell interaction exhibits powerful self- organizing and self- maintenance capacities. It reads: a state which exists in any particu ar cell tends to impose itself upon neighboring cells". Many natural and man-made patterns observed in the real world may be seen as resulting from this rule. To mimic the dynamics of a tissue, we use a 3-d cellular automaton where states represent distinct cell cycle phases and where state transition is controlled by neighboring cells. In simulations, NCP acts as an effective growth regulating operator. A depletion in quiescent cells (i.e. a surplus of senescent and dead cells) increases the division rate while tissue replenishment with new cells diminishes it. Along this line, cell-cell interaction could be consider a sufficient condition for tissue homeostasis. As a corollary, any alteration of cell-cell communi- cation could result in uncontrolled proliferation thus leading to cancer initiation. This hypothesis suggests novel ideas : i) the overall tissue stability would rest on a local cooperative networking and be imposed as a consensus in spite of a high individual cell variability; ii) the intrinsic propensity of a tissue to develop cancer would depend on its cell arangement (3-d allowing for more efficient control than 2-d arrangement); iii) it emphasizes the role of locality, bottom-up structure emergence and cell social interaction as crucial epigenetic biological phenomena.

Aggregation in Cellular Swarms Described by an Active Walker Model

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The formation of clusters and the directed movement is an emergent behavior known from different cells, like human leucocytes. Our model describes this emergence as a self-organizing process based on local interactions of Active Walkers. The term "active" means that the walkers are able to change their "environment" locally by continously dropping a chemical substance, similar to a pheromone, onto the surface. This substance can diffuse and decay again by decomposition, but it influences the further movement of the Active Walkers similar to chemotaxis.

In the model provided, the structure formation solely comes from a non-linear feedback between the cells and the environment: the response to the chemical gradient lowers the effective diffusion coefficient of the cells to a negative value, thus creating an attraction area, where the cells are no longer able to move freely.

The clustering process which occurs eventually, is an example of interactive structure formation, since the cells do not orientate to an external field, but to a field self-consistently created by themselves. This will be analytically described in terms of coupled Fokker-Planck (FPE) and reaction-diffusion equations (RDE).

The numerical simulations presented are based on the Langevin dynamics of the cells. Compared to the usual integration methods of the related FPE and RDE, our approach provides a faster, but stable algorithm for simulations of systems even with large gradients and small particles numbers. Computer simulations demonstrate the time evolution of the the clustering process and of the chemical field produced. The relations to the basic principles of self-organization are discussed.

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Individual Gliding, Collective Movement and Aggregation of Bacteria

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Part of this talk is joint work with Hans G. Othmer, Department of Mathematics, University of Utah, Salt Lake City, UT, USA

The ubiquitous myxobacteria are living in soil. They are known to glide both individually and socially. Under starvation conditions they aggregate and build higher organized structures, so-called fruiting bodies. Up to now it is still not known which mechanisms are responsible for these phenomena. Different biological hypotheses exist to explain this behavior. Among these are trail following of the bacteria and reinforcement of these trails, and the reaction towards a diffusible chemical. These hypotheses are simulated in a discrete mathematical model and also in an approximating continous model. In the talk the latest experimental results of Biologists are introduced. They are related to changing reversal frequencies of the cells. During the talk a video will be shown, which compares the simulated behavior of the cells to the real bacteria and documents the effects of different parameters in the mathematical model. The aggregation of myxobacteria is not only interesting for itself but of more general interest too, since this phenomenon serves as a biological model problem for the main question in morphogenesis: How do cells manage to come together and build higher organized structures?

Cognition and Self-Organization in the Brain

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The process of knowing has, as correlate, a large-scale integration of multiple brain regions. Each region has some specific capacities and performances, but the key of cognition is in the large-scale, self-organizing nature between these distributed processes. In my lecture I will discuss the background for these issues, the new techniques that allow concrete observation into them, and some recent classes of models that provide insights into their mechanism. Most remarkable is the idea of cognitive processes as transient dynamical aggregates that are continously being generated modulated by the organim's coupling and its internal regulation.

Response Characteristics of a Cardiac Nerve Pulse Equation Stimulated Periodically by Dirac's Delta Spikes

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We have modelled the cardiac conducting tissues (His-Purkinje network) by a Lienard-type quiescent nerve pulse equation (NPE) [1]. The NPE is driven by a periodic train of Dirac's delta-spikes to simulate real action poten- tial measurements, where short duration pulses are used as pacing stimuli for sheep and dog cardiac Purkinje tissues [2,3]. For small stimulus inten- sities the response develops for increasing drive frequency from a 1:0 sub- threshold state via Neimark (secondary Hopf) bifurcations and quasiperiodic behaviour to a 1:1 superstimulated state. For stimulus intensities near the single stimulus threshold value period-doubling bifurcations and chaotic behaviour replace the Neimark bifurcation at lower drive frequencies. However, for larger frequencies quasiperiodic behaviour develops via a saddle-node bifurcation from a periodic state. Sequences of N:M -type phase- locked states displaying a Farey-tree and devil's staircase structure appear. For still larger stimulus intensities the tori start to break until only chaos interrupted by periodic windows is present. The calculated results agree well with measured transmembrane action potential responses for supernormal dog and sheep cardiac Purkinje fibres. For increasing drive frequency, however, the NPE appears to develop a bit earlier than the real Purkinje fibres [2,3].

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Effective Modelling of Adaptation in Ecosystems

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To account for changes in the distribution of species or individuals grouped together in an ecosystem compartment, averaged physiological parameters are introduced and equations for their dynamics are derived from the single species'/individuals' interaction laws. These parameters may describe community adaptation to external forces as shifts from smaller to larger species under grazing pressure, for example. Specifically, in a model of the plankton of Lake Constance the dynamics of the effective variables reproduces the succession of algal species observed by Sommer (Prog. in Phycol. Res. 5, 1987, 123-178). In a second application, effective variables successfully describe the self-regulation of single organisms restricted by constraints like mass-conservation-laws. Especially, the sub-optimality of organic matter partitioning in plants is discussed.

Organizational Properties of Structurally Complex Systems

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In previous publications a formalism to assess quantitatively the structural complexity of selected molecules and biosystems was developed (Yagil, 1985; 1993). The basic idea was that complexity is determined by the number of numerical and symbolical values necessary to define a structure in terms of its lower level components. In qualitative terms the structural complexity C of a system can be expressed by:

$$C = \sum_k [c(k)/k]c'$$

where $c(k)$ is the number of times a regularity of order k (a feature repeated k times) is found in the system and c is the number of coordinates necessary to place the system in the external framework (normally six). The idea is that that any repetitive feature, such as a symmetry, a repeat etc., reduces the complexity by the number of times that symmetry etc. appears in that structure. A self consistent set of rules was formulated, and its validity tested on a series of simple point (molecular) structures. It was shown that only Ordered Coordinates, i.e. those which assume the same value for every member of a particular system contribute to the complexity of the system. In this presentation, the complexities of two viral structures are assessed and compared. One structure, that of the Tobacco Mosaic Virus (TMV) virion, represents a classical example of a self assembling biostructure. The other viral structure, that of bacteriophage T4, is well known for its complex assembly pathway; genetic evidence suggests that the activation of several genes, the products of which do not participate in the final virion, or even not to produce any known proteins, is essential for the correct assembly of the virion. The complexity analysis of T4 and related phases supports this idea. The value for the structural complexity of T4 (C = 114 for the tail part) is found to be at least fifty fold higher than that of TMV (C=4) on absolute and relative basis. This supports the notion that while strictly self-organizing processes are the sole operating ones in systems of low complexity, systems of higher complexity require that additional information be supplied at appropriate moments. this information can be genetically coded (internal) or provided by signals transferred from the environment (external). Complexity Analysis can be employed to determine to what extent simple physical forces are sufficient to form a particular structure, or whether additional signals, genetic or other, can be expected and ought to be looked for.

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Evolution of Complexity

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How Science Approaches the World: Risky Truths Versus Misleading Certitudes

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The scientific revolution can be seen as an innovation within the linguistic system currently adopted in ordinary languages. Extraction of quantitative features from observations vie suitable measuring devices means that the words of science are numbers, and the connecting syntaxis is a set of mathematical rules. Once a general law is available (as e.g. Newton gravitation) all consequences can be worked in a purely deductive way. This characteristics of modern physics displays two orders of drawbacks, namely. Gdel undecidability of deductive procedures, and intractability of computer modelings of complex situations. The way out of such a crisis consists in an adaptive strategy, that is in a frequent readjustment of the rules suggested by the observed events. This way, the language has no longer fixed rules, hence it appears as semantically open. Semantic openness implies a re-evaluation of the notion of "truth" as recognition of the essential role of some external features in orienting the cognitive procedures, against "certitude" i.e. self consistency within a deductive procedure.

Meta-Statistical Measures of Complexity

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A crucial distinction between different classes of complexity measures is found to consist in their statistical structure. While first-order statistics always provides one or another kind of a measure of randomness, second-order (meta-) statistics provides more intricate measures of complexity. This difference will be discussed within the framework of the theory of large deviations. A number of important conceptual issues concerning the relevance of meta-statistical concepts of complexity from the viewpoint of cognitive science will be pointed out.

Self-Organization and Higher Order Structures

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We will first discuss the relation of self-organization to emergence and higher order structures, and introduce the notion of a hyperstructure in order to facilitate the discussion. Then we will address the fundamental problem: If we have a set of locally interacting agents, what are the mechanisms that generate collective phenomena at several hierarchical levels? How to model self-organizing structures of higher order? (higher than 2!)

Furthermore, we will discuss the limitations of the dogma: Simple, local rules produce complex structures. Higher order aspects should here be taken into account, and one gets a new notion of complexity. Self-organization may occur through many levels of structure. In mathematical models we will show higher order properties and dynamics which cannot be deduced from lower levels. New types of dynamical systems are needed here.

Finally, we will apply these ideas to concrete models of molecular self-assembly and organization like polymerization, membrane and micelle formation and general pattern formation. These ideas also apply to cognitive structures, performance of tasks, transportation networks and distributed systems – which will be discussed if time allows.

The Evolution of Emergent Computation

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A simple evolutionary process can discover sophisticated methods for emergent information processing in decentralized spatially-extended systems. The mechanisms underlying the resulting emergent computation are explicated by a novel technique for analyzing particle-based logic embedded in pattern-forming systems. Understanding how globally-coordinated computation can emerge in evolution is relevant both for the scientific understanding of natural information processing and for engineering new forms of parallel computing systems.

Information Flow in Chaotic Systems

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The information flow of chaotic systems is studied in the framework of the thermodynamical formulation of chaos, and by using extended concepts from information theory. The information flow is characterized by the evolution of a conditional entropy which generalizes the Kolmogorov-Sinai entropy for the case of observing the uncertainty more than one step ahead in the future. This evolution is studied by analysis of the behaviour of the conditional mutual information between the points a single and p steps ahead in the future given the entire past. In order to have a partition-, i.e. symbolic dynamic-independent result and to describe the true and inherent information flow of chaotic systems, the zeta function formalism is applied. The result obtained yields a rigorous definition of chaotic systems in the language of information theory. A dynamical system is chaotic if the generalized Kolmogorov-Sinai entropy for a point p steps ahead in the future increases linearly with p which is equivalent to say that the conditional mutual information is always constant and equal to the Kolmogorov-Sinai entropy. This fact distinguishes chaotic from stochastic dynamical systems (e.g. higher-order Markov systems) for which the Kolmogorov entropy is positive, too. The formalism is applied to real world problems in economy and industry.

Fractal Evolution in Discretized Systems

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Discrete (1+1) systems like coupled map lattices or quantum cellular automata with any additionally implemented temporal feedback operations (involving some memory of the system's states) and a normalization pro- cedure after each time step exhibit a universal dynamic property called fractal evolution (S.Fussy, G.Grössing, Phys.Lett. A 186 (1994) 145-151). It is characterized by a power-law behaviour of a resolution-like parameter which controls the deviation from an undisturbed (i.e., feedback-less) system's evolution and provides a dynamically invariant measure for the emerging spatiotemporal patterns. Although the system evolves entirely deterministically, it exhibits properties occuring usually only in random models, where the global measures, up to a certain degree, are calculable. The power-law behavior of fractal evolution, its robustness against variations of the systems parameters and the important role of randomness exhibits features similar to (but not identical with) self-organized critical phenomena. Possible applications like self-organized growth of complexity or simulations of biological processes with reagrd to their error tolerance are discussed.

A Stochastic Cellular Automaton of Excitable Media with Long Ranging Inhibitor

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Excitable Media with long ranging inhibitor are known to perform structure formation processes. Travelling and breathing spots as well as stationary inhomogeneous structures are found. But in contrary to Turing unstable media the homogeneous state is stable with respect to small perturbations. So a certain initial excitation is required in order to stimulate structure formation. We investigate these media by means of a stochastic cellular automaton which performs spin flips between excitation and rest in dependence on the coverage. Additionally global coupling is introduced.

An Evolutionary Systems Model of Information - A Philosophical Framework

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To further the achievement of a general information theory it is required to reconstruct the information theory upon the basis of an emergentist philosophical theory of evolutionary systems. Real-world evolutionary systems exhibit the capacity of generating information while they are engaged in self-organization. So a unifying theory of information comprising the manifold information-processing manifestations from the physical realm to the realm of human culture and technology can be conceived as a spiral model or a multi-stage model as the new world view does in describing the evolution and the ordering of systems.

Statistical Theory of Open Systems

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The contribution gives a systematic presentation of ideas, methods and results of the modern statistical theory of open systems - systems capable of exchanging matter, energy and information with the surronding world. The resulting self-organization can lead to more sophisticated and advanced structures.

Central to this work are the statistical criteria of self-organization. The feasibility of a unified description of kintetic, hydrodynamic and diffusion processes in passive and active macroscopic systems without resorting to the methods of perturbation theory is demonstrated. On this basis, a general definition of thermal flux is given in terms of the entropy gradient. Moreover, a consistent method for calculating both kinetic and hydrodynamic fluctuations is proposed. This approach is then used to construct a theory of classical and anomalous Brownian motion in nonlinear media.

This theory makes it possible to treat in an original way the phenomenon of turbulence, and to propose a unified kinetic description of laminar and turbulent motion. The proposed methods are also applied to the statistical description of quantum macroscopic open systems. This provides answers as to whether or not the quantum mechanical description is complete, and whether or not there are hidden parameters in quantum mechanics. This book has no analogy in the existing literature. It is both a monograph and a textbook, and is based largely on the authors original research.

A Model of Spontaneous Aperiodic Pattern Formation: Emergence of Stationary Non-Turing Structures

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The origin of spatial structures is one of the central problems of physics, chemistry and biology. The approach to the solution of this problem, which has become a classical one, was first formulated and developed by Turing, and then elaborated in the works of his followers. The results obtained in the course of these investigations indicate that the initially uniform distribution of reacting components can become unstable under certain conditions. As the instability develops further, a spatially uniform and stationary periodic distribution of the reacting components, i.e. a periodic structure occurs. It is worth noting that such instability can be characteristicnot only of physico-chemical, but biological systems as well.

In this work the dynamics of spatial patterns in the biological system: motile cells in a nutrient substrate, is studied by applying both the cell automata model and the model based on differential equations. It is shown that as the substrate is consumed by the cells, this system exhibit a transition from structurless cell distributions to aperiodic spatial patterns. The formation of these patterns is a result of the "freezing" of cell density fluctuations in the regions with decreased substrate concentration where cell motility drastically falls.

Complex Patterns in Chemical Reaction-Diffusion Systems

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The emergence, growth and stabilization of stationary concentration patterns in a continuously fed chemical reaction-diffusion system are studied through numerical simulation of the Lengyel-Epstein model. This model represents a key to understanding the recently obtained Turing structures in the chlorite- iodidi-malonic acid system. The model is distinguished from previously studied, simple reaction-diffusion models by producing a strongly subcritical transition to stripes. This allows for a variety of local structures to arise

and be stable. The speed of propagation for a front between the homogeneous steady state and a one-dimensional Turing structure is obtained. This velocity shows a characteristic change in behavior at the crossover between the subcritical and supercritical regims for the Turing bifurcation. In two- dimensions, the nucleation of hexagonal structures shows characteristic differences from the nucleation of such structures in, e.g. the Brusselator model. In the region where they are both stable, the competition between Hopf oscillations and Turing stripes is studied by following the propagation of a front connecting these two modes. There are indications of a locking between the two modes such that the front propagates an integer number of stripes per oscillation. Finally, the observation of one- and two-dimensional spirals with Turing induced cores is reported.

Self-Organization of a Multi-Agent System in Pattern Formation

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We present a simple self-organizing rule which we term "minimax" applied to a multi-agent system leading to the formation of various stable patterns depending upon the number of agents. The dynamics of each agent is governed by a rule-based ordinary differential equation where inertia is neglected. For a system consisting of 6 or less agents, several distinctive stable pattern formations are observed whereas for a system consisting of more than 6 agents, we observed a stable (n-1)-gon with a center formed, where n is the number of agents in the system. In effect, the final stable formations are completely predictable based upon the number of agents in the system. Firstly, the convergence to stationary formations is studied by way of computer simulation. Secondly, we formulate the dynamical behavior of the multi-agent system as a fixed-point problem and rigorously demonstrate the results observed in simulation.

Probabilistic Approach to Complex Systems

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One of the principal signatures of complex systems is a marked sensitivity toward disturbances or fluctuations, in the sense that initial states that are experimentally indistinguishable may follow quite different histories. This entails, in turn, that the concept of a single well-defined phase space trajectory loses its operational significance and that one must resort to a new approach incorporating probabilistic elements.

In this talk the probabilistic approach to complex systems is outlined. It is shown that complexity leaves a clearcut signature in the spectrum of the Liouville or Frobenius-Perron operators governing the evolution of probability densities. The general ideas are illustrated on two case studies pertaining to the normal form of pitchfork bifurcation and to fully developed chaos in 1-dimensional maps.

On Self-Organized Criticality in Chemical Reactions

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In the last years it has become clear that many systems in physics, biology, social and economic sciences drive themselves in to critical state. Bak, Tang and Wiesenfeld have emphasized the notion of self-organized criticality to describe this behavior. They proposed 4-state cellular automation model called sandpile. We observe correspondence between a chemical reaction and 2-state sandpile model. It is shown that the this model and 4-state sandpile model proposed by Bak et al. are in the same universality class.

Dynamical Hierarchies

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We shall review the problem of the creation of higher order emergent structures in formal dynamical systems.

In biological systems higher order hyperstructures occur both in an intuitive and a formal sense. But in models of these systems it has turned out to be quite difficult to produce higher order emergent structures from first principles.

The first problem is to agree on what a higher order structure is. We shall define that through the introduction of an observational function [1]. It is well known that second order structures occur relatively easy so the problem is how to proceed to third and higher order without external interference.

We shall discuss these problems in the light of a lattice gas style discrete field automata for molecular self-assembly where we can demonstrate the generation of higher order structures from first principles.

Then we shall extract some of the formal principles involved in the generation of higher order (hyper-) structures and relate it to dynamical systems. One of the central issues becomes the notion of simulation as a synthetic mathematical method. We shall conclude by discussing some of the elements of a mathematical theory of simulation .

Interactive Structure Formation with Active Brownian Particles

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The major challenge of a physical approach to the phenomenon of structure formation is to develop models of microscopic interacting elements which on one hand should be general enough to be applied to a large variety of structure formation processes and on the other hand should be detailed enough to provide a physical insight into the dynamics of the process. Moreover, the model should be easily tractable for fast and stable numerical calculation.

The model proposed here, is based on Active Brownian particles with the ability to generate a self-consistent field, which in turn influences their further movement and physical and chemical behavior. This non-linear feedback between the particles and the field generated by themselves results in an interactive structure formation process, which, on the macroscopic level in most cases can be described by sets of coupled reaction-diffusion equations.

The main idea of our approach is to solve the LANGEVIN equations for an ensemble of active Brownian particles instead of the related nonlinear partial differential equations (PDE).

In order to demonstrate the applicability of our approach, we first investigate structure formation processes known from different reaction diffusion systems, like the formation of Turing patterns, spirals, localized spots and Liesegangs rings.

Further, we discuss the formation of patterns which are intrinsically determined by the history of their creation. Here the model will be extended by considering internal degrees of freedom for the active Brownian particles.

Our approach provides a quite stable and fast numerical algorithm for simulating these processes even for large density gradients and is applicable also in cases where only small particle numbers govern the structure formation.

Self-Organization, Entropy and Order

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P.T. Landsberg (In "On Self-Organization", R.K. Mishra et al. eds., Springer, Berlin, pp. 158-184, 1994) has referred to the "popular per- ception: self-organisation −¿ greater order −¿ lower entropy". However, he has also noted several times that the concomitant increase in entropy and disorder may not follow our intuition about disorder in growing systems. This is the case since entropy is an extensive quan- tity and will increase with the size of the system, whereas what we perceive as order may also increase.

Landsberg has proposed that dis- order be defined as the actual entropy normalized to the maximum pos- sible entropy for a given number of states. Order is then defined as 1 - disorder. We investigate the suitability of this definition as a measure of order in what is perhaps the epitome of self-organization, evolution. We calculate order as indicated by the number of distinct cell types throughout phylogeny using both the actual number of cell types and the number of cell types predicted by Kauffman's Boolean NK networks ("The Origins of Order", Oxford,1993). Although we find that the order of even the simplest organisms is very high, we also find that order increases together with entropy throughout phylogeny. We conclude that Landsberg order may be one appropriate definition of order for self-organizing systems.

Temporal and Spatial Entropies in Two-Dimensional Coupled Maps

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Temporal and spatial entropies are investigated in a class of coupled map lattices. A measure for the geometrical structure in two-dimensional lattices is introduced and interpreted as spatial entropy. We compare the temporal evolution of this measure to the CP-entropy per unit time of the local dynamics and the fluctuation spectra of the binary sequence obtained by observing the system via a finite partition. A strong dependence on the system size is observed. An explanation of this dependence in terms of Large Deviation Theory is proposed.

Evolutionary Optimization

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Global Optimization using Ensembles

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Searching for the global minimum in a complicated configuration space often requires a computational effort which grows exponentially, or faster, with the size of the problem. Nonetheless, Nature has managed to find good minima for many of its processes with amazing speed. Several global optimization methods have been inspired by these: e.g. simulated annealing from chemical reactions - genetic algorithms from evolution - neural nets from neurology. All of these methods rely on a statistical component which permits the algorithm to arrive at a good guess of the minimum after having searched only a very small fraction of state space.

In most cases it is not a good idea to let a single "walker" do the statistical exploration of state space, because it can easily get caught in deep local minima or get lost in huge flat areas. It has proven much more efficient to let loose a host of "walkers", an ensemble, which share the same rules and control variables but otherwise meander independently. Such an ensemble has the added quality that it permits estimation of thermodynamic descriptors of the system using ordinary statistical mechanics without having to resort to an assumption of ergodicity which is often not justified. Ensembles of neural nets, e.g., permits "voting" among the nets as well as self repair and self instruction, leading to overall better performance. Such ensembles of "walkers" have also shown collective phenomena such as freezing out of certain degrees of fredom which are typical of large dynamic systems.

The Course of Evolution of Biopolymer Structure Formation

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RNA is viewed as the simplest know example to simulate evolution of complex entities under reasonable assumption.

We compute large ensembles of RNA secondary structures by means of various computer algorithms. Structures are sorted and ranked with respect to their frequencies. The number of neutral neighbours, that are mutants of a sequence folding to the same structure, are computed as well as the length of neutral paths, the number of adjacent neutral neighbours.

We find few structures that are very frequent and many that are rare for each alphabet, folding algorithm and resolution. The former have more neutral neighbours and longer neutral paths but even nets of very rare structures have a surprisingly high chance to percolate Sequence Space. We also use an algorithm with simplified energy rules. Predefining the minimal size of structural elements restricts the Shape Space and enforces a higher degree of neutrality.

Together with findings from the shape space covering this implies a new perspective on the efficiency of evolution by point mutations: from any random sequence it is not far to any desired structure, and yet most mutations will preserve the structure.

Possible implications for the efficiency of evolutionary strategies in searching sequence space as well as implications for the representations of other biopolymer, such as lattice proteins are discussed.

Self-Organization and Self-Teaching in Ultra Media

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Ultra media is a new type of intellectual systems in artificial intelligence.The conception of ultra media was appeared and is develo- ping at Moscow State University as the summation of multimedia's ide- as. Ultra media is a self-teaching and self-organizing intellectual media, has two interacting model medias (one is analog and the other is symbol), has two types of states (basing and working). The ultra- media basic state is the storage of intellectual structures (radi- cals). The radicals are formed in teaching process and make intellec- tual fund of intellectual system. The ultra media working state is the self-organization of radicals into the working net structure, oriented for the definite type of the intellectual problems. The wor- king structure is two interacting operating networks. One of them is a support net of support (S-) radicals for the analog modeling and the other is an ultranet of ultra (U-) radicals for symbol modelling of the object region of intellectual system. The interaction between both nets is made by terminal (T-) radicals, transmitters and execu- ters. So there are S-,U- and T-radicals.

The S-radical is an analog of the definite object region. Any S-ra- dical models some objects and some relations of the object region.

The U-radical is an object-oriented distributed data and knowledge base in the shape of net consists of data accumulators and transfor- mers. The accumulator is a local database (LDB), the transformer is a local knowledge base (LKB).

T-radical is a transmitter and an executer between S- and U- radicals. Radical self-organization in working net (WN) occurs in ultra me- dia depending on the type of intellectual problems for the purpose of solution these problems. " The equations of ultra media dynamics" are THE PRINCIPLES OF RADI- CAL SELF-ORGANIZATION TO A WORKING NET. " The equations of ultra media evolution" are THE PRINCIPLES OF RADI- CAL SELF-TEACHING.

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Breaking Neutrality into Pieces

Applying Kimuras Theory on RNA Secondary-Structure Folding-Landscape

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Neutral evolution in the sense of Kimura [2. 3] has been studied recently by Huynen et al. [1] on RNA secondary-structure folding-landscapes with computer-simulation and by Reidys et al. on generic fitness-landscapes induced by a random-graph approach [4] with simulations combined with a mathematical treatment. The concept of partly neutral landscapes has been investigated by Schuster et al. [6]. these neutral networks of sequences which each fold into one single structure are "essential" topological elements in the RNA-folding landscape. Reidys et al. have used this approach for construction of generic fitness-landscapes [5]. By exhaustive numerical determination of secondary structures for all binary RNA-sequences of length 30 (AU and GC alphabet) it can be shown [7] that depending on structural motifs the corresponding neutral networks consist of more than one component. This observation i crucial for any optimization-process. An evolving population on these landscape would almost explore one component of each neutral network. this leads to an significant bias in the distribution of bases in the sequences which bias the whole evolutionary search. For general base-alphabets and arbitrary chain-length we now present a statistical method for determination of the existence of more than one component. We also have developed an algorithm for characterizing dependencies of base-frequencies by structural motifs. As references experiment we cross-check our methods by applying them to the fully determined hypercube for binary RNA-sequences of length 30 [7].

Exploration of Artificial Landscapes Based on Random Graphs

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The mapping from sequences to secondary structures in RNA has been proven to inherit essential information on the evolutionary optimization process. Based on the RNAfold Fontana and Schuster [FONTANA, 1989], Hogeweg [HOGEWEG, 1984] and others have studied those RNA landscapes in great detail. Instead of using a folding algorithm [HOFACKER, 1994;ZUKER,1 1981] Reidys and coworkers [REIDYS, 1995A] have modeled the preimage of a fixed RNA secondary structure as a random graph. This approach allows for very fast simulations of dynamics on those nets and leads to following results: above a certain threshold value the preimage of a secondary structure is a *dense* and *connected* network (a *neutral network*, see below) in sequence space. The threshold value is given by the fraction of *neutral neighbors*, i.e. the fraction of adjacent sequences folding into the same structure. The random graph approach allows an explicit description of the optimization process on these nets and gives insight in theoretical aspects of evolution. The mathematical modeling of a single *neutral network* (that is a preimage with respect to one secondary structure) is now extended to complete sequence to structure mappings. The resulting networks are analyzed (i) for density and (ii) for connectivity, i.e. the so called *sequence of components* is evaluated. Further the performance of an evolutionary search process is studied: how many "new" secondary structures are found diffusing on a neutral network [HUYNEN, 1994;REIDYS, 1995B]? Schuster's so called *shape space covering conjecture* [SCHUSTER, 1994] is checked and finally the results are compared with those from RNAfold.

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Smoothing Representation of Fitness Landscapes and the Density of States

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We consider a simple evolutionary game as an example for the investigation of the structure of the fitness landscape of discrete problems. In the evolution of biological system an individual comes into being by expression of a genotype. Each phenotype will be valuated in the selection process which determines the fitness value. We show the smoothing action of the genotype-phenotype mapping which can be understood as a suitable choice of the representation of the problem in optimisation algorithms. Further we propose the density of sequence states as a classifying statistical measure of fitness landscapes and determine this density for our example.

Evolving Molecular Cooperation

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A massively parallel multi-custom computer has been developed for the theoretical study of collective phenomena arising from microscopic dynamics. The application of this computer to cooperative phenomena in molecular evolution will be described. A solution to the problem of molecular cooperation in terms of self-replicating spots is proposed. An experimental route to achieving cooperative functions of molecules making using of spatial effects is presented.

Evolution Strategies in flat and rugged fitness landscapes

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Evolution Strategies with stepsize adaption can be understood as markov processes. The high dimensional linear equation of motion for the probability distribution can be reduced to a one dimensional nonlinear equation. Different flat and rugged fitness landscapes are discussed and analytical as well numerical results are presented.

Neutral Evolution on RNA-Secondary Structures

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In this paper we study evolutionary optimization on RNA "toy" landscapes. To a pair of RNA secondary structures we construct corresponding *neutral networks* and assign to each vertex that belongs to a neutral network a superior fitness. The neutral networks are constructed as random graphs and their topology is analyzed. Two neutral networks of RNA secondary structures induce a *double shape* landscape where the simulations are based on. We perform simulations of finite populations of asexually replicating strings on those networks. Depending on various parameters *transitions* i.e. a switch of the complete population from one network to the other are observed and the neutral evolution of the population is studied. We show that the transition phenomenon is related to the so called *intersection set* of corresponding *compatible sequences.* This set is investigated and finally the results of the computer simulation are discussed.

Combinatorial Optimization Based on the Principles of Selection and Competing Processes

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The principles of selection and competing processes applied in biological models are used for combinatorial optimization. Herein one looks for the optimal order of processes. In contrast with genetic algorithms (GA) the method presented here is deterministic. In order to minimize the total costs of the combinatorial optimization problem, competing processes are applied to the elements of the cost array which is defined by the optimization problem. Each process favours the selection of the lowest costs by considering the constraints. The stable fixpoints are placed in a way to get decision variables as output of the competing, self-organizing dynamics with respect to the constraints. One gets the here used non-linear coupled ordinary differential equations by selection equations (e.g. those of M. Eigen and P. Schuster) with special coupling terms. These "cost oriented competing processes" (COCP) can be described in a vivid manner by a potential function and a gradient descent method with suitable initial conditions. The dynamics can be interpreted as a neural network with higher order couplings. Examples of possible applications of the COCP to scheduling problems (manufacturing planning and flexible manufacturing systems) are given.

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Critical Fluctuations and Phase Transitions in Decentralised Agent-Resource Systems

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Currently, most probabilistic models for multi-agent systems can only be studied analytically when fluctuations or internal noise is neglected. One has to resort to intensive numerical simulations to study the effects of noise in these systems. Fluctuations become crucial if the system has a finite size, or more importantly when the system undergoes a phase transition or is near a critical point. Based on an analogy with the WKB method in Quantum Mechanics, the approach we

follow allows us to study the dynamics of the agent-resource system, previously studied in the context of computational[1] and market-based[2] systems, with fluctuation effects included. Unlike previous studies, this approach has the advantage of dealing with microscopic as well as macroscopic fluctuations. This makes it particularly suited for the analysis of criticality and phase transitions within large distributed systems.

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Planning and Control in Self-Organized Production Systems

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Today there are some ideas under discussion to organize production systems in a new way. Segmentation, Fractal Factory, Holonic, Bionic or Agile Manufacturing Systems are some examples. They all refer to an increasing complexity. With the exception of some differences in details there is a consensus that in future more has to be dealt with on the spot. Besides "self-organization" is meanwhile a key word. But both complexity and self-organization are often discussed without theoretical foundation. Metaphors mentioned above are used instead to describe how the concepts should work. That is a good starting point but not sufficient for the future. Expressive models are needed as well as applicable procedures and powerful tools. The contribution will present some suggestions. As a basis the agent theory is utilized. This theory has two fields of applications namely the information science (Distributed Artificial Intelligence) and the economic science. Derived from the first mentioned domain, coming production companies are described as distributed systems. In addition some organization models (e.g. blackboard, scientific community, market) which are developed for distributed information systems can be transferred to production systems. In this contribution mainly the market model will be described. Examples will give an impression how planning and control can work via negotiation between autonomous employees. Additionally tools will be described which are able to support this processes. Furthermore considerations made in economics give an idea of the relation of risk, incentive and control in distributed systems. For the organization of complex production systems that gives e.g. the change to define adapted types of revenue for all employees who works autonomously. The described aspects are parts of a research project which is funded by the Deutsche Forschungsgemeinschaft. The conference gives the chance to present first results.

Trade Off Between Global Socio-Spatial Structure and Local Individual's Behavior in a Self-Organizing City

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The self-organization of the city's socio-cultural structure is considered in terms of a trade off between the residential choice of individuals at the local level and the evolving socio-spatial structure of the city at the global level. This is done by means of a family of models termed "City". In the model the city space is presented by means of a cell-space submodel, and individual behavior is modeled by means of submodel of free agent individuals, who move between the cells, as well as between the city and the external environment. The cells' features are defined by economic and cultural properties of their occupants; the residential choice of the individual depends on cognitive dissonance between the individual's properties and the properties of the neighboring cells and their occupants. In previous studies we have examined the conditions, by which local interactions between individuals and their neighbors entails the emergence of new local socio-cultural groups in the city. In the present paper we study at what extent the individual's knowledge about the city as a whole, defines the evolution of the global socio-cultural structure of the city.

Decision Making Under Uncertainty and the Evolution of Risk Aversion

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For more than one hundred years scientists try to model decisions under uncertainty. Many different approaches have been put forward but they all have one assumption in common: People are risk averse from birth. The paper presented takes a different point of view. It shows how risk aversion can develop by mutation-imitation-processes and studies the impact of the external conditions. Therefore, an evolutionary algorithm is developed and implemented on the computer. The agents face the same decision again and again but the only knowledge about the alternatives they have are their own experience and informations they get from other agents. As long as they are satisfied with the results, they do not alter their decision. If they are not satisfied, they either try a new alternative by chance (mutate) or choose the same alternative a successful agent has chosen (imitate). After some time the fluctuations of the system become smaller and the behaviour of the simulated agents can be analysed. The agents choose more or less risky alternatives dependent on circumstances and individual characteristics. It results from the simulations that agents with low expectations, and therefore low aspiration levels, are less risk averse, agents with realistic expectations are most risk averse, and agents with high expectations are not risk averse or even searching for risky alternatives. It is also shown by simulations how decision behaviour changes with changing circumstances.

Self Organisation Among Business Establishments

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In previous work the authors have studied the interconnections among autonomous and semi-autonomous business establishments, and the evidence of self organisation. Types of groupings include industrial regions (large geographical areas with extensive networking among separate manufacturers), industrial parks (formal areas set aside by a government unit or developer), business incubators (separate buildings providing support services for start-up to one "parent" organisation but often having extensive informal lateral contact among franchisees through self-generated networks or advisory councils). The network data collected include both unidirected (information) ties and reciprocal relationships. The adopted methodology focuses on computerized graph analysis (UCINET) identifying e.g. cohesion and structural equivalence.

Our intention is to describe the entrepreneur as thriving on complexity and seeking " the edge of chaos", and explain entrepreneurial behaviour as a catalyst for self organisation. We are in a continuing process of trying to develop a model relating cellular automata to separate establishments. We will not present completed work but rather the issues we are pursuing in hopes that the ensuing discussion will be informative to both the authors and the participants.

Self-Organisation in Social Systems: The Procces of Integration

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In this study, integration is conceived as the process through which a social, economic or political system, national or international, advances its measure of order or information. Such order appears to form the essential precondition for the system's internal peace, its capacity for collective action, its power, survival and prosperity, and for its legal, institutional and cultural development. Rather than forming the product of human intervention and design, it results from a process of self-organisation, a typically evolutionary and autocatalytic process which, apart from exogenous disturbances, itself generates the forces which drives it. In this, however, it is governed and constrained by a most fundamental (non-linear) relationship or law, to wit, that the extent to which a social system will thus order itself is itself determined by its initial level of order.

How Egotism Helps to Solve Global Problems

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A new method for finding optimal solutions to complex problems with many competing requirements is proposed. Such problems typically lead to "fitness" or "energy" landscapes (over the space of all possible configurations of the system) characterized by a complicated "rugged" structure with many local optima. Algorithms searching for a global optimum of this landscape have to avoid the danger of getting trapped into one of these local optima, which is usually achieved by allowing temporarily 'steps into the wrong direction'.

Instead, the strategy proposed here is based on the assumption that the evolution of the system towards an optimal state can be driven by an admixture of the interests of the system, of its subsystems and of the individuals forming it. In a Monte Carlo realization, a change of configuration is, therefore, accepted if it enhances the fitness of the system or of any of its subsystems.

This scenario has been tested for the N-k model describing a system of N sites each of which interacts with k of its neighbors, for a variant of the Coulomb glass, and for an ordered spin system with long-range interactions. It turns out to give excellent results in all cases: choosing the weight factors between global and individual interests in an appropriate way, the strategy finds configurations which are better than the average local optimum by up to seven standard deviations of the distribution of local optima.

Dynamics of Innovations in Technology and Science-Including Individual Development

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The basic step of the evolution of technology/science is the replacement of old by new elements (technologies, ideas, inventions etc.) of the competition process. A model of the replacement dynamics is developed which includes: (i) stochastic effects due to the initially small number of the new elements, (ii) the individual development and aging of the new elements, (iii) competition in populations of developing/aging elements. It is shown that the evolution of the overall quality may be interpreted as the envelope of many sigmoid elementary developmental steps.

Connectivity and Financial Network Shutdown

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Connectivity is a measure of the number of connections in a network. It is applied here to financial network shutdown due to inter-institutional default.

With the increase in the market for over-the-counter inter- institutional contracts, especially in the interbank market for foreign exchange, interest has increased in the consequences in the consequences of an unwind in payments due to default. This paper is meant to address this interest. To date not one purely descriptive paper has been published on the effects of defaults in payments systems.

That paper reports the results of three scenarios for settlement in CHIPS, one of two US dollar payments systems. By contrast, analytic results (not inferred by simulation) on the statistical properties of payments mechanisms are derived here. These results are obtained given the simple clearing mechanisms of no netting and bilateral netting. The model is applied to default propagation in the foreign exchange market. Boolean graphs are used to obtain the results.

Since 1797 when Sir Francis Baring introduced the concept of "lender of last resort" concepts such as "too-big-to-fail," "lender-of-last-resort," and systemic risk have belied a need for a quantitative approach to default propagation. Concepts new to finance and economics are introduced.

Specifically, those of "network architecture" and "connectivity" of that architecture are defined. Starting from assumptions on the "connection matrix", Markov transition matrices are obtained where each state is the number of firms in default. Debt maturity, connectivity and initial defaults are used to calculate the transition matrices.

Besides deriving the stochastic difference equations for the number of failed firms results were obtained on the effect on default propagation of netting liabilities. It is shown that the connectivity value which maximizes the speed of default propagation under netting is not that when liabilities do not offset. For netted liabilities this value is 1/2. For non-offsetting liabilities, this value is 1. The reduction in connectivity by netting, given an initial connectivity g, is shown to be the connectivity squared g^2.

Results were obtained demonstrating that when bankruptcy propagation is fast relative to the maturity of obligation the extent of network shutdown can be less than when propagation is slower. Reducing the maturity of obligations definitely increases propagation speed and may increase the extent of default propagation.

Complexity and Self-Organization in Socio-Economic Systems: A Structural Approach

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A firm is - in accordance with J. Weber's controlling theory - seen as consisting of sets of interrelated operations. In this functional view, directing operations determine the degrees of freedom of executing operations. (Each institutional unit, e.g. individuals, performs bundles of these different kinds of operation.) Facing an increasing variety, an enterprise's capacity to process information is limited. Hence, patterns in space and time are built. Both types of order (planned and spontaneous ones) introduced by F.A. von Hayek are discussed in this context. Effects of rules and regularities in the conduct of the existing operations are described. The emergence of new entities is elaborated on the basis of the substitution principle and a bottleneck-oriented adjustment of effort. According to the systems concept of M. Bunge this phenomenon is classified as a process of self-organization. Based on these relations, a structure is specified which contributes to the explanation of functional pattern formation. Central elements are sequences of specialization and coordination as well as slaving principle-like micro-macro-dependencies. The integration of functional, operation-focussed structure and institutional considerations enables investigations about the attributes of differentiation and participation, which lead to the notion of complexity.

Leaders and Clusters in Social Impact Model of Opinion Formation

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A particular case of a social impact model of a two–state opinion formation in a social group with a strong leader is studied. We consider 2D Euclidian geometry of a social space and mutual interactions $\propto 1/r^n$. The model shows an interesting collective dynamics which can be easily calculated. There are two stable states of the system: cluster around leader and unification of social opinions. Unstable clusters may also appear. Variation of parameters like leader's strength or "social temperature" can change the size of cluster or, when they reach some critical values, make the system jump to another state. For certain range of parameters the system exhibits bistability and hysteresis phenomena. We obtained explicit formulas for cluster size, critical leader's strength and critical "social temperature". These analytical results are verified by computer simulations.

Market Organization

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In this paper we consider a simple market in which n symmetric buyers meet m symmetric sellers of a perishable product. The market is repeated daily and the sellers charge prices according to their experience with clients and clients accept or refuse and decide how much to buy in the light of their own experience. We examine under what conditions links will develop between specific buyers and sellers. When buyers are strongly linked to sellers, we refer to this as "an organised market", whereas when buyers choose their sellers at random we refer to "a lack of organisation". We show that in the simplest version of the model a small change in the parameter governing the sensitivity of individuals to their previous experience can make a radical change in the organisation of the market. Simulations show that this characteristic carries over to more complicated versions of the model.

Dynamic Social Impact and the Clustering and Bundling of Cultural Elements

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Summary. According to dynamic social impact theory, spatially distributed populations of interacting people should organize themselves with respect to their socially influenceable individual attributes. Individual attributes are conceived to be jointly determined by 1) individual interests, inheritances, and/or experiences and 2) social influence exerted through such processes as imitation, argumentation, and intimidation. The domain of the theory thus includes beliefs, values, practices, moods– anything at least partially affected by other people. The theory predicts the emergence of four forms of global self-organization– clustering, correlation, polarization, and stable diversity– from individual-level social influence processes. These emergent phenomena may help to explain several puzzling aspects of human culture– the long-term persistence of regionally-differentiated, temporally evolving patterns of partially coherent culture elements.

Computer simulations of populations ranging in size from 9 to 192,000 people suggest these phenomena will emerge whenever spatially distributed people are more influenced by their neighbors than by those further away, and these surprising predictions are quite robust, holding over a wide variety of assumptions, parameters, and initial conditions. Computer-mediated discussion groups provide strong empirical confirmation of the emergence of these forms of self-organization. Members of electronic juries, participants in a conformity game, and people discussing political and social issues all became more similar to their neighbors in electronic space, helping minorities to hold their own in a hostile intellectual environment, while the degree of correlation among originally independent issues increased as a result of discussion.

The lecture will include a live demonstration of self-organization in face-to-face groups. Members of the audience will be given the opportunity to briefly discuss two issues before indicating their final opinion. Judging from extensive pretesting in both classrooms and professional meetings, spatial clustering should be quick and obvious.

Note. Social psychologist Bibb Latan is Professor of Psychology at Florida Atlantic University. Former President of the Society of Personality and Social Psychology and the Midwestern Psychological Association, he has published extensively in venues ranging from Readers Digest to Physical Review A. His research on dynamic social impact is supported by grants from the National Science Foundation.

Strategic Issue Management in Complex Socio-Political Environments

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Today, management is confronted with increasing complexity of socio-political environments. That makes strategic issue management more important as well as more difficult. The basic question is how to detect issues very early in their life cycles when their implications have not become obtrusive yet. Causal modelling will mean a futile attempt when environmental trends lead to novel structural relationships. Therefore, management must be provided with an instru=1Fment for trend tracking that is principally open and has no prejudice towards specific causal mechanisms. The model must accept that seemingly small changes in the landscape of trends may lead an issue beyond its point of no return. One basic idea of our concept is to discard the well-known categories of environmental scanning - techno=1Flogical, social, political, etc. - because most trends cut across all of them; they no longer make a meaningful difference. Instead, we propose a large set of =93reference objects" that ac= t as crystallization points in order to combine trends. Experience shows that * reference objects play an important role in processes of cognitive self-organization: e.g., the new social movements use =93identity" as a general theme when formulating their issues; * at least three or four trends are commonly linked in order to gain strategic importance. Granovetter showed that associations stemming from separate contexts are particularly powerful in their effects. This means that when environments are complex and ignorance is high, association is a more adequate modelling concept than causality. We will show how to implement such a model; i.e., how to generate the relevant set of reference objects, how to find associations across different contexts and how to generate landscapes of trends and early warning sings.

Complexity in Manufacturing Systems in Search for a new Paradigm

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The manufacturing is an important human endeavour, contributing a major part to the generation of wealth. The structuring and control of M-systems is still following to a great extent the Taylorian principles, developed after the first industrial revolution. The formation of work structures and operations are based on a priori knowledge and information expressed predominantly by the conventional laws.

The contribution reveals the structure of interconnected objects forming a work system, a factory or a set of factories for manufacture of discrete products. These multilevel structures represent complex objects of control and organisation. The influences resulting from the 1. environment, such as market dynamics, competition, life cycle etc., 2. the existing technologies and 3. future developments and research in relevant fields, affect the managerial decision processes and control of these complex adaptive systems.

In search for a new paradigm in manufacturing it is of importance to include into the system the subject (an individual, a team ....) as an integral part of it and his ability to learn, to cooperate and to compete, to be motivated, including also the self organisation abilities.

The paper will present some relevant arguments showing that the M-Systems are complex objects in which the subject is a significant part. For this very reason the search for a new paradigm in manufacturing is eminent and is now starting to accelerate the research activities on manufacturing systems and technologies based on the complexity concepts.

Self-Organization of Trade Networks in a Transition Economy

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The work considers dynamic behavior of a complex stochastic system that consists of different consumers, producers and traders in an economy with an imperfect infrastructure. The methodology of emergent computations is applied. At each moment of time every economic agent makes decisions on which price to sell at, from whom and how much to buy etc., trying to maximize his objective function according to his own forecasts, internal parameters and observed behavior of other agents. As adaptation of agents happens over time, the structure of the trade links in the system changes. The model is studied both analyticly and via computational experiment. It is shown that while in the case of almost perfect infrastructure the system quickly converges to a near-competitive equilibrium, more imperfect infrastructure results in significant oscillations of prices and of the structure of the trade networks, persistent shortages and longer chains of traders, the breakdown of large trade firms into individual traders; the system may converge to multiple equilibria including the suboptimal ones. All these phenomena have been observed in Russian economy since the beginning of the economic reform in 1992. The impact of such factors as heterogeneity of consumers, speed of adaptation, that influence the stability and dynamic properties of the system, is studied.

Is There Evolution After Economics?

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The mainstream conception of economic man, homo oeconomicus, regards her as being fully informed about the state of the world (up to actuarial uncertainty) and of all possible actions and their consequences. Being fully rational, she is able to make immediately the optimal choice, and the collective society of rational agents consequently always finds itself in an unchanging rational expectations equilibrium where no one can improve her performance without imposing on someone else (Pareto optimality). Thus evolution is excluded, except possibly as a response to exogenous change.

An alternative conception regards information processing and the metabolic interaction with the environment as being emergent phenomena of a process of collective self-organization. This process displays specific features within each evolutionary stage, but also distinct structural stages dependent on the combination of "technologies" of information retention and transmission: asexual or sexual, DNA-based reproduction; neurological learning (brains and senses); sociocultural (language and ritual); exosomatic (written language, cultural and industrial artefacts, information processing machinery). At all of these stages universal laws of evolution hold, even if the overlapping of "technologies" sometimes makes this hard to discern (e.g., the biologically based internal processes of the brain enabling social learning as neuronal group selection within a cultural context). I will focus on the latest stage of exosomatic evolution (also known as industrial society) and ask if modeling can provide insight on 1) the general direction of evolutionary change 2) patterns of collective organization 3) temporal fluctuations and phase transitions.

Kin Selection and Cooperating Agents

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This paper attempts to answer the question, "How can a computer system be designed such that cooperation among its constituent agents is inherent?" There are two main approaches to this question: reciprocal aid and kin selection. Reciprocal aid is often studied through computer simulations of the iterated prisoner's dilemma. This work shows that there are reward/punishment environments that tend to encourage cooperation. However, for a given system, it is often difficult to incorporate such an environment in the system. There appears to be more promise in the application of kin selection. There has been a lot of confusion between the units of selection associated with kin selection, and this confusion has been mirrored in the application of related biological paradigms to computer systems—with the consequence that, if cooperation is required within a system, then it has to be engineered in. A proper understanding of kin selection can be used to design systems in which cooperation is a natural consequence, rather than an additional, overcomplicated burden. This paper outlines a general, co-operating system, based on kin selection.

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Modelling and Simulation of Regional Dynamic Processes in the Economy

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The possibilities of modelling the dynamic interactions of the economies of different regions are investigated. The approach is to characterize the mechanisms of the commodity markets of single regions as manageably as possible in a descriptive, dynamic, and behavioural decision model. It is continuous in time because of the large number of agents and decisions that are treated. And it also illustrates the importance of time and flexibility in economic behaviour. Special emphasis is given to a modular construction and a big variability of the model frame. The master equation approach by Weidlich and Haag, and an extension of the frequency dependence which has been defined by Leibenstein and Arthur are used as tools. Eventually, model consistent exchange streams between the single regions are formulated for a multiregional application.

In the simulations, the model is specified to two or three regions with two commodities each. Particularly, the mutual influence regarding business cycles and long waves is investigated and the affiliated phase patterns are analysed.

A Statistical Approach to Vehicular Traffic

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A two–dimensional cellular automaton is introduced to model the flow and jamming of vehicular traffic in cities. Each site of the automaton represents a crossing where a finite number of cars can wait approaching the crossing from each of the four directions. The flow of cars obeys realistic traffic rules. We investigate the dependence of the average velocity of cars on the global traffic density. At a critical threshold for the density the average velocity reduces drastically caused by jamming. For the low density regime we provide analytical results which agree with the numerical results.

Microscopic Foundation of Macroscopic Traffic Models

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In principle there are several ways of investigating collective phenomena in multi-vehicle systems. One way is to simulate the individual ('microscopic') dynamics of the single vehicles and to evaluate the temporal development of suitable collective ('macroscopic') quantities afterwards. An alternative way is to derive macroscopic traffic equations from basic assumptions concerning the behavior of driver-vehicle units with respect to acceleration, deceleration, overtaking, and lane-changing maneuvers. This can be done via a generalization and extension of Paveri-Fontana's Boltzmann-like traffic equation and yields theoretical relations for the so-called fundamental diagram of traffic flow, the equilibrium variance-density relation, and other quantities. For the derivation of macroscopic traffic equations the method of Chapman and Enskog is used which not only leads to dynamic equations for the spatial density and average velocity of vehicles, but also for their velocity variance. The variance equation is essential for an exact description of the emergence of traffic jams and stop-and-go traffic above a critical density. An extension of the macroscopic equations allows to take into account the adaptive behavior of drivers with respect to changes of the traffic situation. Finally, corrections due to the space-requirements of vehicles as well as due to finite reaction- and braking times are introduced.

Simulation of Dynamic Traffic Flow in Freeway Networks

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A simulation model for dynamic traffic flow in freeway networks is presented. Traffic flow on a road is described by macroscopic variables: the density of cars and their mean velocity. Each road of a traffic network is divided into segments (so-called "cells") of approximately 100 m length and the temporal evolution of the density and the mean velocity is described by two differential equations for each cell. It turns out, that for certain values of the control parameters a phase transition from stable to unstable traffic flow occurs resulting in macroscopic stucture that is empirically well known as stop-and-go traffic. Comparison of simulation results with empirical data shows an excellent correspondance.

In the model the fitting conditions at traffic nodes can be derived straightforward allowing the construction of arbitrary traffic networks. The introduction of partial densities permits the distinction of drivers with different destinations. This is necessary for a correct description of the turning behaviour at traffic nodes, since the turning probabilities depend on their final destination. Again simulations show a qualitative correct description of traffic flow in networks.

Topological Analysis of Micro-Statistical Data Sets of German Cities

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With respect to the worldwide urbanization processes the analysis and modelling of urban systems is one of the most challenging objectives today. Despite of recent progress in this field our kowledge of the internal processes as well as the systems dynamics at whole is not very extensive. The main reason for the lack of detailed information are (i) the complexity of the structure itself and (ii) the missing of innovative data manipulating and analyzing tools. In order to stimulate progress in understanding the gross factors which are responsible for urban structure dynamics, we report here on the application of methods from the fields of nonlinear dynamics and neural nets. We assume that the average behavior of the agents of an urban area is, to a large extent, already constraint by the system structure itself. Thus the microstatistical data set (land-use, energy consumption, housing etc.) can be understand as a map of the the system under investigation. The major problem, the simultaneous analyzation of large data sets can be managed by the usage of the well-known Kohonen algorithm. In our study we use a cross-sectional database of German cities between 50,000 and 3,4 million inhabitants. A 23-dimensional data set is analyzed and an optimal embedding dimension of four can be determined by the calculation of the topographical product. To a large extent we found an average classification scheme of German cities depending on a few functional parameters. The quality of this clustering is measured by the calculation of the data reconstruction rate which are compared with results obtained from conventional data analytical methods.

Optimization of the Shape of Pedestrian Facilities by Evolution Programs

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Pedestrian flows show a complex behavior that depends sensitively on the geometric shape of their surroundings. Modifications of the developed environment may cause rather "unpredictable" changes of the pedestrian flow due to selfo-rganization effects that arise from the social interactions among pedestrians and their reaction to obstacles, boundaries and walls.

We know that intersecting flows can be made more efficient by suitably places small obstacles, and rounded corners may reduce avoidance maneuvers collisions. But our experience fails for more complex, completely new configurations.

Microsimulations of pedestrian crowds can detect deadlooks and critical situations of the system already during the planning phase. The simulation program bases on a social force model that describes the motion of pedestrians in dependence of the social and psychological impact of their environment. The model considers individual characteristics like the desired speed and the mood of the pedestrians, eg. whether they are just strolling around, in hurry, or in panic. Even the formation in groups like families can be taken into account.

In dependence of the purpose of the pedestrian facilities we can define various performance critera. Whereas the quality of a subway station is determined by the efficency of the pedestrian flow, the optimization of shopping malls and theme parks requires different critera like comfort of usage, or the frequency of avoidance maneuvers.

For the optimization of the planned facility, the distribution of pedestrians characteristics is composed in accordance with the crowds expected in the building. Then an evolution program modifies systematically the shape of corners and walls, and the size and location of entrances and obstacles. For each sample of the new generation the simulation program is run with the given pedestrian crowd for always the same time period. The propability for reproduction of a sample is evaluated with respect to the appropriate performance critera.

The outcome of the evolution process may depend on the applied optimization critera and the composition of the assumed pedestrian crowds.

Which is my Fastest Route to Work ?

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Simple models for particles hopping on a grid (cellular automata) are used to simulate traffic flow. Despite their simplicity, these models are astonishingly realistic in reproducing start-stop-waves and realistic fundamental diagrams. These models are useful for both analytic and computational research. In these models, one finds that the limitation of throughput is caused not by some kind of laminar viscous flow behavior, but by system-spanning traffic jams, i.e. a percolation-type phase transition. Drivers experience this as start-stop-waves. The dynamical picture is consistent with other models and gives a nice and short interpretation for observed data. These jams cause large fluctuations in travel time. Due to its high computational speed while still being microscopic, the model is useful for behavioral simulations of traffic in large road networks. In these simulations, each traveler makes (e.g. routing) decisions according to some simple adaptive rules, using past experience and broadcasted information. One result of these simulations is that the usually necessary diversity of agents to stabilize such systems is unnecessary because of the highly fluctuating dynamics of traffic near maximum flow.

Optimization of Road Networks Using Evolutionary Strategies

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In order to optimize road networks which connect a given set of nodes, one has to consider at least two contradicting demands: (i) to minimize the total costs of constructing the road network, e.g. by minimizing the total length of the roads, (ii) to minimize the detour to reach any given node from any other node. Both demands could not be satisfied at the same time, since a minimized detour means a direct connection between all nodes and therefore, a maximum total lenght of the network, and minimal costs for the network mean the smallest possible total length for the links.

Optimization problems like this are known as *frustrated problems.* Unlike the well-known *Travelling Salesman Problem (TSP)*, where the total length of a round-trip has to be minimized and a final optimum is well-defined (althrough hard to get), the frustrated optimization problem is characterized by a tremendous number of nearly evenly matched solutions.

In order to find some of these matching solutions, evolutionary strategies are applied. This is a special class of stochastic searching strategies in an ensemble of searchers which adapt certain features from natural evolution. Two examples used here, are the BOLTZMANN- and the DARWIN strategy. Further, simulated annealing is applied.

In our case, the fitness function to be optimized during the simulated evolution consists of two parts, representing the mean detour (local demand) and the total lenght of the road network (global demand). A parameter λ can weight between these two contributions.

The computer simulations investigate (i) the evolution of the road network and the related fitness function, (ii) different optimized solutions (graphs of varying density) for the road network in dependence on λ, (iii) the stationary distribution of the BOLTZMANN strategy for the considered case, (iv) a comparison of the optimization results for both BOLTZMANN and DARWIN strategies.

Urban Hierarchies and Fitness Landscape Criteria

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Explaining the empirical regularity of spatial patterns of different-sized urban areas according to hierarchical theories has been a long-standing challenge to urban analysts and social scientists. Examples include the work of Christaller and Beckmann, that relies, however, upon a given spatial configuration of initial nodes, usually attributed to the transportation network with such a network dictating the number of locations between which higher and lower level activities interact.

An alternative approach presented and explored in this paper uses the framework of fitness (or optimality) landscapes as developed by Kauffman in the NK-model (N vertices each of which is connected to or interacts with K others). It can be analytically shown that overall systemic "fitness" or performance is optimized when the value of K is low relative to the magnitude of N. Through stochastic simulations it is demonstrated that for a given nummber of possible states for each node, regardless of the number of nodes, the average collective "fitness" is maximized for a number of interconnections, K, of approximately five. This level of interconnectedness is compatible with a spatial landscape with square road grids where each higher level of economic activity serves its own location plus four of its nearest neighbors. This suggests that the regular spatial configuration may have evolved as a result of some optimal "fitness" satisfaction and not be merely the result of the accident of the initial road network.

Urban Cluster Growth: Analysis and Computer Simulations of Urban Aggregation

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From a physical point of view, urban aggregates can be described as a special form of fractal clusters on a surface. Hence, fractal measures and models of fractal aggregation (DLA, DBM) have been applied in order to describe the distinct form and evolution also of urban aggregates.

Our approach takes into account that urban aggregates are not just one percolating cluster, but a distribution of clusters of different sizes separated by empty space. Therefore, we start from a detailed investigation of the cluster size distribution, obtained from time series of the evolution of different metropolitan areas (e.g. Berlin, Munich, Moscow).

As the result, we found that the rank-size distribution of the clusters approaches a PARETO distribution in time, indicating that the urban aggregation is hierarchically structured by clusters of all sizes. Moreover, different major cities are characterized by approximately the same value of the PARETO coefficient. This fact may serve as an indication of the "quasistationary" state of a spatially developed urban aggregation.

The simulations of the evolution of the urban cluster distribution are based on a Master equation approach. The initial configuration is given by a definite spatial distribution (e.g. Berlin, 1910). Using simple assumpions for the growth of the single clusters and the formation of new clusters, we are able to reproduce given real rank-size cluster distributions for later times (e.g. Berlin, 1920, 1945).

Further, a more detailed kinetic model of urban aggregation is discussed. This model is based on active Brownian particles with an internal degree of freedom, which are able to create an attractive potential (growth field) for aggregating particles. On the macroscopic level, this structure formation process can be described in terms of coupled reaction-diffusion equations. Computer simulations show the non-linear feedback between existing aggregations an their further growth, which is mediated by the growth field, but restricted by the disposal of growth sites.

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Self-Organization of Networks with Active Brownian Particles

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The formation of networks between a given set of nodes is of common interest in many different areas, e.g. in electronics (platines), in biophysics (neurons), in telecommunication, in trade-logistics, in trail formation of biological species, etc. We provide a mechanism for self-organization of networks, which features the emergence of structures and, therefore, is quite contrary to the process of planning a hard-wired network .

Our approach is based on microscopic local interactions between active Brownian particles with the ability to generate a self-consistent field, which in turn influences their further movement and physical and chemical behavior. In the considered case, the particles are able to change the surface conditions locally by producing two chemical substances, which can decay again by decomposition. The particles respond to the gradients of these chemicals by changing their moving direction. Further, the particles have an internal degree of freedom which determines the kind of chemical produced and responded to. This internal parameter can be changed by an interaction between the particles and the nodes, which have either positive or negative potentials. Nodes with opposite potentials should be connected by a link.

The analytic description is based on LANGEVIN- and FOKKER-PLANCK equations for the active Brownian particles, coupled by reaction equations for the chemical fields. The computer simulations show, that, after a time of rather random behavior of the particles, links between nodes of opposite potentials emerge.

As an application of the model, the *trunk trail formation by foraging ants* is simulated. Here, the nodes are given by a nest and some distributed food sources. Just by responding to chemical gradients, the active Brownian particles which have no memory first explore the surface to discover food sources, and then create trails between the nest and these sources. The simulations demonstrate, for two different distributions of food sorces, the emergence of distinctive trail systems commonly used by the particles and the high flexibility for including new sources into the trail network.

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From Fast to Slow Processes in the Evolution of Urban and Regional Settlement Structures

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Complex systems consist of many intertwined organisational levels starting from microstructures and ending with macrostructures. Their evolution takes place on different time scales: Micropatterns exhibit a fast dynamics whereas macropatterns develop slowly. Urban and regional science can make use of this fact by constructing a hierarchy of models on different spatio-temporal scales.

Based on this understanding two models are presented: One for the relatively fast urban evolution on the microscale and one for the relatively slow regional evolution on the macroscale.

The *micromodel* considers the urban structure as a system of squares on which different kinds of buildings (dwellings, schools, stores, service-stations, factories ...) can be erected. The step by step evolution of the building configuration is treated as a stochastic process guided by desirability considerations. The formalization of this concept leads to equations for the evolution of the urban building configuration. Numerical simulations illustrate this urban "microdynamics".

The *macromodel* treats the settlement formation in a region on a more global scale. The evolution of the density of economically active populations who produce and consume goods is considered. The driving force of density changes is the spatial difference of incomes motivating the individuals to migrate to locations of optimal income. This nonlinear process leads to the self-organisation of spatially heterogeneous population distributions forming the settlements. Their micro-structure can thereupon be treated by the micromodel.

Self Organization and Complexity in the Evolution of Urban Systems

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Urban systems have been modelled as dynamical systems consisting of dozens or hundreds of regions competing with each other for residents and economic activity. This approach reveals cities as engendering their own structure as they pass through a series of bifurcation points. However, urban spatial structure has also been shown empirically to have fractal dimensionality. To model the dynamics producing this fractal spatial structure, we use constrained cellular automata, which permit the necessary level of spatial resolution to be achieved. These models give very good agreement with actual measures of urban form, and display the bifurcation process by which cities initiate the large scale features of urban form. In particular they show that the specific urban form originates in the essentially stochastic locational events in a peripheral zone of low dimensionality, and once development reaches the point where the form is largely fixed, the dimensionality increases abruptly; cities are thus bi-fractal structures. There is some evidence from US data that loss of fractility in the urban structure is a characteristic of particular urban pathologies.

Hierarchic Network Optimization

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A well known problem within the framework of network optimization is finding the optimal location of crossing sites connecting a given set of points (i.e. cities) in order to minimize the total lenght and the average connection time of the network. To this end, hierarchic structures are investigated as an alternative to more general graph-oriented approaches, providing a natural way to place the crossings. Subsequent partitioning of the sites allow connections among different groups on the same level to occur at the next higher level only, as in most hierarchic systems.

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