UNIVERSITÄT DORTMUND

Chair of

Systems Analysis

A Review of 2000–2001

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Contents

The Chair of Systems Analysis

In conjunction with the degree program *Applied computer science*, established as a supplement to the traditional subject *Computer science* at the University of Dortmund, the Chair of Systems Analysis was founded in 1985. Since then Professor Schwefel has been holder of the chair. In 1993, Professor Banzhaf joined the team representing the field of *Foundations and applications of computer science in engineering*.

During the past two decades, international interest in artificial neural nets, fuzzy systems, and evolutionary algorithms has increased substantially. Together, these topics now form the important new field of *computational intelligence* (CI) or *natural computing* within the computer sciences – about three decades after the first ideas emerged. One reason for the delay is the fact that only recently the computing power has become available for solving many practical problems by means of those methods, especially since more and more parallel computers and local networks of workstations can be used to exploit with the inherent parallelism of the CI methods.

The group of scientists at the Chair of Systems Analysis has been working in the fields of evolutionary and – to a lesser extent – neural computation for an extended period of time. The international acknowledgment of that work has led to the establishment of a collaborative research center *Design and management of complex technical processes and systems by means of computational intelligence methods* (SFB 531) at the University of Dortmund. It has been financially supported by the Deutsche Forschungsgemeinschaft (DFG) since its inception at the beginning of 1997. The use of parallel computers has a long tradition here, documented by the participation in several national and European initiatives.

Technology transfer via ICD-CASA

The *Informatik Centrum Dortmund* (ICD) was founded in 1989 by a group of professors from the Department of Computer Science at the University of Dortmund. It aims at being a research and development partner of regional and other enterprises from all kinds of economic branches. The ICD cooperates with entrepreneurs via application-oriented joint projects that need modern research knowledge, and it provides courses in order to disseminate that knowledge in industry. North Rhine-Westphalia has sponsored the foundation of the ICD in order to enhance the transfer of computer science achievements from university into practice. A special strength of the ICD results from the fact that computer scientists from various special research fields collaborate with each other as well as with scientists from other disciplines, especially from electrical and mechanical engineering.

Together with the ICD, two other initiatives of similar constitution, RIF and ZEDO, were founded. They are residing in the same building and are operating under the umbrella organization *Forschungs- und Entwicklungsgesellschaft (F&E-Gesellschaft).* More information may be found on the corresponding WWW homepage at `http://www.icd.de/` .

Within the ICD the following departments are active:

- Center for Applied Systems Analysis, CASA
- Software- and Intelligent Technologies SWIT
- Multimedia Systems MMS
- Embedded Systems ES

Our department CASA *(Center for Applied Systems Analysis)* currently cooperates with industrial partners on various real-world applications, e.g. the optimal design of industrial plants (Siemens AG, Munich), the synthesis and analysis of controllers (DaimlerChrysler), the implementation of an integrated GP tool (RML Inc., USA), and the classification of biometric data (Genologic). Technology transfer is realized by various offers ranging from seminars and supply of standard software created by CASA to the conception and realization of specific solutions to problems that are brought to our attention.

Part I
Research and projects

1 Focus of research

1.1 General systems analysis

The analysis of complex systems is a constituent part of nearly every scientific discipline. Astronomy, for example, deals with the largest systems in time and space, with cosmic objects like galaxies, stars, and the forces that act between them, such as gravitation. Biology is engaged with living beings and their mutual relations, e.g., predator-prey systems. Interactions between human individuals and social groups form the research topics of the social sciences, and interactions of organs of an individual are part of the medical sciences.

Since the middle of the 20th century, the reductionist approach, i.e., the bottom-up explanation of the whole from the properties of its elements, has been challenged by the perception that complex phenomena often result from (rather simple) non-linear interactions between the elements or subsystems. Moreover, the rules that determine the systems' behaviors have turned out to be similar in seemingly different systems. As a result, interdisciplinary research fields such as the general systems science and cybernetics emerged. *Systems analysis* and *computer science* (informatics) are late-comers in that historical chain of events. The most important topics of systems analysis are data analysis, modeling, simulation, and synthesis relying on optimization.

1.1.1 Data analysis

The analysis of a system starts with its observation, which supplies various data. Selecting and processing these recorded measurements by using mathematical and statistical methods is usually known as data analysis. The methods of descriptive statistics provide fundamental information about the system, whereas the techniques of conclusive statistics give us knowledge concerning the statistical relevance of the measured data. Data analysis precedes the other phases of systems analysis and influences the attainable results to a large extent.

1.1.2 Modeling

Mostly, the investigation of a system cannot be solely based on real-world experimentation because it is too expensive, too risky or even impossible at all. In this case, computer models can often be utilized as substitutes of reality. In order to do so, the model has to mimic the behavior of the original system closely enough depending on the aim of the investigation. With regard to the information available and the given problem we can choose a purely descriptive, an explaining, a normative, or a mixed model. In addition to analytical models the more powerful computer models are used more and more often. Only these combine a great flexibility with a high processing speed and make it possible to comprehend a complex system.

1.1.3 Simulation

Simulation studies based on computer models generated in the modeling phase can help to get insight into the behavior of a given system even in the case of complex systems with different restrictions. Thus, computer simulation is nowadays well established as a fundamental approach to analysis.

1.1.4 Synthesis

Frequently, if a mathematical or computer model is given, the goal of systems analysis is to find a set of parameters that yields a desired system behavior. Often, analytical methods fail because the model is not given in a closed analytical form. Trying all possible scenarios leads to a best solution only for a very small set of alternatives. That is why algorithms locating the global or at least one good local optimum with a high probability but using only reasonable computing resources become more and more important. In this connection, knowledge in the area of nonlinear dynamics is needed to handle the often observed chaotic behavior of a system for a specific parameter range.

More often than not one has to deal with several contradictory objectives.

In such cases special evolutionary algorithms are well suited to search for the set of (Pareto-)optimal solutions.

1.2 Evolutionary algorithms

For approximately 4 billion years, there has been life on earth. Apart from the amazing diversity of species, the process of evolution has created many organisms and forms that are well adapted to their respective environment, partly even in an optimal way. Why should one not try to come to new and more robust optimization procedures by mimicking fundamental evolutionary principles?

At the beginning of the 1960s, different researchers came up with this question independently of each other. In Germany, this has led to *evolution strategies* (ES), in the U.S.A. to *genetic algorithms* (GA) and the concept of *evolutionary programming* (EP). These procedures as well as *genetic programming* (GP), which transfers evolutionary principles into the search space of programming languages, are summarized today under the names *evolutionary algorithms* (EA) or *evolutionary computation* (EC).

An important advantage of evolutionary procedures is their inherent, scalable parallelism. Thus, EA can easily be adapted to any kind of parallel data processing architecture.

Using the default approach, evolutionary algorithms are applied to optimization problems of the following form: $min\{f(x) : x \in \mathcal{M}\}$. Most often, the objective function f maps the feasible region $\mathcal{M}$ into the real numbers $I\!R$.

An individual can be regarded as a tuple $(x, s_1, \ldots, s_r), \quad r \geq 1$, with $x \in \mathcal{M}$ being a feasible solution, while the $s_1, \ldots, s_r$ represent strategy parameters. Usually, the objective function's value at its position x is taken as the individual's fitness.

A number of individuals form a population, which evolves from one generation to the next by means of the following genetic operators: Mutation is a stochastic operator that modifies the genetic information of an individual after recombination has assembled the genetic material of two or more parents to a descendant. Selection then determines which individuals may reproduce in the next generation. Figure 1 depicts the general iteration pattern of an evolutionary algorithm.

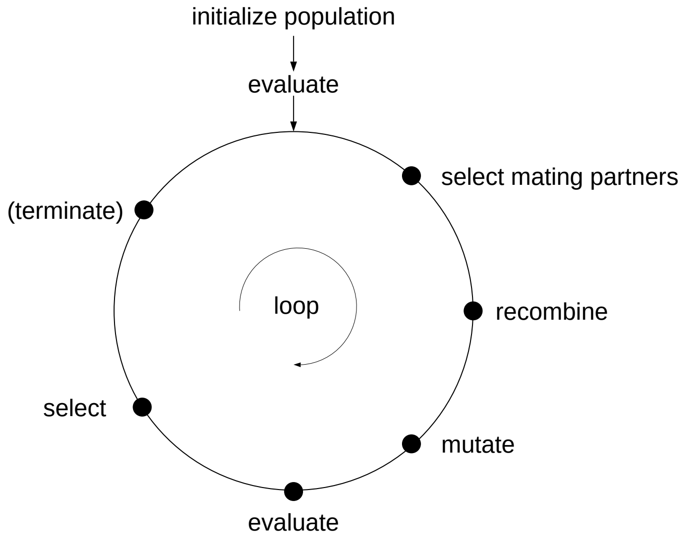

Figure 1: Iteration scheme of a standard EA

The different classes of evolutionary algorithms differ by the representation of the individuals and by their variation and selection operators.

1.2.1 Evolution strategies

Although invented originally for experimental optimization and discrete search spaces, typically the $\mathbb{R}^n$ is the search domain of evolution strategies since their implementation on computers. For this case, the theory of ES progressed furthest. Accordingly, an individual consists of an n-dimensional real valued vector x representing the object variables and a number of strategy parameters controlling mutation. The number of strategy parameters can vary between 1 and $n + n(n-1)/2$ depending on the user's choice.

The special feature of ES is recombining and mutating both object and strategy parameters. This and an appropriate selection pressure provide the possibility of a permanent self-adaptation of mean step sizes, and sometimes even the preferred directions the strategy takes in the search space emerge.

For the success of the self-adjustment, a surplus of descendants is crucial, which is diminished again by selection. Researchers in our group examine convergence properties, the influence of different operators, and extensions of the basic algorithm for multi-objective and dynamic optimization problems. Different parallel approaches are being investigated, too.

1.2.2 Genetic algorithms

Typically, in GA, bit strings of a fixed length l represent an individual. Hence, the individuals are elements of $\mathbb{B}^l$. This does not mean, however, that GA can only solve pseudo-Boolean problems, for which this coding is directly suitable. More complex data structures like real numbers, lists, trees etc. can be mapped to bit strings in an appropriate way. However, each additional mapping between the binary and the problem representation weakens the necessary causality between genotype and phenotype. For each optimization problem one has to decide whether to choose a representation tailored for the problem and to adapt the genetic operators, or using a standard GA by coding the decision variables more or less skillfully in a bit string.

A GA population consists of μ individuals. Selection chooses, at least, two individuals for the next mating with a probability proportional to their relative fitness. Furthermore, a number c is randomly taken from the set $\{1, 2, \ldots, l-1\}$. The descendant receives the first c bits from one parent, the remainder from the other. Then, the descendant's bits are mutated (i.e. inverted) with a small probability. The individuals produced in this way replace the parental generation. This procedure is repeated until a termination criterion is fulfilled.

1.2.3 Genetic programming

Genetic programming (GP) designates a set of evolutionary processes that generate computer programs representing algorithms. These algorithms are meant to solve a specific problem. The problem solving capability (fitness) of such genotypes is given by its algorithm's capability of approximating a problem-specific input-output relation. GP processes can be used practically in many problem domains like data mining, control, robotics, economics, or socionics.

Depending on the representation of individuals, different variants of GP may be distinguished nowadays. In the traditional approach programs are represented as syntax trees of a functional programming language. Another established variant, *linear GP*, uses imperative program code instead, and includes the evolution of machine programs. In the AIMGP approach (*Automatic Induction of Machine Code with Genetic Programming*) programs are executed directly as binary machine code without passing an interpretation step first. By this, the time-critical step of genetic programming is accelerated significantly. Another possibility of reducing the execution time of programs is the removal of non-effective code before the fitness of a program is calculated. The existence of non-used parts of programs is typical for the linear representation, in particular.

Other GP approaches use program graphs or combine different forms of representation within one individual. In this context especially branching graphs of linear instruction sequences (so-called *linear graphs*) may promise a better performance.

1.3 Artificial neural networks

When regarding (artificial) *neural networks* as biologically inspired structures showing several of the brains' characteristics, unsupervised learning (i.e. learning without an external guidance) gains major attention as it is known for its biological plausibility (as opposed to supervised learning involving a teacher).

Unsupervised learning neural networks aim at building *useful* representations from the external data world by learning from input examples (regarded as sensory inputs in biological terminology). These representations may be used for probabilistic reasoning, solving classification tasks, modeling theories of human perception, etc. Representations considered as useful are typically those that form topographic maps, model the input data density, construct dimensionality reducing mappings, identify clusters – depending on what purpose the unsupervised learning network serves. We are interested in studying the links between representations and the learning target focussing on the computational aspects.

In particular, we look into graphical models forming a successful probabilistic modeling approach encoding relationships among a set of random variables and provide a representation for the joint probability distribution over these variables. The advantages of the graphical formalism have their origins in probability theory and graph theory, the structural modularity favoring parallel computations, and its clearness.

Addressing the model selection problem of unsupervised trained structures by using evolutionary algorithms suggests itself, as we remain in the area of parallel computing inspired by nature.

1.4 Artificial life

The research area artificial life (ALife) is a relatively young branch of computer science. After some preliminary work in the 1950s and 1960s, a first meeting at Los Alamos NM in 1987 provided the publicity required to establish artificial life as a research field. ALife approaches to understanding life are synthetic in that the creation of life-like systems in artificial media (e.g. computers) is at their center. Biology, in contrast, is dominated by an analytic approach to the living. ALife considers life as a property of the organization of matter and is looking at man-made systems where the same organizational structures may be found. One could say that, whereas biology is focusing on the material basis of life, ALife tries to discover the formal basis, the 'logic of life' by abstracting from the physical and bio-chemical representation of (organic) life forms.

In our studies, we examine the phenomena of self-organization (the build-up and break-up of organizational structures), evolution and information processing in artificial chemical systems. In such systems, mathematical/algorithmic objects interact according to simple formal rules. These rules are inspired by the chemical metaphor of information processing and by ideas about the origin of life in a prebiotic soup of RNA molecules. A large number of simple interactions among objects create a complex dynamical process, where unstable organizations emerge and decay until more stable (for example, self-maintaining) ones appear.

We investigate a simple binary-string system with the interactions among strings leading to self-replication and metabolic networks. In our current project *BinSys*, we investigate more complex, constructive systems with different interaction schemes, including applications of such systems in robotics.

1.5 Molecular computation

We investigate molecular computation under two aspects:

1st: As a metaphor for information processing:

For this purpose we examine computing methods that are based on the ensemble idea of thermodynamics, and chemical kinetics also plays a role as model. The philosophy is to regard interactions between inputs and program in a computer in such a way as if chemical substances reacted in a test tube. This is a massively parallel model of computation in which single reactions (individual calculations) do not count very much. Rather it is the collective behavior of many of these reactions that becomes important. In a way, the results emerge from the mass of calculations by being more frequent products of these than others. Systems of this type are inherently fault-tolerant. At the moment we study the problem of how to control and program a system of this kind.

2nd: As an approach to DNA computing:

In 1994, Leonard Adleman implemented the first in vitro encoding of an algorithm in DNA molecules. The hope was to build a molecular high-performance computer by use of the huge amount of DNA molecules in solution. Although this hope has not been fulfilled yet, DNA computing opens a lot of possibilities for applications in the field of nanotechnology. Particularly the methods of self-assembly of molecules allow completely new construction methods in the nanoscale. We investigate the approach of programmable self-assembly and its application possibilities in information processing, the digital DNA-based labeling of materials and molecular encryption.

1.6 Nonlinear dynamics

Apparently stochastic, erratic behavior of a deterministic simulation model, describing the convection in the atmosphere by a system of three coupled nonlinear differential equations, led to the fall of the world view that was based on strong causality. During the past three decades, new terms like *chaotic attractor*, *bifurcation*, and *fractals* emerged together with the hope to understand and describe complex phenomena by means of small-scale models.

Whereas there have to be at least three interacting variables in the case of continuous-time systems for such phenomena to arise, in discrete systems one variable is sufficient. Due to this fact, in our opinion students of computer science should get the opportunity to learn about these aspects.

One consequence of the new world view is the distinction between weak and strong causality. Weak causality means that same causes are followed by same consequences, and strong causality means that similar causes are followed by similar consequences. Today, it has to be accepted that even deterministic systems do not always react in a strongly causal way. Although deterministic chaotic trajectories may locally diverge in time and phase space, there can exist complex order in strange attractors. This order can be characterized by non-integer valued (fractal) dimensions or corresponding Rényi entropies, and often simple nonlinear models can be found that produce the observed complex behavior.

Practical applications of the relatively new field of research called nonlinear dynamics are investigated together with engineers and other scientists.

1.7 Parallel computing

Despite ever faster processors, the computational power needed for the simulation of large and complex dynamical systems and superimposed optimization is so immense that it can only be provided by parallel distributed computing. Therefore, the Chair of Systems Analysis committed itself early to the parallel computing approach.

Also, the collaborative research center SFB 531 predominantly considers methods, which show an inherent parallelism. For this reason, we initiated the acquisition of a powerful parallel computer system. At the end of 1998, this computer (Silicon Graphics Origin 2000) has been taken into operation by the Chair of Systems Analysis. Since then the system provides parallel computing resources to all those projects within the SFB 531 that require it.

2 Projects

2.1 Collaborative research center (SFB) 531

Contact: Lutz Schönemann

The demand for robust methods for design and control increases with the growing complexity of technical systems. These methods have to cope with imprecise, imperfect, and partially ambiguous information to get appropriate results in noisy and time dependent environments.

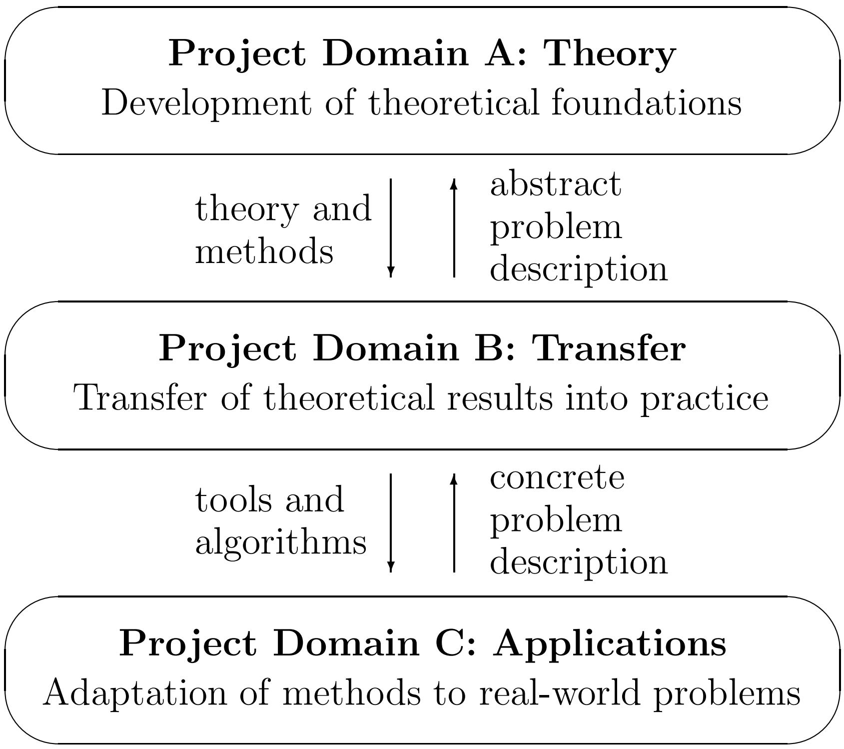

Figure 2: Structure of the SFB 531

The methods of *Computational Intelligence* (CI), such as fuzzy logic, neural nets, and evolutionary algorithms mimic the information processing within natural systems. They have proven their applicability in many cases in which traditional methods fail. Real-world problems are often solved by combining different CI methods with each other or with methods from the field of machine learning.

The current state of research is marked by a gap between the successful application of CI methods and a formal proof of their applicability. To bridge this gap, scientists from different subject areas are working together in the Collaborative research center (SFB) 531 *Design and Management of Complex Technical Processes and Systems by Means of Computational Intelligence Methods*. The SFB is divided into three areas: A (theory), B (transfer), and C (application). The projects of area A focus on theoretical issues, the application-oriented projects of area C investigate the performance of CI methods on diverse problems in the domains of process engineering as well as mechanical and electrical engineering. The projects of area B are intended to bridge the gap between theory and application by, for example, supplying appropriate software tools. Figure 2 gives an overview of the structure of the SFB.

The SFB is now in its second period of funding and going to apply for a third one. Currently, Professor Schwefel is the spokesman of the collaborative research center, its management thus being in the hands of the Chair of Systems Analysis. Furthermore, members of the chair are doing research in the following projects of the SFB 531:

2.1.1 Analysis and design of evolutionary algorithms and interacting automata for optimization problems

Contact: Dr. Günter Rudolph and Priv.–Doz. Dr. Hans–Georg Beyer

Apart from the enhancement of the theoretical foundations of evolutionary algorithms, this project is also engaged in examining the relationships between agent systems, cellular automata, evolutionary algorithms, and other locally interacting systems. In the period under review the main focus lay on two topics: The analytical treatment of so-called takeover times of selection methods as well as the convergence properties of evolutionary algorithms when fitness sets are not totally but partially ordered.

The takeover time is known as the mean number of iterations required by a selection method, until a population of n individuals consisting of one good and $n-1$ worse individuals contains n individuals with good fitness for the first time. It was shown that all commonly used non-generational selection methods are describable as random walk problems and that they are therefore amenable to a mathematical treatment. For all selection methods under consideration the takeover time is of order $\Theta(n \log n)$. In case of spatially structured populations we falsified the common conjecture that all growth curves of the number of best individuals are of logistic nature. It was proven that the growth curves are linear for neighborhood structures like array and ring.

In case of optimization problems under a single objective function the fitness set is always totally ordered, i.e., each pair of fitness values is comparable. This is no longer true for partially ordered fitness sets: there exist pairs that are *incomparable*. This case surfaces for example when optimizing under multiple objectives (vector optimization), or if there are noisy, fuzzy or interval-valued objective functions. We developed several optimization methods that provably converge to the *set of minimal elements* (i.e., 'the optimum'). These results generalize theoretical findings that are known for the special case of single criterion optimization. For if we reduce the number of objective functions to a single one, or if we reduce the noise amplitude to zero, the fuzziness to sharpness, or the intervals to single points, then we obtain totally ordered fitness sets again.

2.1.2 Genetic programming and neural networks

Contact: Markus Brameier

After examininig the combination (hybridization) of neural networks and genetic programming (GP) in the first years of the SFB, we recently concentrated more on GP itself. In particular, methodical developments in the area of linear GP have been dealt with. This GP variant differs from the traditional form in that the genetic programs have an imperative representation instead of functional program trees. Transforming a linear program into a functional representation results in a directed graph. In contrast to a tree structure a program graph tolerates the existence of *inactive* code, i.e., non-contiguous components.

The architecture of linear programs offers some advantages for the development of efficient variation operators, especially concerning pure mutation-based variation. Using small mutation steps on the symbolic level allows smaller structural variations and, thus, a more precise approximation of solutions (sub-optima). If, in addition, only the active program component is varied, program solutions show a significantly reduced complexity. Thus, the bloat effect that is observed in genetic programming turns out to be less significant with our approach. The reason for this lies in a reduction of inactive program parts in particular. On the other hand, program graphs facilitate a multiple reuse of code fragments, by definition, and, thus, allow a more compact representation than would be possible with tree-based representations.

In addition, methods have been developed that control the step size of mutations as well as the diversity concerning the active program code. Both methods require the definition of appropriate metrics that determine the structural distance between genetic programs.

2.1.3 Non-standard representations in evolutionary algorithms and integration of domain knowledge

Contact: Dr. Dirk Wiesmann

The aim of the project is to systematize the design of evolutionary algorithms. The application of evolutionary algorithms requires two basic design decisions concerning the representation and the variation operators. In the context of computer based optimization the genotype and the phenotype space have to be represented by appropriate data structures. The data structures have to support the efficient (fast) evaluation of the fitness function as well as the efficient implementation of the variation operators. The variation operators (mutation and recombination) have to be chosen in accordance with the optimization problem. To obtain a fast and reliable approximation of a good (optimal) solution, it is important to integrate the available domain knowledge into the design of the evolutionary algorithm. E.g. estimating the noise level in case of stochastically disturbed fitness function values may lead to the implementation of an improved selection operator. Especially for problems concerned with structure optimization the integration is not straightforward. To support the integration of domain-knowledge the project follows an algorithmic design approach. Based on theoretical results, design guidelines are formulated in order to systematize the design of problem-specific evolutionary algorithms.

2.2 Collaborative research center (SFB) 559

Contact: Andreas Reinholz

The aim of the Collaborative research center SFB 559, entitled *The modeling of large networks in logistics*, is the creation of a theory and the development of tools for designing, organizing and managing large logistic networks. The functionality of corresponding systems and processes is optimized with regard to technical, economical, and ecological objectives.

The main task of the project *M8 - Integral optimization* is the development and formulation of a standardized procedure to design hybrid evolutionary algorithms for optimization problems in the field of logistics. We aim for an optimization tool that may be improved successively through shaping and adding new components and will be available at an early stage of this procedure.

The project is in the phase in which the behavior and performance of different optimization procedures that were developed for the p-hub problem in accordance with the standardized design procedure, are examined on the basis of two evaluation models.

The results and realizations of these extensive empirical investigations are used in particular to increase the efficiency of the optimization procedures implemented so far and are also used to design new operators, components and optimization procedures for the p-hub problem.

2.3 Bio-inspired learning and optimization methods for networks

Contact: Dr. Thomas Bäck

Within the research project LEONET, natural computing methods are used for solving problems in complex and strongly interconnected systems. Concerning the application fields, the project focuses on road traffic, internet computing, and telecommunication networks. Concerning the natural computing methods used for tackling these applications, mainly fuzzy logic, neural networks and evolutionary algorithms are exploited.

As a part of the LEONET project activities, the cooperation between the Informatik Centrum Dortmund (ICD) and Siemens AG focuses on solving qualitatively new problems arising at Siemens AG in the fields of multi-agent systems for internet-based personal travel assistance, the design and management of telecommunication systems, and the design and dimensioning of power plants. In all three cases, evolutionary algorithms are used to arrive at high-quality solutions of these innovative and complex application problems. The research work at the ICD within the LEONET project is supported by the Federal Ministry of Education and Research (bmb+f).

2.3.1 Learning of user preferences for agent systems

Contact: Boris Naujoks and Martin Schütz

Software agents are autonomous, active, and compact software components. They form an innovative design paradigm for the efficient realization of complex, heterogeneous software systems with a high rate of interaction. Software agents must be able to communicate with other agents and external components. Furthermore, they need the ability to adapt to individual requirements of the agent system's user.

At the ICD, learning multi-agent systems are used as basic components for a *personal travel assistance* (PTA) system and an *electronic commerce* system. The PTA system has been developed by Siemens AG for the optimal use of travel resources by supporting the planning and realization of journeys. By using all available electronic services, the traveler can use the tool for booking flights, reserving hotels and parking, and for planning routes for public and individual transport.

The ICD contributes to the task by realizing system components that learn travel preferences of a user. For that purpose, a *learning agent* (LA) is to be created. This gives the system the ability to use such information in the planning process. Furthermore, the LA sorts the travel alternatives given from the PTA system according to the user's preferences.

Another main task is the sorting of services according to their availability and reliability. This data is required for submitting fast and secure requests to travel service providers. Based on the incoming results, heuristics for further requests are developed.

For both tasks different methods are implemented and used within the PTA system. These methods range from relatively simple statistical tools to new ones for *data mining* by means of evolutionary algorithms.

2.3.2 Routing and dimensioning of telecommunication networks

Contact: Jörg Ziegenhirt

Within this part of the LEONET project, optimization methods based on evolutionary algorithms are developed for solving problems which are of paramount importance for the design and management of telecommunication systems.

The particular focus is on private telecommunication networks that realize the communication in large companies and public authorities.

The network performance is defined by its connectivity. The connectivity is equivalent to the total probability of end-to-end-blockings within the network while taking into account as constraints the grade-of-service requirements. The connectivity is determined by the network design and the routing table of the network. The routing table consists of a set of alternative paths, ordered by priorities, to facilitate a so-called fixed alternate routing of messages from an origin to a destination node.

For any optimization, the (maximal) given topology of the network and the traffic matrix are fixed input variables.

There are two aims for optimization. The connectivity is to be increased, and the network costs have to be minimized. Both aims are considered within the LEONET project. The routing table was used to develop a novel evolutionary algorithm. This algorithm yields solutions of much better quality than those obtained by means of traditional algorithms. The implementation of these solutions is very cheap, for only software requirements must be changed. For the first time a cheap correction of the network due to changed traffic situation has become possible.

Within the second phase of this project, the capacities of the connections are varied to optimize the cost. The algorithm for routing optimization was integrated in a very complex evolutionary algorithm. With these two algorithms the software tool for design and management of private networks is completed.

2.3.3 Design and dimensioning of power stations

Contact: Michael Emmerich

This project, which has now been successfully completed, dealt with the conception of problem specific evolutionary algorithms (EA) for the coupled structure and parameter optimization of thermal power plant processes. Problem specific search methods have been developed and successfully integrated into the power plant design environment of the industrial partner, the Siemens AG.

In thermal power cycles, heat is transformed into electrical power. An optimal choice of apparatus in the pre-heating section and the adjustment of process parameters can contribute mainly to an increased thermal efficiency of the power stations. Pre-heating systems can be very complex and contain a large number of components such as heat-exchangers, pumps, tanks and mixers.

Problem-specific EA proved to be robust global optimization strategies that required no analytical target function. Furthermore, they offered many ways for the integration of problem specific knowledge into the search process.

An important question was the choice of an adequate representation. Two methods, the superstructure representation and a variable-dimensional graph representation, have been used. For the first approach the user has to define a so-called superstructure that comprises all alternative processes. A special solution is selected from this superstructure by means of binary decision variables. The application of this method was successful and new efficient power cycles have been discovered with that method by the Siemens AG. For the knowledge-based search for new alternative designs also a dynamical graph-based evolutionary algorithm has been developed, which is capable of searching more complex structural search spaces and which simplifies the integration of knowledge into the search process.

2.4 Theoretical investigations of evolutionary algorithms

Contact: Dr. Dirk Arnold and Priv.–Doz. Dr. Hans–Georg Beyer

It is the goal of this project, which is supported financially by the Deutsche

Forschungsgemeinschaft (DFG), to further the theoretical understanding of the behavior of evolutionary algorithms and in particular of evolution strategies in real-valued search spaces. More specifically, it is determined how the performance of such strategies scales with parameters of the problem — such as the dimensionality of the search space — or of the strategy — such as the population size. By virtue of such scaling laws strategy variants can be compared, guidelines for tuning evolution strategies for maximum performance can be given, and insights and an understanding of the behavior of the strategies can be gained that goes beyond what can be learned from mere experimentation.

More specifically, a focus of the present project is the influence of noise on the performance of evolution strategies. Noise is a common factor in real-world optimization problems. Sources of noise include, to name but a few, physical measurement limitations, stochastic simulation models, incomplete sampling of large spaces, and human-computer interaction, and there is empirical evidence that evolutionary algorithms are particularly effective in the presence of noise. We have considered various features that set evolutionary algorithms apart from other direct optimization strategies and have studied the effects they have on the performance of the strategies, in particular,

- the performance of the $(1 + 1)$-ES and the occurrence of systematic overvaluation of the parental fitness. We have seen that overvaluation is a factor that can be beneficial in that it prevents regression, but that it can also render commonly used mutation strength adaptation schemes worthless;
- the benefits of using distributed populations of candidate solutions at the example of the (μ, λ)-ES;
- the effects of genetic repair in the presence of noise by considering a strategy employing global intermediate recombination;
- cumulative mutation strength adaptation.

We also compared empirically the performance of evolution strategies in the presence of noise with that of other direct optimization strategies. In our experiments, evolution strategies proved to be competitive in the absence of noise and more robust than any other strategy considered in its presence.

Future goals include the improved understanding of the dynamics of step size adaptation mechanisms.

2.5 Unsupervised learning in neural networks

Contact: Ralf Garionis

Supervised learning procedures for neural networks have become synonymous to learning in neural networks while they have been successfully used in various applications. This applies in particular to the protagonist among the learning procedures, *backpropagation*.

The possible applications of these learning procedures are, however, limited by the bad scaling behavior (complexity explosion due to up-scaling of the networks) and by requiring the presence of a teacher, which is biologically implausible.

A promising alternative for these problems is the design of unsupervised learning procedures, which can learn to code the systematic structure of their input data as network-internal representation. For building an internal representation of the external data world it is not necessary to give any desired responses to the network.

While conventional data analysis usually requires the specification of modeling hypotheses the parameters of which have to be estimated, neural networks offer the chance to discover structure within data without the need for specifiying special models.

During the active phase (until the year 2000) of this research project funded by the Deutsche Forschungsgemeinschaft (DFG), we focused on identifying mechanisms controlling unsupervised neural learning algorithms. For example, we were able to name schemes realizing topographic mappings that can be controlled by a variety of unsupervised learning mechanisms.

2.6 Evolution of gait coordination with genetic programming

Contact: Jens Ziegler

The goal of this project, which is part of the german priority program *Autonomes Laufen*, is to develop a method for automatically designing robot controllers for moving arbitrary robot hardware architectures. It should then be possible to explore the space of potential gait patterns of any robotic hardware with little or no need for a kinematic model of the robot's architecture. The system SIGEL (http://LS11-www.cs.uni-dortmund.de/∼sigel) integrates a multibody simulation component, genetic programming, a parallel virtual machine and a graphical user interface and provides an easy to use tool for analyzing properties of the genetic programming system. It demonstrates the flexibility of the approach by evolving walking programs for many different robots.

Furthermore, we try to close the gap between simulation and reality by evolving walking programs for a simulated version of our humanoid biped robot **ZORC** that are translated and downloaded to the real robot after successful evolution.

2.7 DNA computing

Contact: Udo Feldkamp

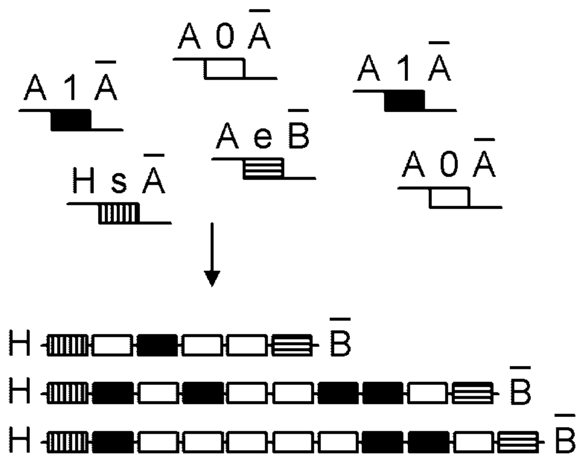

Figure 3: An in vitro random number generator
top: These molecules implement a simple random number generator. They consist of a double stranded core sequence encoding one bit and single stranded *sticky ends* controlling the *self-assembly*.
below: After *self-assembly* the molecules form longer sequences, thus encoding bitstrings. If the *sticky ends* have been designed properly, for each position there are even probabilities to contain 0, 1 or an end molecule (s or e).

In 1995 a cooperation in the field of DNA computing started between the Chair of System Analysis and the Institute of Genetics, University of Cologne. In this project, methods for the computer-aided design of DNA molecules and their application in DNA computing and DNA nanotechnology are investigated. The focus is on the mechanism of *programmable self-assembly*, the automatic assembly of molecules to larger structures, which is to some extent controllable (programmable) by presetting physical and chemical properties of the molecules. In this project a system of programmable digital DNA molecules was implemented (see figure 3). This system allows the molecular implementation of simple algorithms, DNA cryptography, and DNA labeling. The research on this system led to the foundation of the spin-off company Informium AG in 2001. The main product of this enterprise is the labelling of various substances with DNA molecules. In addition, software tools for molecular design have been developed.

2.8 BinSys — Self-organization in binary-string systems

Contact: Dr. Peter Dittrich and Jens Ziegler

In the (now completed) project BinSys self-organization phenomena in artificial chemistries were studied. An artificial chemistry is roughly defined by a set of objects - the molecules - and a set of interaction rules. In our case the objects were mostly binary strings. The phenomena of evolution, information processing, and the problem of visualizing complex population dynamics are of special interest. Autonomous mobile robots serve as an application domain to demonstrate the information processing ability of artificial chemical systems. The project was supported by the Deutsche Forschungsgemeinschaft (DFG).

2.9 Socionics

Contact: Dr. Peter Dittrich and Christian Lasarczyk

Socionics deals with the exploration and modeling of artificial societies. Socionics has one of its seeds in the field of *artificial intelligence* (AI). While the human brain is the origin of intelligence in classic AI, *distributed artificial intelligence* (DAI) assumes that the interaction of many acting individuals leads to the solution of a problem. Hence, the solution of a given problem is not the result of individual intelligence, but of social intelligence.

We can identify three fields of research in the domain of socionics:

- the problem of intelligent social communication between agents,
- the benefit of multi–agent systems for social science,
- and the creation of hybrid communities of artificial and human actors.

To enhance these fields of research, to interconnect them, and to use their synergies is the intention of the research program *Socionics* of the Deutsche Forschungsgemeinschaft (DFG). The DFG–aided projects are a close co-operation between the social and computer sciences. Our project partner is Prof. Dr. U. Schimank from the Fernuniversität–GHS Hagen.

In our project we primarily investigate the dynamics of social systems and the modeling of complex agents. We follow two lines of research in parallel. First, we try to explain the dynamics of structures and system processes with learning and reflexive agents. Secondly, we develop an architecture to create complex agents for modeling social actors.

The first approach asks, how social order may arise without control by social norms or certain intentions of the agent (situation of *double contingency*). To study this problem we developed a new model of mutual communication. In this model coordination is possible by observing each other. Two factors influence the decision process of a social actor represented by an agent. The first factor takes the necessity of expectation-certainty into account. The agent learns to predict the response to its action during interaction/communication and prefers those actions the consequences of which are well known. Due to reflexivity the agent *knows*, that the other agents also try to predict its action. Therefore the second factor, responsible for the chosen action, considers the expectation of the other agents to its action, and the agent learns to rate their expectations (Luhmann: *expectations–expectation*). In systems of two or more agents this model leads to complex communication patterns. We analyze these communication patterns by viewing them as networks.

For our second approach we are developing an architecture of a more complex agent. We integrate different actor models (homo sociologicus, homo oeconomicus, emotional man and identity keeper) into this architecture and design agents with the property of continuous transitions between these models. Currently we try to model a *realistic* situation, known as the bystander problem. Fuzzy–technologies help to interpret the underlying rules of the simulated situation. As a next step we plan to model the dynamics of large social networks, for example networks of scientific cooperation, using this model of a social actor.

2.10 Quantum computing

Contact: André Leier

In theory, certain computational problems can be solved on a quantum computer with a lower complexity than possible on classical computers. Therefore, in view of their potential, the design of new quantum algorithms is desirable, although up to now no working quantum computer has been built. Unfortunately, the development of quantum algorithms seems to be difficult, as they are non-intuitional.

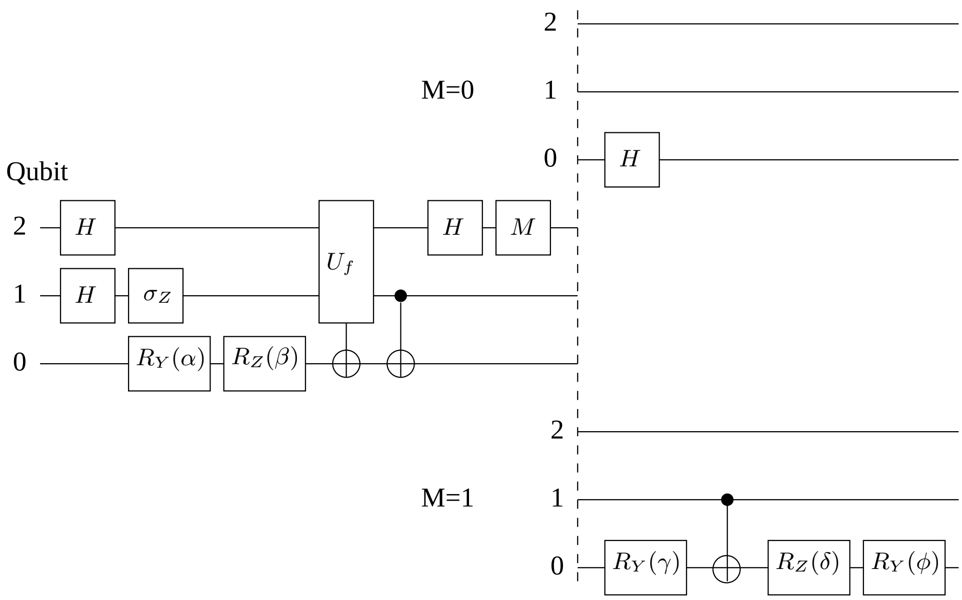

Figure 4: An evolved quantum circuit for the AND-OR$_2$ tree problem: The calculation of $[f(00)ORf(01)]AND[f(10)ORf(11)]$ for an arbitrary Boolean function f needs only one single evaluation of f, having a maximum error of about 0.28. Thus, this quantum algorithm is better than any classical Monte-Carlo algorithm.

Within the framework of the *quantum computing* project, a GP system for the evolution of quantum algorithms was developed. Already simple algorithms with a few qubits could be evolved, among them a quantum circuit for the AND-OR-tree problem (figure 4). Another important aspect is the scalability of algorithms. The simulation of quantum algorithms on a classical computer is calculationally expensive for very few qubits already. Thus, the analysis of the algorithmic structure has to show, whether the algorithms can be extended for an arbitrary number of input qubits.

Since October 2001 the Chair of Systems Analysis participates in a cooperation with the Dept. of Physics in the program *Materials and Concepts for Quantum Information Processing*, which is funded by the Deutsche Forschungsgemeinschaft (DFG). It is intended to analyze quantum algorithms and to evolve new algorithms using genetic programming, especially for the NMR experiments of the Dept. of Physics.

2.11 Bioinformatics

Contact: Udo Feldkamp and Christoph Richter

The necessity for research in bioinformatics has grown rapidly during the past decade, as projects like the *Human Genome Project* are yielding more and more biological data. At this point the purpose of bioinformatics is to handle and analyze the huge amount of data and, more than that, also to gain new information from these data.

At the Chair of Systems Analysis two current focal points of bioinformatics research are found in the fields of sequence analysis and sequence design. The comparison of newly gathered data with sequences already available in databases is a very important aspect of sequence analysis. Because of the immense amount of data to be processed, flexible and fast algorithms are absolutely necessary. The aim of a survey of data structures, which seem to be suitable, is to find improved techniques for this comparison of sequences. Complementary to sequence analysis is the field of sequence design. Applications for this field are found for instance in DNA computing and in the design of DNA microarrays, which are in turn used in genomics. Various tools and methods for sequence design have been developed at the Chair of Systems Analysis.

2.12 Automatic optimization of selected chemical processes

Contact: Michael Emmerich and Dr. Thomas Bäck

In the production of intermediate products in the chemical industry, on one hand many requirements for the product quality have to be met, on the other hand a high efficiency of the processes must be achieved. Competition imposing growing pressure on production cost in this industry, the above mentioned targets have to be achieved within shortening time spans.

Today, many processes in the process industries are designed and controlled by empirical knowledge and/or by short-cut calculations. While the former method is often very time and cost expensive, the latter is often too imprecise. To catch up with the increased difficulty, i.e. low error-tolerance, short development times and low production cost, the importance of numerical simulation increases. Today, powerful simulation methods enable the precise estimation of the characteristics of intermediate products under given settings of the process parameters. Usually, processes and therefore also their models have many control variables that determine the performance of the process and the quality of the products. Optimization methods based on simulations aim at finding optimal settings for these parameters. Until today, this kind of process optimization is done manually by simple but time consuming trial-and-error methods (based on the engineers' experiences) or more systematically by DoE techniques (Design of Experiments).

In this project robust strategies for the automatic optimization of chemical process units are developed. By establishing such methods, shorter development intervals and a significantly higher productivity and quality concerning the intermediate products can be achieved. This strategy can contribute in an early stage to the optimization of the whole production system. For this purpose more or less general numerical and stochastic optimization methods are utilized, adopted and validated.

The approach works with simulator-based optimization routines, thereby focusing on modern search strategies, like robust gradient methods, or direct search methods like evolutionary algorithms, which have proven to be useful for tackling difficult nonlinear optimization problems. In particular, methods for dealing with time expensive evaluations on parallel computer systems are selected and/or improved for the given task.

The automatic optimization technique is applied for several test-cases. One of these test cases is the production of high purity silicon within the Siemens C crystallization process. Moreover, the methodology is applied to several similar processes, which are provided by industrial companies. The optimization of these processes is done in close cooperation with these companies.

2.13 Organic evolution and evolutionary algorithms: Using further evolutionary principles

Contact: Karlheinz Schmitt

Evolution is nature's way of solving problems, or better: of striving for new chances. But this way is not a single, compact path only constructed by mutation, selection and recombination. In this project, we focus attention on the manifold of subpaths and their crossways in evolution.

The primary aim of this project is to extract and transfer essential evolutionary principles in order to improve the design of evolutionary algorithms. First of all, we have to understand the spirit of natural principles. For example, gene deletion and gene duplication with suitable data structures can be used for structural and variable-dimensional optimization. But also more special features observed from particular species can help. Some types of bacteria (i.e. Escherichia coli) are able to live in ever changing environments. Working with *stress-dependent mutation rates*, the bacteria are able to cope with a moving target.

Based on application-specific evolutionary algorithms, the long-term goal is finding design rules for EA that can be generalized.

2.14 DREAM — Distributed resource evolutionary algorithm machine

Contact: Mike Preuß

The project is funded by the European Union (EU) and aims at creating a framework for using available computing power of machines distributed on the Internet for applications from the domain of evolutionary computation. Utilizing the DREAM framework, parallelized evolutionary algorithms are

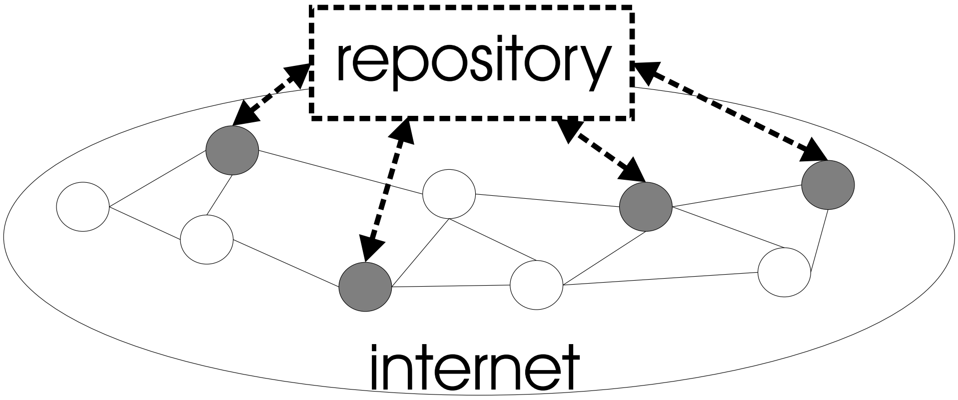

Figure 5: A schematic illustration of the DREAM network.
The computers represented by dark circles cowork on a common task and utilize a virtual shared memory (repository) provided by the DREAM-software.

applied e.g. to scheduling problems and as machine learning methods.

The approach chosen utilizes 'cutting edge' peer2peer technology in contrast to many existing systems that are based on a client-server model (figure 5). Therefore, no special (server) nodes exist. It is up to the applications to set up rôles for the different nodes. Applications themselves are implemented as autonomous agents, being able to self-replicate, move through the network and start up new agents. These design decisions hopefully guarantee scalability of the DREAM platform up to an infinite number of machines. Evolutionary algorithms are well suited to this environment because they are very robust in a sense that e.g. network traffic synchronization is not mandatory, and even malfunction of a remote co-worker does not pose a problem to the optimization. Therefore, application of the DREAM platform is expected to not only result in a performance boost, but it also promotes significant improvement of the existing parallelization methods for evolutionary algorithms.

Research done within the project targets at the investigation and improvement of existing peer2peer networking technology as well as the development of improved parallel evolutionary algorithms and their application to problems with high resource requirements.

Additionally, an extensive library is provided to support application developers, especially those from the field of evolutionary computation.

Apart from the University of Dortmund, five other European institutions take part in the project at the moment: Napier University (Edinburgh), École Polytechnique (Paris), Vrije Universiteit Amsterdam, Universidad de Granada, and Southbank University (London).

2.15 Optimization of electronic circuit designs

Contact: Thomas Beielstein, Christian Feist, and Marc Pompl

The growing demand for high performance mobile electronic systems with enhanced battery lifetime requires the design of fast integrated circuits with very low power consumption. In cooperation with the Chair of Microelectronics at the University of Dortmund, the capabilities of different design choices were analyzed.

We investigated different (multi-)objective functions, e.g. power dissipation, signal delay, chip area, etc., that represent global, high-dimensional optimization problems. Multi-objective optimization evolutionary algorithms (MOEA) have been considered as promising approaches for these complex problems.

During the last decades, many MOEA have been developed. Depending on the underlying fitness functions, these algorithms behave differently. Thus, for many optimization practitioners the following question might be of great importance: *What is the best MOEA for my specific optimization problem?*

Although some MOEA are able to adapt their strategy parameters during the optimization process, there remain some algorithm specific parameters that have to be selected before the optimization goes on, e.g. the particular algorithm used (plus- or comma-strategy), the population size, or the selection strength.

Based on statistical design of experiments (DoE) methods, our approach supports the optimization practitioner to select an appropriate MOEA for his specific problem.

For an additional analysis of this kind of tasks, the project group 419 *Multi-Objective Optimization Using Evolutionary Algorithms* (starting with the summer term 2002) will be established.

2.16 Particle swarm optimization

Contact: Thomas Beielstein

The term *swarm intelligence* is used to describe algorithms and distributed problem solvers that are inspired by the collective behavior of animal societies like insect colonies, schools of fish, or flocks of birds. Under this prism, particle swarm optimization (PSO) is a collective intelligence method for solving optimization problems.

A particle can be represented by two vectors describing its position and its velocity vector. The swarm is manipulated according to two equations that depend on several parameters such as the *inertia weight*, the *cognitive* and the *social* parameter. The inertia weight parameter regulates the trade–off between the global (wide–ranging) and the local (nearby) exploration abilities of the swarm and is considered critical for the PSO's convergence behavior. Regarding different parameter settings, there are currently only rule-of-thumb recommendations available.

In cooperation with Prof. Vrahatis (Artificial Intelligence Research Center UPAIRC of the University of Patras), we are developing methods to improve the search behavior of PSO. Since PSO and evolutionary algorithms (EA) are based on common principles, it might be interesting to develop a theoretical framework to enable the comparison and analysis of PSO and EA. A detailed investigation of PSO and EA may give the practitioner valuable hints for selecting an appropriate algorithm for his specific optimization task.

2.17 Elevator group controller optimization

Contact: Thomas Beielstein

In cooperation with Fujitec Co., Ltd. (Japan) and NuTech Solutions GmbH (Germany), an elevator group control optimization problem is investigated. The elevator group control task is a real-time optimization problem of allocating elevator cars to passengers requesting service. Although it has been investigated for many decades, it is still an open research problem. The main difficulties lie in the stochastic nature of passenger arrivals, and in the combinatorial explosion of system states with the number of cars and floors. There are many proposed control methods, but because of the huge varieties concerning buildings, traffic patterns, and elevator systems, the published results cannot be compared directly, and their critical evaluation is difficult.

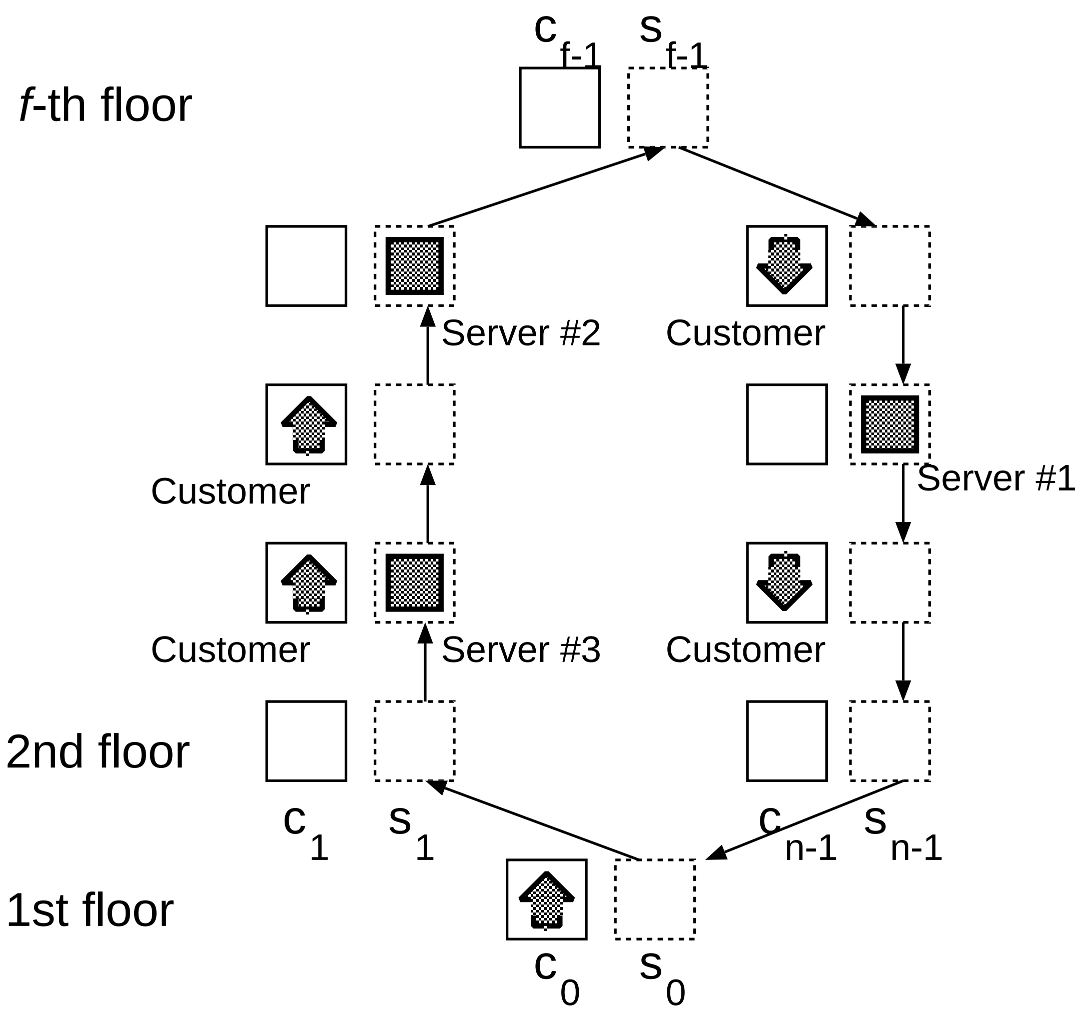

Figure 6: The S-ring as a simplified elevator system.

We investigate a closely related artificial problem, the so-called *S-ring model*. The S-ring has properties that make it useful for an analysis of an elevator group control simulation (figure 6):

- It can be solved exactly for small problem sizes, while still exhibiting non-trivial dynamics.
- It retains interesting properties of the elevator system.
- It has a problem complexity similar in order to the elevator problem.

Since the S-ring is easily reproducible, other researchers should be able to compare their work with our results. Therefore, the S-ring can be used as a benchmark problem.

We developed and analyzed an improved selection mechnism for evolutionary algorithms: *threshold selection* (TS). TS can be applied to any stochastically disturbed fitness function and it has been applied to the S-ring, successfully.

3 Networks and technical committees

3.1 EvoNet

The international *Network of Excellence* (NoE) EvoNet (Evolutionary Computation Network) is part of the essential activities of the 4th and 5th framework program of the European Union (EU). This program aims at promoting research and innovation within the EU. Research teams – the members and nodes of an NoE – co-ordinate their research and teaching activities in order to reach long-term goals.

EvoNet came into existence in 1995. The Chair of Systems Analysis and ICD–CASA belong to the central managing nodes of EvoNet. Currently, about 50 universities, other research institutes, and well-known companies from 18 European countries as well as from the U.S.A. and Japan belong to this network.

EvoNet's primary objectives are

- the co-ordination of the basic and application-oriented research done by the members,
- offering better solutions for complex real-world problems, and
- the promotion of technology transfer from research into industry.

Among others, EvoNet supports two working groups, one for *genetic programming* and one for *dynamic optimization problems*, both being led by members of the Chair of Systems Analysis. More information is available at `http://evonet.dcs.napier.ac.uk/` .

3.2 INGENET

INGENET, a *thematic network* (TN) funded by the European Union, has been set up by the Directorate General XII in November 1997. Its complete title is: *Networked industrial design and control applications using genetic algorithms and evolution strategies.*

Twelve industrial partners, mainly working in the fields of fluid dynamics, acoustics, structure mechanics, electromagnetics, automatic control, and energy, as well as eleven academic partners from eight countries are involved. The Informatik Centrum Dortmund (ICD) serves as one of the six kernel nodes. The main goal of INGENET is to stimulate the dissemination of innovative methodologies based on evolutionary computation in Europe.

Since 1997, INGENET participates in the organization of the biennial *European short course on genetic algorithms and evolution strategies* (EUROGEN). The following events have already taken place:

- EUROGEN 1995 at Las Palmas de Gran Canaria, Spain
- EUROGEN 1997 at Trieste, Italy
- EUROGEN 1999 at Jyväskylä, Finland
- EUROGEN 2001 at Athens, Greece

More information is available at `http://ingenet.ulpgc.es/` .

3.3 GMA committee of experts in neural networks and evolutionary algorithms

The Society for Measurement and Automation Technology (*Gesellschaft für Mess- und Automatisierungstechnik*, GMA) of the Association of German Engineers (*Verein Deutscher Ingenieure*, VDI) and the Association of German Electrical Engineers (*Verein Deutscher Elektrotechniker*, VDE) has been offering a forum for exchange of experience and knowledge transfer in the fields of measurement, control, and automation technology since 1973.

The GMA committee of experts in *neural networks* and *evolutionary algorithms* was founded in 1991. It supports

- discussions between industry, university, and research institutes,
- exchange of experience of its members,
- industrial transfer, and
- communication with other committees.

Due to its heterogeneous composition of experts from industry, academia, and research institutes, it is a competent partner in the areas of neural networks and evolutionary algorithms.

Prof. Schwefel was appointed member of this committee in 1997. Its name and range of topics were extended by *evolutionary algorithms* at that time. Together with the GMA committee of experts in fuzzy control, a symposium on *Computational intelligence — neural networks, evolutionary algorithms, fuzzy control — in industrial use* was organized at Berlin in March 1998. The second event of that type took place at Baden-Baden in May 2000 in cooperation with the German Society for Informatics (Gesellschaft für Informatik, GI). More information is available at `http://wwwhni.uni-paderborn.de/sct/GMA/` .

4 Hardware resources

The equipment needed for the experimental work performed by the working groups is a local area network (LAN) comprising 44 Sparc workstations and 14 Linux workstations. Additionally, eight file servers provide all workstations with user data and utilities.

In order to use idle CPU power and to improve computing resource accessibility, thus increasing job throughput on all workstations, a load sharing and distributed batch-queuing software resides on all workstations. In parallel, this system schedules all jobs such as parameter studies and other computer-aided tests of techniques and applications performed at the chair.

For the development and exploration of parallel algorithms, there are two systems available, additionally:

- A separate SUN workstation cluster with 10 dual-processor computers connected via a Fast-Ethernet Switch.
- A supercomputer, an Origin 2000 from Silicon Graphics with 16 processors MIPS R10000/250 MHz and 2 GB shared memory, which has been provided for the Collaborative research center SFB 531.

Additionally, we sometimes use an IBM 9076 POWERparallel System with 30 computing nodes for parallel computations. This machine is residing at the Computing Center of the University of Dortmund.

5 Our team 2000–2001

5.1 University teachers

Prof. Dr. Hans–Paul Schwefel
Prof. Dr. Wolfgang Banzhaf
Prof. Dr. Thomas Bäck
PD Dr. Hans–Georg Beyer

5.2 Teaching and research associates

Dr. Dirk Arnold
Thomas Beielstein (from 3/00)
Markus Brameier
Jens Busch
Markus Conrads
Dr. Peter Dittrich
Oliver Dolezal (1/01 – 11/01)
Michael Emmerich
Udo Feldkamp (from 1/00)
Ralf Garionis
Ulrich Hammel (until 05/00)
Wolfgang Kantschik
Christian Lasarczyk (from 4/02)
André Leier (from 4/00)
Boris Naujoks
Jens Niehaus
Mike Preuß
Andreas Reinholz
Christoph Richter (from 4/00)
Dr. Günter Rudolph (until 5/01)
Karlheinz Schmitt (from 11/00)
Lutz Schönemann
Martin Schütz (until 5/01)
Pietro Speroni di Fenizio (2/00 – 2/01)
Ralf Stadelhofer (from 11/01)
Dr. Dirk Wiesmann
Jörg Ziegenhirt (until 12/00)
Jens Ziegler

5.3 Student assistants

Hassan Abu Raya (until 7/00)
Oliver Brühl (until 9/01)
Christian Düntgen (until 6/01)
Kai Engel (until 6/01)
Marco Erling (from 10/00)
Christian Feist
Peter Fricke (6/00 – 3/01)
Roderich Groß (until 12/00)
René Hoferichter
Dirk Hoppe

Rafael Hosenberg
Frank Rainer Kalthoff (until 6/00)
Andreas Klapschus
Jörn Kleene (until 3/01)
Martin Kleefeld (from 11/01)
Ahmet Koç
Torsten Kohlen
Christian Kuck (from 02/00)
Stefan Kusper (until 6/01)
Philipp Limbourg (from 1/01)
Veruschka Link (until 1/00)
Patrick Matters (from 10/01)
Martin Michalak (from 7/01)
Walter Nowak (2/01 – 5/01)
Marc Pompl
Mutlu Özdemir
Marc Pompl
Christian Reichmann (until 2/00)
Tina Schmitte (1/00 – 12/01)
Bastian Schmitz (6/00 – 3/01)
Peter Schmutter (from 1/01)
Andre Skusa
Christian Varcol (from 8/01)
Martin Villwock
Martin Wenig (6/00 – 3/01)

5.4 Technical and administrative staff

Maria Bayer-Botero (from 12/01)
Heike Bracklo (until 7/00)
Ulrich Hermes
Gundel Jankord

5.5 Members emeriti

- Dr. Ivan Campos-Pinto (1987-1989) (DAAD grantee)

  at present: Head of software development, Banco Sud Americano, Santiago de Chile

- Dipl.-Inform. Oliver Dolezal (2001)

  at present: Research associate, Montantechnik, Lünen

- Prof. Dr. Dr. Pierre Frankhauser (1992)

  at present: Professor at the Université de Franche-Comté, Institut de Recherche et d'Analyse des Dynamiques Economiques et Spatiales, Besançon, France

- Dipl.-Inform. Jeanine Graf (1994-1996)

- Dipl.-Inform. Ulrich Hammel (1985-2000)

  at present: Senior partner, NuTech Solutions GmbH, Dortmund

- Dipl.-Inform. Frank Hoffmeister (1985-1993)
  at present: Manager internet services, Colt Telecom GmbH, Frankfurt
- Dipl.-Inform. Robert E. Keller (1993-1999)
  at present: Scientific assistant, University of Leiden, The Netherlands
- Dr. Frank Kursawe (1988-1998)
  at present: Senior manager, NuTech Solutions GmbH, Dortmund
- Dr. Martin Mandischer (1993-1999)
  at present: Research associate, BROCKHAUS Software & Consulting AG, Dortmund (Lünen)
- Dr. Peter Nordin (1994-1996)
  at present: Associate professor, Chalmers University, Gothenburg, Sweden
- Dr. Irfan E. Oyman (1995-1999)
  at present: Research associate, SchlumbergerSema Engineering, Dreieich
- Dr. Ernst Peters (1986-1991)
  at present: Director of production, Springer-Verlag, Heidelberg
- Dipl.-Biol. Hilmar Rauhe (1996-1999)
  at present: Manager, Informium AG, Cologne
- Dr. Günter Rudolph (1989-2001)
  at present: Product development at Parsytech, Aachen
- Dipl.-Inform. Martin Schütz (1994-2001)
  at present: Senior manager, NuTech Solutions GmbH, Dortmund
- MSc. math. Pietro Speroni di Fenizio (2000-2001)
- Dr. Joachim Sprave (1992-1999)
  at present: Scientific coworker, DaimlerChrysler, Berlin
- Dipl.-Inform. Jörg Ziegenhirt (1998-2000)
  at present: Senior developer, NuTech Solutions GmbH, Dortmund

Part II

Facts 2000–2001

1 Educational activities

ST: summer term, WT: winter term

1.1 Lectures (with exercises) and courses

WT 1999/00	Systems analysis II [Schwefel] Systems analysis — exercises [Schönemann] Introduction to genetic programming [Banzhaf] Introduction to genetic programming — exercises [Ziegler]
ST 2000	Systems analysis [Banzhaf] Evolutionary algorithms — an introduction [Beyer] Introduction to UNIX [Beielstein, Garionis, Rupflin] Sabbatical [Schwefel]
WT 2000/01	Introduction to genetic programming [Banzhaf] Introduction to genetic programming — exercises [Feldkamp] Introduction to UNIX [Beielstein, Garionis] Sabbatical [Schwefel]
ST 2001	Systems analysis [Schwefel] Systems analysis — exercises [Schmitt] Autonomous robots [Banzhaf, Marwedel, Müller, Reusch] Computational intelligence [Banzhaf] Evolutionary algorithms — an introduction [Beyer] Introduction to UNIX [Beielstein, Garionis]
WS 2001/02	Technical optimization [Schwefel] Computer organization A [Banzhaf, Marwedel] Computer organization B [Banzhaf, Marwedel] Computer organization — exercises [Feldkamp a.o.] Introduction to UNIX [Beielstein, Garionis]

1.2 Seminars

WT 1999/00	Socionics [Banzhaf, Dittrich]
ST 2000	Artificial life [Banzhaf]
WT 2000/01	Programmable molecules [Banzhaf]
ST 2001	Small-world networks [Banzhaf]
WT 2001/02	Metaheuristics for optimization [Schwefel]

1.3 Project groups

WT 1999/00 - ST 2000	GenScha	Evolution of GP agents with a knowledge of chess and their integration in a computer chess system [Busch, Kantschik]
WT 2000/01 - ST 2001	SIGEL	Simulation and visualization of GP-evolved control programs for arbitrary legged robots [Busch, Ziegler]
WT 2001/02 - ST 2002	ROBOCUP	Sony legged league: Design and implementation of a modular control architecture for a team of soccer playing walking robots [Ziegler, Dahm]

1.4 Academic self-organization

Wolfgang Banzhaf :
Member of the department's budget and structure committee (since 1996; since 1999 deputy chairman)

Jens Busch :
Coordinator of the department's open house (since 2000)

Michael Emmerich :
Subject adviser for applied computer science students (since 2001)

Ulrich Hammel :
Lecture hall administrator for the department (1994–2000)

Hans–Paul Schwefel :
Vice rector for research and junior scientists of the University of Dortmund (1998–2000)
Member of the review committee of the University of Dortmund (1998–2000)
Member of the faculty council (since 2001)

Jens Ziegler :
Subject adviser for applied computer science students (1999–2000)

2 Guests

- Dr. D. Mester, Informational Databank & Business Network Ltd. and Technion, Haifa, Israel, November 1999–January 2000
(sponsored by the Collaborative research center SFB 559)
- Prof. Dr. K. Deb, Indian Institute of Technology, Kanpur, India, February 2000
(sponsored by the Collaborative research center SFB 531)
- Dr. A. Ghosh, Indian Statistical Institute, Calcutta, India, March 2000
- Dr. L. Kallel, Centre de Mathematiques Appliques, École Polytechnique, Paris, April 2000
(sponsored by the Collaborative research center SFB 531)
- Prof. Dr. P. Bock, George Washington University, Washington D.C., May 2000 (sponsored by the Collaborative research center SFB 531)
- Prof. Dr. T. Bossomaier, Charles Sturt University, Bathurst, Australia, July 2000
- F. Schmitt, University of Bayreuth, October 2000
- Dipl.-Ing. G. Krismanic and Dipl.-Ing. L. Mehnen, Technical University of Vienna, October 2001
(sponsored by the Collaborative research center SFB 531)
- Prof. Dr. M. N. Vrahatis and Math. K. Parsopoulos, M.Sc., University of Patras, Greece, November-December 2001
(sponsored by the Collaborative research center SFB 531)

3 Co-organized conferences

- Dagstuhl-Seminar *Theory of Evolutionary Algorithms*, February 13–18, 2000, Schloss Dagstuhl near Saarbrücken
- Third Int'l Workshop *Frontiers in Evolutionary Algorithms* (FEA 2000), Febr. 27 – March 3, 2000, Atlantic City NJ
- Int'l Workshop *Evolutionary Computation*, April 3–7, 2000, Wuhan, China
- Third European Workshop on *Genetic Programming* (EuroGP 2000), April 15–16, 2000, Edinburgh
- EvoNet Workshops, April 17–19, 2000, Edinburgh
- Third *Int'l Conf. Evolvable Systems: From Biology to Hardware* (ICES 2000), April 2000, Edinburgh
- *Adaptive Computing in Design and Manufacture* (ACDM 2000), April 26–28, 2000, Plymouth, U.K.
- GI and VDI/VDE-GMA Conf. *Computational Intelligence, Fuzzy Systems, Neuronale Netze, Evolutionäre Algorithmen, Data Mining — im industriellen Einsatz*, May 11–12, 2000, Baden-Baden
- Sixth Int'l Meeting *DNA Based Computers* (DNA6), June 13–17, 2000, Leiden, The Netherlands
- Second *Genetic and Evolutionary Computation Conf.* (GECCO 2000), July 8–12, 2000, Las Vegas NV
- *Congress on Evolutionary Computation* (CEC 2000), July 16–19, 2000, La Jolla CA
- Sixth Symposium *Foundations of Genetic Algorithms* (FOGA 6), July 21–24, 2000, Charlottesville VA
- Seventh Int'l Conf. *Artificial Life* (ALIFE VII), August 2, 2000, Portland OR
- Ninth Int'l Colloquium *Numerical Analysis and Computer Sciences with Applications*, August 12–17, 2000, Plovdiv, Bulgaria
- Int'l Symposium *Computational Intelligence*, September 6–9, 2000, Košice, Slovakia

- Int'l Conf. *Evolutionary Computation*, Sixth Int'l Conf. *Parallel Problem Solving from Nature* (PPSN VI), September 16–20, 2000, Paris
- WSES Conf. *Evolutionary Computation* (EC 01), February 11–15, 2001, Teneriffa
- First Int'l Conf. *Evolutionary Multi-Criterion Optimization* (EMO'01), March 7–9, 2001, Zurich
- Int'l Symposium *Adaptive Systems* (ISAS 2001), March 19–23, 2001, Habana
- EvoNet Workshops, EuroGP 2001, April 18–20, 2001, Lago di Como, Milan, Italy
- *Congress on Evolutionary Computation* (CEC 2001), May 27–20, 2001, Seoul
- Third Int'l Conf. *Optimisation in Industry*, June 17–22, 2001, Il Ciocco Resort, Tuscany, Italy
- Int'l Conf. *Artificial Intelligence* (IC-AI 2001), June 25–28, 2001, Las Vegas NV
- Third *Genetic and Evolutionary Computation Conf.* (GECCO 2001), July 7–11, 2001, San Francisco CA
- WSES/IEEE Conf. *Neural, Fuzzy and Evolutionary Computation*, July 8–15, 2001, Rethymno, Crete
- Curso de Verano de El Escorial *Encuentro sobre Computación Natural*, August 6–8, 2001, Universidad Complutense de Madrid
- Sixth *European Conf. Artificial Life* (ECAL 2001), September 10–14, 2001, Prague
- *Evolutionary Methods for Design, Optimisation, and Control with Applications to Industrial Problems* (EUROGEN'01), September 19–21, 2001, Athens
- Dortmunder *Fuzzy-Tage*, October 1–3, 2001, Dortmund
- *Evolution Artificielle* (EA'01), October 28–30, 2001, Le Creusot, France

4 Further activities

4.1 Awards

- Grant of the Graduiertenkolleg GK 726 *Materials and Concepts for Quantum Information Processing*, University of Dortmund, for two years to André Leier and Ralf Stadelhofer, 2001

4.2 Memberships

- **AFN**: Arbeitsgemeinschaft Fuzzy-Logik und Softcomputing Norddeutschland [Working Group on Fuzzy Logic and Soft Computing, Northern Germany] (Thomas Bäck and Hans–Paul Schwefel)
- **ACM**: Association for Computing Machinery (Wolfgang Banzhaf)
- *Artificial Life*, Int'l Journal, The MIT Press, Cambridge MA (Wolfgang Banzhaf: co-editor)
- *Applied Soft Computing*, Int'l Journal, Elsevier, Amsterdam (Wolfgang Banzhaf: co-editor)
- *BioSystems*, Journal of Biological and Information Processing Sciences, Elsevier, Amsterdam (Hans–Paul Schwefel: co-editor)
- *Complexity International*, A Hypertext Electronic Journal (Wolfgang Banzhaf: member of the advisory board)
- **ESMTB**: European Society for Mathematical and Theoretical Biology (Hans–Paul Schwefel)
- *Evolutionary Computation*, Int'l Journal, The MIT Press, Cambridge MA (Thomas Bäck: associate editor; Hans–Paul Schwefel: member of the editorial board)
- **EPS**: Evolutionary Programming Society, San Diego CA (Thomas Bäck)
- *Genetic Programming and Evolvable Machines*, Kluwer Academic Publishers, Norwell MA (Wolfgang Banzhaf: editor)
- **GI**: Gesellschaft für Informatik [German Society for Informatics] (Wolfgang Banzhaf, Ulrich Hammel and Christoph Richter)

- **GTBB**: Gesellschaft für Technische Biologie und Bionik [Society for Technical Biology and Bionics] (Hans–Paul Schwefel)
- *Handbook of Evolutionary Computation*, Oxford University Press, New York (Thomas Bäck: editor-in-chief; Günter Rudolph: member of the editorial board; Hans–Paul Schwefel: member of the advisory board)
- **ICD**: Informatik Centrum Dortmund
(Hans–Paul Schwefel: head of the board of trustees;
Wolfgang Banzhaf: member of the board of directors)
(Thomas Bäck: Managing director of the department **CASA-A** [Center for Applied Systems Analysis])
(Wolfgang Banzhaf: Group leader **CASA-B**)
- **IEEE**: The Institute of Electrical and Electronics Engineers (Thomas Bäck, Günter Rudolph, and Hans–Paul Schwefel)
- *IEEE Transactions on Evolutionary Computation* IEEE Press, Piscataway NJ (Thomas Bäck, Hans–Georg Beyer, Günther Rudolph, and Hans–Paul Schwefel: associate editors)
- **IIASA**: International Institute for Applied Systems Analysis, Laxenburg near Vienna, Austria, (the University of Dortmund, represented by Hans–Paul Schwefel, is member of the German Association for the Advancement of IIASA)
- **ISCB**: International Society for Computational Biology (Wolfgang Banzhaf)
- **ISGA**: International Society of Genetic Algorithms (Hans–Paul Schwefel: elected member of the council)
- **ISGEC**: International Society of Genetic and Evolutionary Computation (Wolfgang Banzhaf: member of the council)
- *Journal of Advanced Computational Intelligence*, Fuji Technology Press, Japan (Thomas Bäck: member of the editorial board)
- *Journal of Natural Computing*, Kluwer Academic Publishers
(Thomas Bäck: *Area Editor* Evolutionary Computation;
Hans–Paul Schwefel: member of the editorial board)
- **MCDM**: International Society on Multiple Criteria Decision Making (Hans–Paul Schwefel)

- *Natural Computing Series*, Springer Verlag, Berlin
(Thomas Bäck: member of the editorial board;
Hans–Paul Schwefel: member of the advisory board)

- **NVTI**: Nederlandse Vereniging voor Theoretische Informatica [Dutch Association for Theoretical Computer Science] (Thomas Bäck)

- **SIAM**: Society for Industrial and Applied Mathematics
(Günter Rudolph)

- **SZF**: Schweizerische Vereinigung für Zukunftsforschung
[Swiss Association for Futures Research] (Hans–Paul Schwefel)

4.3 External cooperations

- National University of Athens, Laboratory of Technical Turbomachinery (Prof. Dr.-Ing. K. Giannakoglou)

- Institut IRADES, Université de Franche-Comté, Besançon, France (Prof. Dr. Dr. P. Frankhauser)

- Rijksuniversiteit te Leiden, The Netherlands, Leiden Institute for Advanced Computer Science (LIACS) (Prof. Dr. J. N. Kok)

- University of Patras, Greece, Artifical Intelligence Research Center (UPAIRC) (Prof. Dr. M. N. Vrahatis)

- Stockholm University, Dept. of Sociology (Prof. Dr. P. Hedström)

- University of North-Carolina, Charlotte NC, Dept. of Computer Science (Prof. Dr. Z. Michalewicz)

- University of Illinois, Urbana-Champaign IL, Dept. of General Engineering (Prof. Dr. D. E. Goldberg)

- Aachener Centrum für Erstarrung unter Schwerelosigkeit e.V. (ACCESS) (Dr. F. Hediger)

- Max Planck Institute for the Research on Economic Systems, Jena (Prof. Dr. U. Witt)

- Fraunhofer Institute for Environmental, Safety, and Energy Technology UMSICHT, Oberhausen (Prof. Dr. R. Kümmel)

- German National Research Centre of Mathematics and Computer Sciences (GMD), St. Augustin (Dr. H. Mühlenbein)
- Aachen University of Technology RWTH, Institute of Technical Thermodynamics (Prof. Dr. K. Lucas)
- Technical University of Berlin, Section for Bionics and Evolutionary Techniques (Prof. Dr. I. Rechenberg)
- Ruhr-University Bochum

  Faculty of Civil Engineering (Prof. Dr. D. Hartmann)

  Institute for Neuro–Informatics (Prof. Dr. W. v. Seelen)

  Institute for Neuro–Physiology (Dr. F. Wörgötter)
- University of Cologne, Institute for Genetics (Prof. Dr. J. Howard)
- FernUniversität-GHS Hagen (Prof. Dr. U. Schimank)

5 Working results

5.1 Diploma theses

[1] Dominic Heutelbeck. Genetische Programmierung und das minimal consistent OBDD Problem mit Optimierung der Variablenordnung, May 2000.

[2] Jochen Hagemann. Exploration von Laufverhaltensweisen auf Roboterplattformen, May 2000.

[3] Dimitri Knjazew. Application of fast messy genetic algorithms to permutation and scheduling problems, June 2000. In cooperation with the University of Illinois, Urbana-Champaign IL.

[4] Oliver Dolezal. Lernen eines Weltmodells für einen Random Morphology Robot, July 2000.

[5] Georg Conrads. Klassifikation von EEG-Signalen mit genetischer Programmierung, September 2000.

[6] Karlheinz Schmitt. Gendeletion und Genduplikation in evolutionären Algorithmen, October 2000.

[7] Marco Wörmann. Untersuchungen zum Einfluss der maximalen Lebensdauer auf das Konvergenzverhalten evolutionärer Algorithmen, October 2000.

[8] Claus-Peter Ewald. Design, Entwicklung und Evaluation eines allgemeinen Clusteringservices für Text im R/3 Umfeld, October 2000.

[9] Johannes Levermann. Entwicklung eines spieltheoretischen Lernalgorithmus für das Spiel Poker mit neuronalen Netzen, November 2000.

[10] Frank Grürmann. Beschreibung des Partikelflusses beim Drehprozess mit Hilfe symbolischer Regression und genetischem Programmieren, November 2000. In cooperation with the Faculty of Mechanical Engineering, Institute for Production Engineering, University of Dortmund.

[11] Sven Jansen. Untersuchung über die Eignung verschiedener Geschlechter für die Restriktionsbehandlung in Evolutionsstrategien, December 2000.

[12] Winfried Thieme. Dynamische Nachbarschaftsstrukturen in parallelen evolutionären Algorithmen, February 2001. In cooperation with the Faculty of Mechanical Engineering, Institute for Production Engineering, University of Dortmund.

[13] Jörn Kleene. Nichtlineare Modellierung von Zeitreihen mit Hilfe von evolutionären Algorithmen, March 2001.

[14] Markus Heller. Berechnung approximierender Triangulationen mittels evolutionärer Algorithmen, April 2001. In cooperation with the Faculty of Mechanical Engineering, Institute for Production Engineering, University of Dortmund.

[15] Karsten Hörmann. Entwicklung eines Konzeptes zur Klassifizierung und zielgerichteten Nutzung historischer Materialstammdaten mit Methoden des Data Mining am Beispiel von SAP, June 2001. In cooperation with the Faculty of Mechanical Engineering, Chair for Plant Organization, University of Dortmund.

[16] Andre Skusa. Simulation von Zellen: Möglichkeiten direkter und abstrakter Modellierung, December 2001.

[17] Keno Albrecht. Entwurf eines applikationsunabhängigen Multiagentensystems als Basis einer internetweiten Evolution schachspielender GP-Individuen, Teil I, December 2001.

[18] Roderich Groß. Entwurf eines applikationsunabhängigen Multiagentensystems als Basis einer internetweiten Evolution schachspielender GP-Individuen, Teil II, December 2001.

5.2 Dissertations

[1] Martin Mandischer. An empirical investigation of neural networks, evolution stragegies, and evolutionary-trained neural networks and their applications to chemical engineering. Dr. rer. nat.–Dissertation, University of Dortmund, Department of Computer Science, Chair of Systems Analysis, June 2000. (Schwefel).

[2] Jörn Mehnen. Evolutionäre Flächenrekonstruktion. Dr. Ing.–Dissertation, University of Dortmund, Faculty of Mechanical Engineering, Institute of Machining Technology, September 2000. (Schwefel).

[3] Thomas P. Runarsson. Evolutionary problem solving. Dr. Ing.–Dissertation, University of Iceland, Reykjavik, Faculty of Engineering, January 2001. (Schwefel).

[4] Peter Dittrich. On artificial chemistries. Dr. rer. nat.–Dissertation, University of Dortmund, Department of Computer Science, Chair of Systems Analysis, January 2001. (Banzhaf).

[5] Dirk Wiesmann. Anwendungsorientierter Entwurf evolutionärer Algorithmen. Dr. rer. nat.–Dissertation, University of Dortmund, Department of Computer Science, Chair of Systems Analysis, November 2001. (Schwefel).

[6] Dirk Arnold. Local performance of evolution strategies in the presence of noise. Dr. rer. nat.–Dissertation, University of Dortmund, Department of Computer Science, Chair of Systems Analysis, November 2001. (Beyer, Schwefel).

5.3 Publications

2000

[1] Alexandru Agapie. Genetic algorithms: Theory and applications. *Int'l Journal of Computing Anticipatory Systems*, **7**:35–44, 2000.

[2] Russell W. Anderson, David B. Fogel, and Martin Schütz. Other operators. In Th. Bäck, D. B. Fogel, and Z. Michalewicz, editors, *Evolutionary Computation 1 – Basic Algorithms and Operators*, pages 308–330. Institute of Physics Publ., Bristol, 2000.

[3] Dirk V. Arnold and Hans-Georg Beyer. Efficiency and mutation strength adaptation of the $(\mu/\mu_I, \lambda)$-ES in a noisy environment. In M. Schoenauer, K. Deb, G. Rudolph, X. Yao, E. Lutton, J. J. Merelo, and H.-P. Schwefel, editors, *Proc. Parallel Problem Solving from Nature – PPSN VI, Paris*, pages 39–48, Springer, Berlin, 2000.

[4] Dirk V. Arnold and Hans-Georg Beyer. Local performance of the $(1 + 1)$-ES in a noisy environment. Technical Report of the Collaborative Research Center 531 *Computational Intelligence* CI–80/00, University of Dortmund, January 2000.

[5] Dirk V. Arnold and Hans-Georg Beyer. Performance analysis of evolution strategies with multi-recombination in high-dimensional R^N-search spaces disturbed by noise. Technical Report of the Collaborative Research Center 531 *Computational Intelligence* CI–94/00, University of Dortmund, September 2000.

[6] Thomas Bäck. Industrial applications of evolutionary algorithms: Case studies. In *Proc. Genetic and Evolutionary Computation Conf. (GECCO 2000) – Tutorial Program*, pages 538–552, Las Vegas NV, 2000.

[7] Thomas Bäck. Introduction to evolutionary algorithms. In Th. Bäck, D. B. Fogel, and Z. Michalewicz, editors, *Evolutionary Computation 1 – Basic Algorithms and Operators*, pages 59–63. Institute of Physics Publ., Bristol, 2000.

[8] Thomas Bäck. Binary strings. In Th. Bäck, D. B. Fogel, and Z. Michalewicz, editors, *Evolutionary Computation 1 – Basic Algorithms and Operators*, pages 132–135. Institute of Physics Publ., Bristol, 2000.

[9] Thomas Bäck. Mutation parameters. In Th. Bäck, D. B. Fogel, and Z. Michalewicz, editors, *Evolutionary Computation 2 – Advanced Algorithms and Operators*, pages 142–151. Institute of Physics Publ., Bristol, 2000.

[10] Thomas Bäck. Self-adaptation. In Th. Bäck, D. B. Fogel, and Z. Michalewicz, editors, *Evolutionary Computation 2 – Advanced Algorithms and Operators*, pages 188–211. Institute of Physics Publ., Bristol, 2000.

[11] Thomas Bäck, Agoston E. Eiben, and Nikolai A. L. van der Vaart. An empirical study on GAs 'without parameters'. In M. Schoenauer, K. Deb, G. Rudolph, X. Yao, E. Lutton, J. J. Merelo, and H.-P. Schwefel, editors, *Proc. Parallel Problem Solving from Nature – PPSN VI, Paris*, pages 315–324, Springer, Berlin, 2000.

[12] Th. Bäck, D. B. Fogel, and Z. Michalewicz, editors. *Evolutionary Computation 1 – Basic Algorithms and Operators*. Institute of Physics Publ., Bristol, 2000.

[13] Th. Bäck, D. B. Fogel, and Z. Michalewicz, editors. *Evolutionary Computation 2 – Advanced Algorithms and Operators*. Institute of Physics Publ., Bristol, 2000.

[14] Thomas Bäck, David B. Fogel, Darell Whitley, and Peter J. Angeline. Mutation operators. In Th. Bäck, D. B. Fogel, and Z. Michalewicz, editors, *Evolutionary Computation 1 – Basic Algorithms and Operators*, pages 237–255. Institute of Physics Publ., Bristol, 2000.

[15] Thomas Bäck and Boris Naujoks. Innovative methodologies in evolution strategies. INGENET Project Report D 2.2, Center for Applied Systems Analysis (CASA), Informatik Centrum Dortmund, January 2000.

[16] Thomas Bäck and Boris Naujoks. State of the art in evolution strategies. In J. Périaux, G. Degrez, and H. Deconinck, editors, *Proc. VKI Lecture Series 2000-07 'Genetic Algorithms for Optimisation in Aeronautics and Turbomachinery'*, pages 1–23, Von–Karman–Institute for Fluid Dynamics, Rhode Saint Genèse, Belgium, 2000.

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[24] Hans-Georg Beyer. Evolutionary algorithms in noisy environments: Theoretical issues and guidelines for practice. *CMAME (Computer Methods in Applied Mechanics and Engineering)*, **186**:239–267, 2000.

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[28] Jens Busch and Wolfgang Banzhaf. The construction of an automated theorem prover based on emergent systems. In K. K. Lai, O. Katai, M. Gen, and B. Liu, editors, *Proc. Second Asia-Pacific Conf. Genetic Algorithms and Applications (AGPA'00)*, pages 132–143, Global-Link, Hong Kong, 2000.

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5.4 Further presentations

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[19] Martin Schütz. Airfoil design optimization (Poster). VDI-VDE-GMA-Fachtagung Computational Intelligence (CI 2000), Baden-Baden, May 11, 2000.

[20] Peter Dittrich. Der komplexe Agent. FernUniversität-GHS Hagen, June 6, 2000.

[21] Peter Dittrich. Integrative Handlungstheorie. Sozionik Workshop, Kloster Seeon/Chiemsee, June 12, 2000.

[22] Udo Feldkamp. A DNA sequence compiler (Poster). Sixth DIMACS Workshop on DNA Based Computers, Leiden, The Netherlands, June 13–17, 2000.

[23] Hilmar Rauhe. Digital DNA molecules (Poster). Sixth DIMACS Workshop on DNA Based Computers, Leiden, The Netherlands, June 13–17, 2000.

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[44] Andreas Reinholz. How to combine grey code and fast function evaluation to accelerate tree search methods like branch and bound. OptTek Systems, Inc., Boulder CO, November 12, 2001.

[45] Andreas Reinholz. Optimization of logistic systems. University of Colorado at Boulder CO, Leeds School of Business, November 28, 2001.

Editorial staff: Dirk Hoppe, Christian Feist, Antje Schwefel
Date: April, 2002

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