Report on the Research at the Institute of Informatics of the University of Szeged

2006–2009

Szeged, 2010

A Short Introduction of the Institute

I. HISTORY AND MISSION

Systematic education in computer science was launched within the Mathematical Institute at the end of the 1950's by László Kalmár. The Institute of Informatics was founded as an independent unit in 1990. The head of the Institute: Prof. Zoltán Fülöp. The deputies of the head: Dr. Éva Gombás (student affairs) and Dr. Károly Dévényi (management).

The Institute consists of five departments and a research group:

- Department of Computational Optimization, head of the department: Prof. Tibor Csendes
- Department of Computer Algorithms and Artificial Intelligence, head of the department: Prof. János Csirik
- Department of Foundations of Computer Science, head of the department: Prof. Zoltán Ésik
- Department of Image Processing and Computer Graphics, head of the department: Dr. Zoltán Kató
- Department of Software Engineering, head of the department: Prof. Tibor Gyimóthy
- Research Group on Artificial Intelligence of the Hungarian Academy of Sciences, head of the research group: Prof. János Csirik

The main activities of the institute are the education and research of modern informatics and computer science knowledge. Here we provide a sketch of our educational programs and research activities.

II. EDUCATION

The institute offers BSc, MSc, MA and PhD degrees. The curricula consist mainly of mandatory courses for undergraduates and a broad spectrum for specialization at graduate level. The curricula have already been adjusted to conform to the so-called Bologna project, embracing most of the topics of modern informatics and computer science.

The informatics/computer science and some of the engineering courses belong to the departments of the Institute of Informatics. The Institute of Mathematics and the Faculty of Economics and Business Administration are responsible for the mathematics and economics courses. The physics courses are taught by the Departments of Physics.

BSC PROGRAMS

Presently we have three programs at undergraduate level: Business Information Technology, Engineering Information Technology, and Software Information Technology.

Business Information Technology, BSc

The normal duration of the program is 7 semesters. The program produces experts who are well versed in the information society, and are able to understand and solve the problems arising in real business processes. They can manage the information technology supporting the business needs, such as to improve on the knowledge base and business intelligence of companies, model the cooperation of info communication processes and technologies, control those processes, identify problems, and develop applications (and also maintain and monitor their quality). Moreover the graduates are equipped by the theoretical basics to continue their studies at MSc level.

Engineering Information Technology, BSc

The normal duration of the program is 7 semesters. The goal of the program is to train computer experts with solid engineering skills. The graduates are expected to install and operate complex systems, especially in the information infrastructure area, and also to plan and develop the data and program system of such systems. This means skills both in hardware and advanced software technology, involving modeling, simulation, performance, reliability, configuration, trouble shooting, maintenance, and development of systems. They are also provided with appropriate basic knowledge to continue their studies at MSc level.

Software Information Technology, BSc

The normal duration of the program is 6 semesters. The graduates are supposed to have high skills in planning and development of company information systems using modern software tools. Furthermore, they are trained in the planning, development and operation of decision support systems, expert systems, and multimedia systems. The graduates also receive firm basis in Computer Science knowledge in order to have suitable knowledge to continue their studies at MSc level.

GRADUATE PROGRAMS

Software Information Technology, MSc

The normal duration of the program is 4 semesters. The goal of the training is to produce informatics/computer science experts who have firm theoretical basis, and they are able to expand their knowledge autonomously in a long run. They can work in teams or on their own, to develop, produce, apply, introduce, maintain, and to service information systems at high level. Furthermore, they possess the necessary cooperation and model making skill that are needed for solving of the informatics problems arising in their fields. They are also able to conduct research work, and to continue their studies at PhD level. There are six offered fields for specializations: Image Processing, Artificial Intelligence, Model Making for Informaticians, Operations Research, Computer Science, and Software Development.

Business Information Technology, MSc

The normal duration of the program is 4 semesters. The goal of the training is to produce experts who are able to understand complex business

processes, to explore the arising problems and work out alternative solutions. They can recognize the surfacing demands that appear while using information systems supporting those processes. They are prepared to develop those and to manage ready-made applications. They possess the necessary skills to coordinate and conduct research and development, and to continue their studies at PhD level.

Teacher of Informatics, MA

The normal duration of the program is 4 or 5 semesters, depending on the number of certifications. The program is based on the previous knowledge of the candidates acquired in BSc or MSc level in informatics. The goal of the training is to produce teachers, who can teach various subjects in informatics, and execute tasks arising at schools in connection of training and development of information and communication technology or research. Furthermore the program prepares the students to continue their studies at PhD level.

PhD program in Computer Science

In addition of the above programs, a doctoral program in Computer Science is available since 1993. The aim of this program is to support graduate studies, leading to the degree of PhD in computer science.

The program was part of the Doctoral School in Mathematics and Computer Science of the Faculty of Science of the University of Szeged till the end of 2008, then a new Doctoral School on Computer Science have been founded.

There are three main research areas in the School: Theoretical Computer Science, Operations Research and Combinatorial Optimization, and Applications of Computer Science. The possible research topics preferably, but not exclusively can be chosen among those parts of computer science and related areas, which are being investigated at the Institute of Informatics. The normal duration of the program is 6 semesters. Students are required to take entrance examinations for the admittance. The State of Hungary usually supports up to 6-7 new fellowships every year that is offered to Hungarian citizens. Foreign students are not entitled for that fellowship, their tuition and other expenses have to be supported from other sources.

III. RESEARCH THEMES AND CO-OPERATIONS

The departments of the Institute conduct research in the following areas.

Department of Computational Optimization

Reliable computing, interval optimization, discrete optimization, PNS problems, extremal graph theory, combinatorial games, and history of mathematics.

Department of Image Processing and Computer Graphics

Image models based on random Markov fields, Parametric estimation of transformations, Higher order active contour models, Analysis of satellite pictures, Digital spatial models. Vectorization of scanned drawings, Computer-Aided surgery. Medical image analysis, Skeletonization by thinning, Image registration, and Discrete tomography.

Department of Foundations of Computer Science

Algebra and logics in computer science, Automata and formal languages. Tree-automata and tree-transducers. Term rewriting systems, and fixed points in computer science. Process algebras, Temporal logics. Structures in computer science: semirings and semi-modules, and categorical algebras.

Department of Computer Algorithms and Artificial Intelligence

Automata theory, Fuzzy theory, Bin packing, Meta heuristics, String matching, On-line algorithms, Machine Learning and Computational Learning Theory, Multi-Criteria Decision Making, Scheduling, Robotics, and Mechatronics.

Department of Software Engineering

Static and dynamic analysis of software systems. Slicing for imperative languages and logical programming. Reverse engineering. Open source software development. Linux file system and GCC compiler optimization. Embedded systems. Ad-Hoc networks. Process synthesis. Optimization problems arising in chemistry, biology and industry.

Research Group on Artificial Intelligence

Machine learning, Computational learning theory. Natural language procession, Language technology, Speech technology, Peer-to-peer algorithms and systems.

Partners

The Institute of Informatics has joint programs and research cooperation (e.g. CEEPUS, SOCRATES/ERASMUS) with the following higher education institutes from North-America, Europe, and Asia.

Canada: University of Waterloo, Canada, Queen's University, Canada.
USA: Boston University, MA, City University of New York, NY, Columbia University, New York, NY, The University of Iowa, Iowa City, IA, University of Illinois at Urbana-Champaign, IL, Stevens Institute of Technology, Hoboken NJ, AT&T Labs.
Austria: Technische Universität Wien, Medizinische Universität Graz, Technische Universität Graz.
Bulgaria: University of Rousse.
Czech Republic: Charles University, Prague.
Denmark: University of Aalborg, The University of Copenhagen.
England: University College London, Coventry University.
Finland: University of Turku, Lappeenranta University of Technology.
France: University of Bordeaux, INRIA, Sophia Antipolis, University of Paris 6 and 7, Université Pierre et Marie Curie.
Germany: Technische Universität Ilmenau, Technische Universität Dresden, Universität Hamburg, Technische Universität München, Universität Erlangen-Nürnberg, Universität Mannheim, Universität Karlsruhe, Universität Stuttgart, Universität Koblenz-Landau.
Greece: Aristotle University of Thessaloniki.
Poland: Uniwersytet Rzeszowski.
Switzerland: University of Bern.
Iceland: Reykjavik University.

Italy: University of Rome La Sapienza, Universita degli Studi di Firenze, Universita Deglie Studi di L'Aquila, and Universita Deglie Studi di Siena.
Netherlands: Technical University of Eindhoven.
Serbia: University of Nis, University of Novi Sad, Institut Mihajlo Pupin, Belgrad.
Slovenia: University of Maribor and Univerza na Primorskem, Koper.
Spain: Universidad de Almeria, Universidad de Tarragona.
Turkey: Bahçeşehir Üniversitesi, Fatih Üniversitesi.
China: Hong Kong University of Science & Technology.
Israel: Ben-Gurion University of the Negev, University of Haifa.
Japan: Kyoto Sangyo University, University of Aizu.

IV. OTHER ACTIVITIES

ACTA CYBERNETICA

A scientific journal, Acta Cybernetica has been published since 1969 by the Institute in English. The journal is available in about 150 university departments worldwide, its homepage is: `www.inf.u-szeged.hu/actacybernetica/starthu.xml`

OTHER SCIENTIFIC SERVICE

Several members of the faculty work as editors in international scientific journals; they play significant roles in major scientific organizations and serve in program committees of major conferences.

Some of those journals: Acta Cybernetica, Central European Journal of Operations Research, Grammars, IEEE Transactions on Image Processing, Informatica, Pure Mathematics and Application, Theoretical Computer Science, Theoretical Informatics and Applications, Optimization Letters, and Oriental J. of Mathematics.

Organizations in which the Institute is represented: European Association for Theoretical Computer Science, European Association for Computer Science Logic, Gesellschaft fr Angewandte Mathematik und Mechanik, International Federation of Information Processing, and Association for Computing Machinery.

V. RESOURCES

LIBRARIES

The Institute of Informatics has a library of which holds about 5000 Hungarian and English volumes and subscribes over 200 scientific journals. The recently renewed University Library also an invaluable resoure for both our faculty and our students. It offers not only numerous scientific books, journals but it serves as a place for study and host of conferences. The directories of all libraries at the University are connected together, and their shelfed items are searchable by browsers.

HARDWARE/SOFTWARE

The institute provides computer access for about 4800 users. Students may use 280 workstations (Core 2 Duo or better CPU, NVIDIA graphics card), on which both Windows and Linux operating systems are available. All machines are linked to network switches with 1 Gbps, and the Institute's redundant network also has 1 Gbps link to the University Computer Center. The Institute's server park includes: 2 Sun Fire 280R, 5 HP ProLiant DL380, 16 HP ProLiant BL460c blade servers, connected with 4 TB (MSA 1000) + 12.5 TB (EVA 4000) fiber channel mass storage with regular tape backup. The servers are run by Solaris, RedHat Enterprise Linux, CentOS, Windows 2003 Server, and VMware ESXi. Several native and virtualized HA clusters provide the services to education, research, and business.
`http://www.inf.u-szeged.hu/starten.xml`

Research by Departments

Department of Computational Optimization

I. ALGORITHMS ON GRAPHS AND HYPERGRAPHS

We investigate the edge-bandwidth of grid-type graph in [1]. Let $G = (V(G), E(G))$ be a simple graph with n vertices. A *labelling* η is a bijection of $V(G)$ to $\{1, \dots, n\}$. The *bandwidth* of η is

$$B(\eta, G) = \max\{|\eta(u) - \eta(v)| : uv \in E(G)\}.$$

The *bandwidth* $B(G)$ of G is $B(G) := \min_\eta\{B(\eta, G)\}$. The edge-bandwith of G is $B'(G) := B(L(G))$, where $L(G)$ is the line graph of G. The considered graphs are the $n \times n$ planar grid $P_n \oplus P_n$ and tori $C_n \oplus C_n$, the n-dimensional cube P_2^n, and the $K_n \oplus K_n$. In all cases asymptotically sharp bound on the edge-bandwidth are given, such that $B'(P_n \oplus P_n) = 2n + O(\sqrt{n})$, $B'(K_n \oplus K_n) = \frac{3n^3}{8} + o(n^2)$, and

$$B'(P_2^n) = \left(\frac{n}{2} + o(n)\right)\binom{n}{\lceil \frac{n}{2} \rceil}.$$

One of the most fundamental notion in combinatorics is the matchings in bipartite graphs. We studied the on-line version of getting minimal weight perfect matching on-line in arbitrary metric spaces. The greedy algorithm has exponential competitive ratio, and all deterministic algorithms must have at least $2n - 1$ competitive ratio. It turned out that randomized algorithms, assuming oblivious adversary, might perform much better than the deterministic ones. Our randomized greedy algorithm, based on random HST-trees, has expected competitive ratio $o(\log_2^3 n)$, [3]. The lower bound is $\log_2 n$, which was latter achieved by Bansal et al.

In [6] we give a very short proof of an Erdős conjecture that the number of edges in a non-2-colorable n-uniform hypergraph is at least $f(n)2^n$, where $f(n)$ goes to infinity. Originally it was solved by József Beck in 1977, showing that $f(n)$ at least $c \log n$; he later proved that $f(n) \geq cn^{1/3+o(1)}$. We proved a weaker bound on $f(n)$, namely $f(n) \geq cn^{1/4}$. Instead of recoloring a random coloring, we take the ground set in random order and use a greedy algorithm to color. The same technique works for getting bounds on k-colorability, and has close connection to the theorem of Gallai and Roy. It is also possible to combine this idea with the Lovász Local Lemma, reproving some known results for sparse hypergraphs (e.g., the n-uniform, n-regular hypergraphs are 2-colorable if $n \geq 8$).

II. POSITIONAL GAMES

The paper [2] solves some biased graph games. Firstly, it extends the result of Székely and Beck on degree game, and the method has consequences for the balance games. We discuss the general diameter games on the complete graph on n vertices. The diameter is a notorious parameter of the graphs, it was hard to determine for random graphs and it also defies the heuristic intuition for the 1:1 case. The main result of the paper is that the acceleration of the game smooths out some of the irregularities. Namely, Maker wins the game $\mathcal{D}_2(2 : \frac{1}{9}n^{1/8}/(\log n)^{3/8})$, and Breaker wins the game $\mathcal{D}_2(2 : (2+\epsilon)\sqrt{n/\ln n})$ for any $\epsilon > 0$, provided n is large enough.

The survey paper [5] gives a detailed introduction to Positional Games, while it contains some new results. These are as follows: new proof for the equivalence of hex theorem and the exclusion of a draw in the y-game, the bandwidth games on $n \times n$ grid, random proof for Chooser's win in some Picker-Chooser games, an Erdős-Selfridge type of theorem for random hypergraph games, bounds on Chooser-Picker degree games etc.

In [4] two new versions of the so-called Maker-Breaker Positional Games are investigated, that were defined by József Beck. In these variants Picker takes unselected pair of elements and Chooser keeps one of these elements and gives back the other to Picker. In the Picker-Chooser version Picker is Maker and Chooser is Breaker, while the roles are swapped in the Chooser-Picker version. It is conjectured that both the Picker-Chooser and Chooser-Picker versions are not worse for Picker than the original Maker-Breaker versions. Here we give winning conditions for Picker in some Chooser-Picker games. We improve the results of Beck, solve the matroid case, and extend the ideas to infinite games.

Acknowledgements

The research was partially supported by OTKA grants T049398 and K76099.

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Computers play a more and more important role in proving theoretical statements. The major obstacle is in this field the rounding applied in numerical calculations and its effect on the reliability of computational results. Interval arithmetic based inclusion functions provide safe and effective tools for this purpose. In some publications we have summarized the general features and applicability of such techniques [8–10]. During the 2006-09 period we have summarized our results on circle packing in a book (with a CD) [27] and some articles. In these years, Balázs Bánhelyi has defended his PhD dissertation [1], and Tibor Csendes his DSc dissertation [7].

Let us mention here the related special issue [15] of the Hungarian Operations Research Conference, that appeared in the Central European Journal of Operations Research. And also another special issue of the Journal of Global Optimization devoted to the late Tamás Rapcsák [14]. These were coedited by Tibor Csendes.

III. GLOBAL OPTIMIZATION

Global optimization plays a central role in solving real life practical problems and theoretical ones as well. The key point is that it happens often that some nonlinear constraints must be satisfied while an objective function must be optimized (such as cost or profit). Still the nonlinearity of the involved functions is usually prohibitive, and a general user is typically satisfied with an approximate solution without having a guarantee that the obtained parameters are optimal, or even are feasible. The advent of available and programming language supported interval calculations with directed rounding facilitated research in this direction. Most of the problems reported to be solved in this paper are related in one way or the other to this technology. Summaries on this subject are available in [10] and [11].

This is why we have invested much effort in the development and sophistication of global optimization techniques. In [16] and [21] we have updated the traditional, floating point calculation based GLOBAL procedure, and reported the new numerical test results obtained with it. The program is available from the web page

`www.inf.u-szeged.hu/~csendes/Reg/regform.php`

It has been downloaded several thousand times already, also be leading software firms and research institutes. The package contains C, Fortran and Matlab code as well, and also our interval calculation based verified global optimizer code. The algorithm was also extended to constrained problems in [26].

The latter has been developed further in several articles. [20] extended the earlier bound constrained algorithm to the more general nonlinear constrained problem class, while keeping the new efficient adaptive accelerations tricks within the B&B framework. The paper [22] reported the new Matlab/Intlab based implementation of our verified global optimizer code together with computational tests.

Chandra Shekar Pedamallu visited our institute for 6 months as a part of his PhD fellowship at the Nanyang Technological University, Singapore. Later he has successfully defended his dissertation in part on the subjects we have jointly investigated. These comprise mostly such acceleration devices for the verified global optimization algorithms that are based on the know expression of the objective function and make use of it [23–25]. We have applied this new form of information to make a better decision on the subdivision directions, on developing rejection rules, and their application to difficult real life constrained global optimization problems.

IV. CIRCLE PACKING

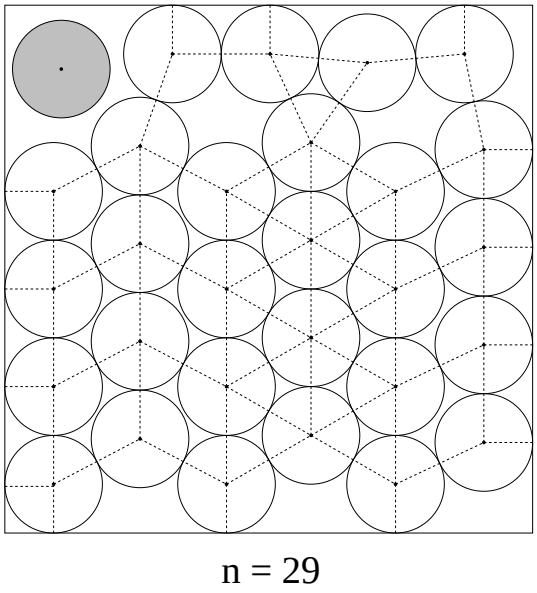

Figure 1. The proven optimal packing of 29 circles in the unit square with a free circle.

Our research team, and its subset at our department has a longer history of research in circle packing. For the reporting interval of 2006-2009, mostly the summarizing publications remained. The paper [19] actually provides one of the key novelties that enabled us to solve the packing of 28, 29, and 30 circles in the unit square problems. The monograph [27] collected the state of the art procedures and theoretical knowledge necessary for a possible progress in solving similar discrete geometry related optimization problems. A sensor location problem led to circle packing, and we studied it in [32]. The papers [29, 30] focused on three special cases, and in [31] we considered a simulation of the growth process of water lilies in a square pool.

And finally, [28] gives good new packings for larger number of circles. The applied computational method was this time a quick approximation algorithm, without a mathematical proof strength numerical background.

V. DYNAMICAL SYSTEMS

Dynamical systems, mostly described by differential equations, are hard to investigate, and the usual techniques use more or less exclusively theoretical tools. In contrast to these approaches, our research team invested much time to develop a toolbox that enables us to follow trajectories in a reliable, verified way, and we are then capable to draw theoretical conclusions based on computer runs.

The paper [2] describes a computer program that allows us to investigate the trajectories of delay differential equations. This tool is an essential procedure of

our quest to prove an old conjecture of E.M. Wright. Our present results are promising, and the related paper will be submitted soon.

The papers [3] and [6] are devoted to the proof of a ten years old conjecture of Hubbard on the chaotic behaviour of the forced damped pendulum. The first mentioned paper describes the applied technique, while the second one gives the proof in detail. This result has reached also some daily newspapers, among them the Frankfurter Rundschau and die Welt. The importance of the result lies in the fact that the studied mechanical system is one of the simplest that is proven to be chaotic.

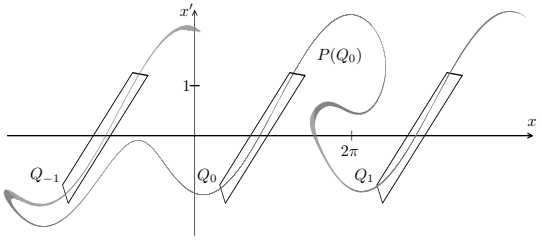

Figure 2. Proven passage of the trajectory through the Poincaré sections.

The publication [4] is more a methodology oriented one, that provides the algorithms which are capable to recognize certain types of chaos in simple to describe dynamical systems. In contrast to this earlier paper, [5] shows a computer aided procedure to give good lower bounds for the topological entropy of some classic systems like the Hénon mapping.

VI. APPLICATION

Among the possible applications of the above mentioned techniques, [11] gives a summary of the fields where the aim is to help mathematical theorem proving by reliable optimization methods.

The papers [17] and [18] discuss the use of validated numerical methods in chemical engineering, for finding limiting flows of batch extractive distillation. The applied computer aided methods enabled us to locate special points in the phase space in a verified way.

While [33] provides an analysis of the reliable numerical techniques used for facility location problems. The main point here was to describe the quality of the inclusion functions used, and its measuring in terms of a novel methodology, by the empirical convergence speed.

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VII. HISTORY OF MATHEMATICS AND INFORMATICS

László Kalmár (1905-1976) was the leader of Hungarian mathematical logic at the University of Szeged. He was an excellent mathematician and one of the best-known pioneers of Computer Science in Hungary [9].

Kalmár's scientific legacy is an important source of the History of Mathematics and the History of Computer Science. In his working career he had over 700 corresponding partners, mathematicians, and other scientists among them.

In our project, we published the second volume of KALMÁRIUM [2] based on Kalmár's legacy (the first volume came out in 2005). The book contains eleven articles on Kalmár's life and works written by his colleagues, students, and friends. The reader can find an interview with Kalmár, amusing selected notes from his approximately 150 notebooks, and a collection of short stories and anecdotes about Kalmár. The main part of this book is the correspondence of Hungarian (or of Hungarian origin) mathematicians with Kalmár. These mathematicians are the following: János Aczél, István Fenyő, Béla Gyires, György Hajós, John von Neumann, Imre Lakatos, Dezső Lázár, Tibor Radó, János Surányi, Barna Szénássy, Béla Szőkefalvi-Nagy, and István Vincze. The KALMÁRIUM I and II contain more than 500 letters with 1000 comments and many other documents, photos, and biographical data.

The Riesz brothers, Frigyes Riesz (1880-1956) and Marcel Riesz (1886-1969) were world-famous mathematicians in the 20th century. They were not only excellent scientists but mathematical school-founder professors too. Frigyes Riesz taught at the universities in Hungary (Kolozsvár, Szeged [12] and Budapest), and Marcel Riesz in Sweden (Stockholm and Lund).

Marcel Riesz's scientific legacy is very interesting in history of mathematics point of view. It is in the Department of Mathematics of Lund University. László Filep, a Hungarian historian of mathematics ordered this legacy in 2003. He planed to publish the Riesz brothers's correspondence in a book, but unfortunately Filep died in the next year. In our project we continue his work [7].

We studied also a forgotten article in Nonlinear Optimization [5, 11]. This paper written in 1932, and considered an inequality constrained nonlinear optimization problem motivated by an analytical mechanical investigation. We worked on to publish a new edition of the Farkas Bolyai's book written by Kálmán Könyves Tóth [3]. We wrote papers on the renaissance mathematics [8], Leonhard Euler [6], Bolyai's Appendix [13] and Lajos Dávid [1,4]. Finally, we published some word articles on János Bolyai, Lipót Fejér, Alfréd Haar, Károly Jordán, Ottó Petzval, Pál Sipos, and Pál Turán [10, 14].

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VIII. APPLICATIONS OF COMBINATORIAL OPTIMIZATION TECHNIQUES

Optimization of complex transportation procedures

During the organization of the transportation procedures many optimization problems arise. The decision maker has to assign goods to different vehicles and the optimal paths in the road system has to be determined. The optimal path and also the cost of the path may depend on the type of the used vehicle. In [20] we suppose that two places are given the destination point and the termination point and some amount of good must be transported between these places. We have a practical packing problem that the goods are packed into three dimensional boxes, a box can be described by its size and its weight. Vehicles belonging to different types can be used for the transportation of the boxes. Our optimization subproblem can be formulated as a generalized version of the three-dimensional bin packing problem. In box packing problem three dimensional boxes must be packed without overlapping into the minimal number of three dimensional unit cube. This problem was defined in previous papers and later many algorithm were developed for the solution of the problem. In our model there are different boxes which can be used for packing the items, thus our model is related to the variable sized bin packing problem, where the bins which can be used to pack the elements may have different size. The notion of bin packing and its multidimensional versions with variable sizes and heuristic algorithms to it were developed as we noted in references of [20]. The new model differs in two ways from the variable sized multidimensional model. In this model there is a further restriction on the bins, each type of bins has a weight limit and the total weight of the boxes assigned to a bin (vehicle) cannot be more than the weight limit of the vehicle. Moreover in the new model we have a more general cost function, the cost of a bin depends on its type, but it can be an arbitrary value it is not the volume of the bin.

We also consider [2, 3] the model where a vehicle has to visit the places but it can be used for internal transports. This means that in the case when a place i is visited before a place j then the vehicle can be used to transport some goods from i to j. The profit which can be achieved by such a transport is denoted by B_{ij}. Thus the goal is to find an ordering of the places which maximize the total profit which can be achieved by the internal transports according to the cost of traveling. We call this problem min-cost Hamiltonian path problem with internal transport, $HPPIT$ in short. This problem is a common generalization of the well-known TSP and LOP (linear ordering) problems. Heuristics on TSP or LOP can be modify to our problem and give new ones. In [3] we defined 14 heuristic algorithms for the solution of this problem and evaluated them by an experimental analysis.

In [4] we investigated an extended version of the vehicle routing with time windows problem. The model can be also interpreted as a new scheduling model for parallel machines, which extends the multiprocessor scheduling problem with release times for minimizing the total tardiness. This new model is motivated by a resource allocation problem which appears in the service sector. We introduce two classes

of heuristic algorithms for the solution of the problem, the first class is a class of greedy algorithms, the second class is based on the solutions of linear assignment problems. Furthermore we present a rescheduling algorithm for improving a feasible solution of the problem.

Applications in Chemical Engineering

In chemical engineering many optimization problems appears, we achieved some results in the following subareas.

In [5] a novel class of separation-network synthesis (SNS) problems is examined, where the separators in the separation network can be affected by various separation methods subject to different constraints imposed on the product specifications. Such a class of SNS problems has been rapidly gaining importance for chemical processing in general and biochemical processing in particular. The available methods for SNS are not intended to address these problems; therefore, an efficient method is proposed in this paper to amend this situation. The method composes algorithmically the necessary mathematical model of the super-structure on which the determination of an optimal separation network is based. The resultant mathematical model is linear, thus the proposed method renders it possible to generate the optimal solution without fail. The solution might serve as the lower bound for a separation network with a non-linear cost function. The uniqueness and efficacy of the proposed method are amply demonstrated by two examples of different complexities.

In [6] we consider the Process Network Synthesis (PNS) problem which has an enormous practical impact. The problem is very difficult it belongs to the complexity class of NP-complete problems therefore it is important to develop reduction algorithms which can reduce the size of the problem. In this paper we overview the known reduction techniques for PNS problems and we present a new reduction algorithm. The performance of this new algorithm is examined by an empirical analysis.

Applications in workflow management

Workflow technology has become a general tool for a wide range of business and management applications. The major source of this success in the applications is the resultant higher efficiency of business and management systems. To satisfy the requirements defined by the applications, the mathematical basis has been developed mainly on Petri net theory. Even though this mathematical methodology provides a foundation for optimal operations of workflows, it is incapable of optimal design of the structure of workflows. The efficiency of a workflow system highly depends on its structure or network. Since the same set of workflow problems can usually be solved by a large number of structurally different workflow systems with wide range of costs, the synthesis of the optimal network is crucial in practice.

In [7] and [8] a new mathematical model is introduced and investigated for workflow system synthesis. The solution of this model is partly based on a methodology formerly developed for processing network synthesis, the P-graph framework. This framework includes a specific modeling techniques and effective algorithms for network synthesis. Even though there are similarities between production processes and workflow processes, the differences prevent the direct applications of the tools of the design of production processes for the design of workflow systems

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I. AUTOMATA THEORY

Little is known on the general properties of tree languages recognized by deterministic root-to-frontier tree recognizers (DR tree languages). Therefore, we have started to study special classes of DR tree languages the counterparts of which are well-known in the theory of finite state recognizers (definite, nilpotent, monotone languages). Paper [2] deals with the closedness of nilpotent DR tree languages with respect to the Boolean operations union, intersection and complementation. Necessary and sufficient conditions are given under which the union of two DR tree languages is also deterministic. It also contains a characterization of the largest subclass of the class of nilpotent DR tree languages closed under the formation of complements.

We have continued to study complete systems of tree automata. In [4] we defined asynchronous tree automata and characterized isomorphically complete systems for them with respect to the α_i-products. Moreover, tree languages recognizable by asynchronous tree automata were also described.

We say that a class **M** of finite monoids determines a class **K** of recognizable tree languages if a recognizable tree language is in **K** if and only if its syntactic monoid is in **M**. Results in [3] show that the class of definite DR tree languages can be determined by the same class of monoids as the class of definite string languages. The same is true for the class of nilpotent DR tree languages. This was the observation which motivated us to give general conditions in [1] under which a class of tree languages with a given property can be determined by the same class of monoids as the class of string languages having the same property.

Connections of Research to Education

Tree automata and tree languages constitute different graduate and PhD courses. The open problems can serve as research subjects for PhD students.

Acknowledgements

Research sketched above was supported by the Hungarian National Foundation for Scientific Research, Grant T 48786.

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II. Analyis of algorithms

Bin packing problem and its versions

In the classical bin packing, we are given a list L of items $(a_1, a_2, \ldots, a_n)$ each item $a_i \in (0, 1]$ and the goal is to find a packing of these items into a minimum number of unit-capacity bins. In [7] we present the theoretical results on the on-line Sum-of-Squares algorithm. SS is applicable to any instance of bin packing in which the bin capacity B and the item sizes s(a) are integer (or can be scaled to be so), and runs in time O(nB). It performs remarkably well from an average case point of view: For any discrete distribution in which the optimal expected waste is sublinear, SS also has sublinear expected waste. For any discrete distribution where the optimal expected waste is bounded, SS has expected waste at most $O(\log n)$. We also discuss several interesting variants on SS, including a randomized $O(nB \log B)$-time online algorithm SS^* whose expected behavior is essentially optimal for all discrete distributions. Algorithm SS^* depends on a new linear-programming-based pseudopolynomial-time algorithm for solving the NP-hard problem of determining, given a discrete distribution F, just what is the growth rate for the optimal expected waste.

The efficiency of online algorithms is usually measured by the competitive ratio (which is a worst case bound) or by an average case analysis where the authors usually assumes independent, identical distributions for the inputs. A further method is a mixed version of these measures, which compares optimal performance with the performance of A for the worst input set when the ordering of the input is randomized. In [1] we use this a new technique to analyse the well-known online bin packing algorithm NF.

In the class contrained bin packing problem we are given a set of items, where each item has a (non-negative) size and a color. We are also given an integer parameter k, and the goal is to partition the items into a minimum number of subsets such that for each subset S in the solution, the total size of the items in S is at most 1 (as in the classical bin packing problem) and the total number of colors of the items in S is at most k (which distinguishes our problem from the classical version). In [9] we follow earlier work on this problem and study the problem further in both offline and online scenarios. We present an AFPTAS for the offline problem if k is considered as a constant. In the online case we give an algorithm with asymptotic competitive ratio 2.63492, which performance is better than the performance of the best previously known algorithm.

In [8] we consider the class contrained version of bin covering with unit size items. In this problem a set of unit sized items is given, where each item has a color associated with it. We are given an integer parameter $k \geq 1$ and an integer bin size $B \geq k$. The goal is to assign the items (or a subset of the items) into a maximum number of subsets of at least B items each, such that in each such subset the total number of distinct colors of items is *at least* k. We study both the offline and the online variants of this problem. We first design an optimal polynomial time algorithm for the offline problem. For the online problem we give a lower bound of $1 + H_{k-1}$ (where H_{k-1} denotes the

$k-1$-th harmonic number), and an $O(k)$-competitive algorithm. Finally, we analyze the performance of the natural heuristic First-Fit.

In [6] we consider the following modification of the bin covering problem. Given a set of m identical bins of size 1, the online input consists of a (potentially, infinite) stream of items in $(0, 1]$. Each item is to be assigned to a bin upon arrival. The goal is to cover all bins, that is, to reach a situation where a total size of items of at least 1 is assigned to each bin. The cost of an algorithm is the sum of all used items at the moment when the goal is first fulfilled. We consider three variants of the problem, the online problem, where there is no restriction of the input items, and the two semi-online models, where the items arrive sorted by size, that is, either by non-decreasing size or by non-increasing size. The offline problem is considered as well.

In [2] a novel classification scheme is presented for bin packing problems. Classification of the papers and results in fields of research are helpful in placing new results in a historical context and in identifying open problems. The paper contains several examples on using the classification scheme for the known results on the area of bin packing.

Scheduling

In [15] we investigate the scheduling problem with rejection where it is allowed to reject the jobs, and the objective function is the sum of the makespan and the total penalties of the rejected jobs. We present a new online algorithm for the problem. The algorithm is a parameter learning extension of the well-kown total reject penalty (TRP) algorithm. Since TRP has the smallest possible competitive ratio which can be achieved for scheduling with rejection, it is clear that the new algorithm cannot have better competitive ratio. We measured the efficiency of the algorithm by an experimental analysis, and the tests show that the parameter learning extension can improve the efficiency in average case.

For most scheduling problems the set of machines is fixed initially and remains unchanged for the duration of the problem. Recently online scheduling problems have been investigated with the modification that initially the algorithm possesses no machines, but that at any point additional machines may be purchased. In all of these models the assumption that each machine has unit cost have been supposed. In [12] we consider the problem with general machine cost functions. Furthermore we also consider a more general version of the problem where the available machines have speed, the algorithm may purchase machines with speed 1 and machines with speed s. We defined and analyzed some algorithms for the solution of these problems and their special cases. Moreover some lower bounds on the possible competitive ratios are presented.

In [13] we define and investigate a further scheduling model. In this new model the number of machines is not fixed; the algorithm has to purchase the used machines, moreover the jobs can be rejected. We show that the simple combinations of the algorithms used in the area of scheduling with rejections and the area of scheduling with machine cost are not constant - competitive. We present an exponential time 2.618-competitive algorithm called OPTCOPY.

Other areas of online algorithms

In [11] we investigate such online algorithms for the data acknowledgement problem, which have extra information about the arrival time of the packets in the following time interval of length c. We present an algorithm with the smallest possible competitive ratio for the maximum of delay type objective function. In the case of the sum of delay type objective function we present an $1 + O(1/c)$-competitive algorithm. Moreover we show that no algorithm may have smaller competitive ratio than $1 + \Omega(1/c^2)$ in the case of that objective function.

In [14] we investigate the online hypergraph coloring problem. In this online problem the algorithm receives the vertices of the hypergraph in some order $v_1, \ldots, v_n$ and it must color v_i by only looking at the subhypergraph $H_i = (V_i, E_i)$ where $V_i = \{v_1, \ldots, v_i\}$ and E_i contains the edges of the hypergraph which are subsets of V_i. We show that there exists no online hypergraph coloring algorithm with sublinear competitive ratio. Furthermore we investigate some particular classes of hypergraphs (k-uniform hypergraphs, hypergraphs with bounded matching number, projective planes), we analyse the online algorithm FF and give matching lower bounds for these classes.

Surveys

We wrote surveys on several areas of the analysis of algorithms. A survey on the basic results in the area of competitive analysis of online algorithms is published in the book chapter [10]. The surveys [3–5] summarize some parts of the bin packing research field. In [3] the basic results on the performance guarantees for one dimensional bin packing are summarized. In [4] the different versions of classical one dimensional bin packing and the basic results are presented. The chapter [5] gives an overview on the area of variable sized bin packing and bin covering. In this models it is not supposed that the size of each bin is 1.

Acknowledgement

The mentioned research tasks were supported by the following grants: the Hungarian National Foundation for Scientific Research Grant F048587. Csanád Imreh was supported by the Bolyai Scholarship of the Hungarian Academy of Sciences.

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III. RESEARCH IN FUZZY AND PLIANT SYSTEM

Addition of sigmoid-shaped fuzzy intervals using the Dombi operator and infinite sum theorem

The extension principle defines the arithmetic operations on fuzzy numbers. In the extension principle one can use any t-norm for modeling the conjunction operator. It is therefore important to know, which t-norms are consistent with a particular type of fuzzy number. We call a t-norm consistent, if the arithmetic operation is closed. In this research we investigate the addition of sigmoid and two bell-shaped membership functions. We prove that the addition is closed if the Dombi operator is used.

Many real world applications have to work with imprecise data. Results of measurements, vague statements, flexible constraints can all be a source of in- accurate information. Fuzzy quantities provide a mathematical model for such imprecise quantities and perceptions. The idea that fuzzy quantities could be arithmetically combined according to the laws of fuzzy set theory is due to Zadeh.

Arithmetic operations on fuzzy numbers are defined by Zadeh's extension principle. The sum of fuzzy membership functions $\mu_1(x_1), \mu_2(x_2), \ldots, \mu_n(x_n)$ can be computed using the extension principle as follows

$$\mu(z) = \sup_{x_1+\ldots+x_n=z} \min\{\mu_1(x1), \mu_2(x2), \ldots, \mu_n(xn)\}. \tag{1}$$

It is possible to replace the min function in (1) with an arbitrary t-norm. This is called the sup-T sum,

$$\mu(z) = \sup_{x_1+\ldots+x_n=z} T\left(\mu_1(x1), \mu_2(x2), \ldots, \mu_n(xn)\right), \tag{2}$$

where $T(x_1, x_2, \ldots, x_n)$ is an arbitrary t-norm.

Equation (2) enables computing a wide variety of fuzzy number sums. Some t-norms are consistent with a specific class of membership functions while others do not. We call a t-norm consistent for addition, if the sup-T sum is a closed arithmetic operation. It is therefore important to know for a particular type of fuzzy numbers, which t-norms satisfy this requirement. FullLer has studied the sup-T sum with triangular fuzzy numbers and in a more general context. These results were developed further and extended by Hong and Mesiar.

In this research we use sigmoid-shaped functions, which appear frequently in natural processes and the Dombi operator. We have the following results: we investigate the sigmoid membership function, which provide a method to construct asymmetrical shaped fuzzy numbers, two bell-shaped membership functions are examined. Bell-shaped functions can be used to model symmetrical shaped fuzzy numbers. With these choices we prove that the addition operation is closed even in the case of infinite summation. [1]

Learning Lexicographic orders

In [2] we investigate the problem of learning the order of criteria of lexicographic decision under various reasonable assumptions. Although the lexicographic decision is very simple, it is the most common and used decision model in everyday life. Even if the decision-makers use another model, they translate it (if it is possible) to lexicographic, because for the verbal communication only this approach is good. For learning the order of criteria we give a sample evaluation and an oracle based algorithm. In the worst case analysis of the sample evaluation algorithms we are dealing with the adversarial models. We show that if the distances of the samples are less than 4, then samples are not learnable, but 4-distance samples are polynomial learnable.

Rule based fuzzy classification using squashing functions

In this research we are dealing with the construction of a fuzzy rule based classifier. A three-step method is proposed based on Lukasiewicz logic for the description of the rules and the fuzzy memberships to construct concise and highly comprehensible fuzzy rules. In our method, a genetic algorithm is applied to evolve the structure of the rules and then a gradient based optimization to fine tune the fuzzy membership functions. The introduced squashing function allows us not only to handle the approximation of the operators

and the memberships in the same way, but also to efficiently calculate the derivatives of the membership functions. We also show applications of the model on the UCI machine learning database.

In the past decades neural networks were successfully used in input-output mapping with very good learning abilities. However the comprehensibility of neural networks are low, they lack of logical justification, one does not know why a trained network gives a certain answer. Its knowledge is distributed in its weights and structure and it cannot be directly translated into simple logical formulas. The problem of creating logical rules to describe a set of input-output data or a black box system's internal behavior is still an active area of Computational Intelligence. Many approaches were suggested to explain a neural network's output.

In this research we propose a hybrid method to construct concise and comprehensible fuzzy rules from given training data. We have the following results: we overview the problem and outline the proposed solution method. We introduce the squashing function and soft trapezoidal memberships. The proposed fuzzy rule constructing method is presented. We show examples for the application of the method. [3]

Applying the Generalized Dombi Operator Family to the Speech Recognition Task

In the automatic speech recognition (ASR) problem, the task of constructing one word- or sentence-level probability from the available phoneme-level probabilities is a very important one. Here we try to improve the performance of ASR systems by applying operators taken from fuzzy logic which have the sort of properties this problem requires. In this research we do this by using the Generalized Dombi Operator, which, by its two adjustable parameters and incorporating other well-known fuzzy operators, seems quite suitable. To properly adjust these parameters, we used the public optimization package called Snobfit. The results show that our approach is surprisingly successful: the overall error rate was significantly reduced.

In speech recognition the basic problem is to assign the most probable phoneme sequence (i.e. a word or word sequence) to a given speech sample, which also can be viewed as a decision problem. This process can be divided into several parts. First, we extract various features from the input in the signal processing phase. Next, probabilities are assigned to several small chunks which correspond to different phonemes, usually by applying some statistical machine learning method. Then we consider the possible phoneme-sequences and the bounds between them, and calculate one hypothesis-level score based on the small, individual probabilities. After, we search for the most probable hypothesis of all by applying some search method.

In this research we focus on the third part, i.e. word-level probability aggregation. For this task we will apply the operators called triangular norms taken from the field of fuzzy logic. In the past we carried out some experiments where various well-known and widely-used norms were employed at different levels of the probability calculation tasks. In this research we will describe the results of experiments with the Generalized Dombi Operator, which includes several norms from our past experiments as special cases. This time we seek to find the best combination of its parameter values using an optimization package called Snobfit.

First we define the speech recognition problem, including its various approaches which frequently appear in the literature. Second, we define some basic terms of fuzzy logic, and identify some subtasks of the speech recognition problem where fuzzy functions can and will be applied. Third, we present the Generalized Dombi Operator. Lastly, we describe the test environment and the test process, then analyse and discuss the test results. [4]

Pliant Arithmetics and Pliant Arithmetic Operations

Fuzzy arithmetic based α-cuts, where the result of the α-cuts represent an interval. The arithmetic can be understand as an interval arithmetic of the α-cuts. Instead of dealing with intervals we are dealing with left and right hand sided soft inequalities which define the interval. We offer a new calculation procedure of arithmetics, when these soft inequalities meet certain properties (i.e. strict monotonously increasing function represent the inequality). We show that the result of linear combinations of linear is also linear and the linear combination of sigmoid is also sigmoid function (i.e. they are closed under linear combination). We give the result of other operation, too. The soft inequalities define an interval by using proper conjunctive and disjunctive operator. We give such operations, too.

In real world applications we often need to deal with imprecise quantities. They can be results of measurements or vague statements, e.g. I have about 40 dollars in my pocket, she is approximately 170cm tall. In arithmetics we can use $a < x$ and $x < b$ inequalites to characterize such quantities, e.g. if I have about 40 dollars then my money is probably more than 35 dollars and less than 45 dollars.

Fuzzy numbers can also be used to represent imprecise quantities. Pliant numbers are created by *softening* the $a < x$ and $x < b$ inequalities, i.e. replacing the crisp characteristic function with two fuzzy membership functions and applying a fuzzy conjunction operator to combine the two functions. We refer to the softened inequalities as *fuzzy inequalities*.

We call the distending function corresponding to the $x < a$ interval the left side of the fuzzy number and denote it as δ_l. Similarly we refer to the distending function corresponding to the $x < b$ interval as the right side of the fuzzy number and denote it as δ_r.

Naturally one would like to execute arithmetic operations over fuzzy numbers. Fuzzy arithmetic operations are generally carried out using the α-cut method. We propose a new and efficient method for arithmetic calculations. The next two sections discuss the arithmetic operations and their properties for two classes of fuzzy distending functions. We investigates additive pliant functions, i.e. distending functions represented as lines. We present multiplicative pliant functions, i.e. distending functions based on pliant inequalities. Finally we examine which conjunction operators are suitable for constructing fuzzy numbers from additive and multiplicative pliant. [5]

On Ramanujan's first article and Interpolation of sum of exponential function based on Ramanujan's result

Ramanujan's first article solved the following equation system:

$$y_j = \sum_{i=1}^{n} p_i z_i^{j-1}, \quad j = 1, \dots 2n.$$

In this research we give a new solution of the system. We show also how this equation system can be used for interpolation or approximation of

$$\varphi(t) = \sum_{i=1}^{n} a_i e^{\alpha_i t}.$$

Ramanujan's first article deals with the following equation system

$$\begin{aligned}
y_1 &= p_1 + p_2 + p_3 + \ldots + p_n \\
y_2 &= p_1 z_1 + p_2 z_2 + p_3 z_3 + \ldots + p_n z_n \\
y_3 &= p_1 z_1^2 + p_2 z_2^2 + p_3 z_3^2 + \ldots + p_n z_n^2 \\
y_4 &= p_1 z_1^3 + p_2 z_2^3 + p_3 z_3^3 + \ldots + p_n z_n^3 \\
&\vdots \\
y_{2n} &= p_1 z_1^{2n-1} + p_2 z_2^{2n-1} + p_3 z_3^{2n-1} + \ldots + p_n z_n^{2n-1}.
\end{aligned} \tag{3}$$

The solution of the system lead to solving linear equation system and finding roots of a polynome with degree n. [6, 7]

The Generalized Dombi operator family and the multiplicative utility function.

We start with the multiplicative utility function and we show its associativity. On this basis we construct a general method to develop strict t-norms.

Our main objective is to introduce a class of generalized operators which includes most of the well-known operators. This class is a two-parametrical family of operators which generalize the Dombi operators by preserving its main properties. This operator class contains the product, the Hamacher operators, the Einstein operators and as a limit we can get the min-max and drastic operators, too.

As a corollary of the multivariate Einstein operator we get the closed form of the additivity law of velocities in the framework of special relativity theory. We give a new form of the Hamacher operator family, with which its multivariate case can be handled more easily.

Finally we show the form of the weighted operator and the impacts of the weights for the min, max operators and for the drastic operator. [8]

Semantic construction and decomposition of functions using aggregation operator.

In this research we will present a new approach to composing and decomposing functions. This technology is based on pliant concept. We will use the proper transformations of conjunction of the sigmoid function to create an effect. We will aggregate the effects to compose the function. This tool is also capable for function decomposition as well.

Functions have a very important role in science and in our everyday lives too. Functions can be given by their coordinates or by using some mathematical expression. Usually if the coordinates are given then it is important to know what kind of expression approximately describes it, because sometimes interpolation or extrapolation question have to be answered. The expression can also use calculating coordinates instead of looking value in the database. In this way we can use more easily handle the function and its parameters. In other words we compress the information which is learning. In science in most cases we can get samples to determine the relations between inputs and outputs, which is called curve-fitting, because usually we do not require the exact fit, only the approximation.

In this research we will present a solution that solves some of these problems. We will introduce positive and negative effects. Their mathematical description can be realized by using continuous valued logic. Here we will use a special one called the pliant concept with Dombi operators. After an aggregative procedure we get the derived function. Aggregation was introduced by Dombi and later the fuzzy community rediscovered and generalized the concept and called it the uninorm. Instead of membership function we use soft inequalities and soft intervals which are called distending function. All of the parameters introduced have a semantic meaning. It can be proved that certain function classes can be uniform approximate.

We concentrate on a certain structure called Pliant concepts for the construction of the operators. A special case of this structure is the Dombi operator class. [9]

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IV. WHEELED AND HUMANOID MOBILE ROBOT NAVIGATION

Sun Spot based remote control of mobile robots

Currently many researches in robotics are dealing with different problems of motion of wheeled mobile robots. Let us consider the wireless sensor-based remote control of autonomous mobile robots motion in an unknown environment with obstacles, using the Sun SPOT technology. The proposed method have been implemented on the miniature mobile robot Khepera that is equipped with sensors and the free range Spot from the Sun Spot technology. The experimental results show the effectiveness and the validity of the obstacle avoidance behavior in an unknown environment.

The mobile robot must be capable of sensing its environment. Conventionally, mobile robots are equipped by ultrasonic sensors and the accurate distance of the obstacle can be obtained from the ultrasonic sensors. In moving towards the target and avoiding obstacles, the mobile robot changes its orientation and velocity. We assume the following conditions: the autonomous mobile robot has two wheels driven independently and groups of ultrasonic sensors to detect obstacles in the front, to the right and to the left of the vehicle, the robot moves on a flat ground without sliding. When the vehicle is moving towards the target and the sensors detect an obstacle, an avoiding strategy is necessary. With obstacles present in the unknown environment, the mobile robot reacts based on both the sensed information of the obstacles and the relative position of the target [1–3]. In moving towards the target and avoiding obstacles, the mobile robot changes its orientation and velocity. When the obstacle in an unknown environment is very close, the mobile robot slows down and rapidly changes its orientation. In this paper we have used SunSPOT-s (Small Programmable Object Technology) to achieve remote control over a Khepera mobile robot [4]. Sun SPOT is a small electronic device made by Sun Microsystems. The Sun SPOT connection strategy is presented in Fig IV..

Figure 3. Remote control system.

For this task we have used 2 SunSPOT-s from the development kit (Sun Microsystems, Inc. 2007). Sun SPOTs are programmed in a Java programming language, with the Java VM run on the hardware itself. It has a quite powerful main processor running the Java VM "Squawk" and which serves as an IEEE 802.15.4 wireless network node. SunSPOT's wireless protocol is Zigbee based protocol. The Sun SPOT is designed to be a flexible development platform, capable of hosting widely differing application modules. We used the SunSPOT base station to read a file from the controlling computer and send its contents to the second free range SPOT. The second SunSPOT when receiving the data in turn opens up its outputs depending on what it received. The miniature mobile robot Khepera that is equipped with: 9 infrared sensors, 5 ultrasonic sensors and integrated Bluetooth communication module. The user can start control experiment of mobile robots [5] in Sun SPOT environment (Fig. IV.).

Figure 4. Remote control experiment.

Locomotion of Humanoid Robots in Presence of Mobile and Immobile Obstacles

Let us consider the control synthesis of an intelligent autonomous locomotion (artificial gait) of biped robots operating in unknown and unstructured dynamic environments, based on perception, spatial reasoning, and learning the skill of human locomotion. Focusing the research activities to the embodied cognition and computational intelligence, this paper contributes to the extension of the intelligent robot behavior through building advanced algorithms for dynamic environment understanding, simultaneous localization, trajectory prediction, path planning, obstacle avoidance, collision avoidance and scenario-driven behavior [6].

The considerations are addressed to the advancements of embodied cognition with humanoid robots through building of intelligent cognitive algorithms for extended autonomy, better environment understanding, spatial reasoning and bio-inspired adaptation to the external world (Fig. IV.).

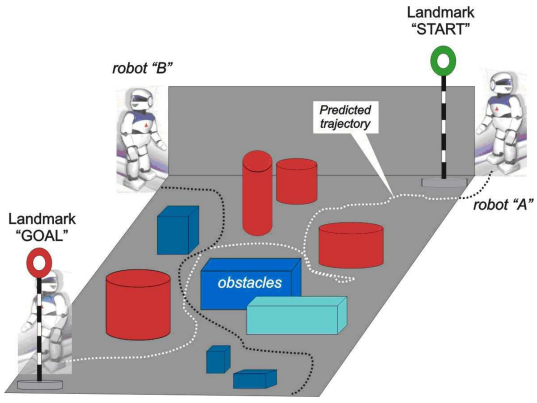

Figure 5. Typical obstacle avoidance and collision avoidance dynamic scenario.

Main objectives are addressed to synthesis of intelligent algorithms for trajectory prediction, path planning, avoidance of static and mobile obstacles in robot environment and human-like (anthropomorphic) locomotion. The paper concerns with the synthesis of an intelligent, autonomous, bio-inspired locomotion (artificial biped gait) in unknown and unstructured dynamic environment. Conventionally, biped robots are equipped by a stereo-vision system (two cameras). The role of cameras is to identify the relative position d and direction of motion (azimuth) β of biped robot with respect to the chosen landmark object (Fig. IV.) with a satisfactory accuracy.

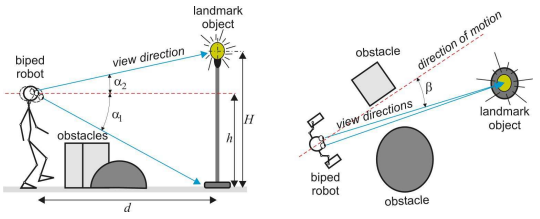

Figure 6. Biologically inspired localization of a biped robot.

An arbitrary indoor scene with a biped robot and obstacles are presented in Fig. IV. in two geometry perspectives - side view and a top view. Elevation angles of robot eyes/cameras α_1 and α_2 as well as their attitude h are known (measurable). Joint trajectory tracking, posture stability and dynamic balance will be ensured using position/velocity feedback in the joint space, impedance control as well as feedback upon dynamic reactions, i.e. feedback upon the Zero Moment Point (ZMP) deviations. Control of biped robot dynamics will be realized at the low-control level (servo level) using the corresponding sensor system (encoders, tension/torques sensors, gyro, etc.). Additional contact force/torque sensors attached to the foot sole of the biped robot are necessary, too. For that purpose, the industrial force sensing resistors or 6-axial Force-Torques sensors have to be implemented. Overall control system structure is shown in Fig. IV.. Two control blocks represent a brain of the system consisting of high-level control block and low-level servo control block. Control of robot dynamics will be designed at the servo-level while the intelligent control algorithms (cognitive behavior) enabling non-restricted autonomous locomotion and advanced reasoning will be synthesized at the high control level.

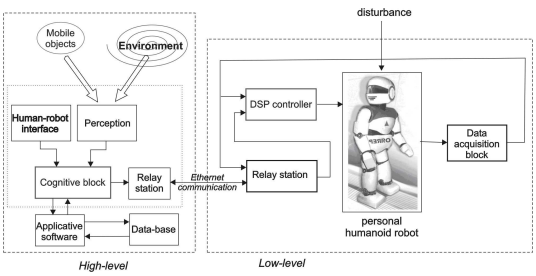

Figure 7. Control system architecture that supports an intelligent autonomous locomotion of biped robot.

Advanced humanoid robot platforms have both control blocks (high and low) integrated on-board in order to speed up the system response. In that sense, we can speak about full system autonomy where the robot is capable to make decisions, plan its trajectories as well as enable stabile and reliable walking in real-time. As an example of demonstration of the intelligent reasoning that is proposed in the paper to be implemented with humanoid robots, some interesting simulation results are presented in Fig. IV.. In that sense, CAD model of an arbitrary environment with immobile obstacles as well as a target trajectory generated by the corresponding cognitive block are illustrated.

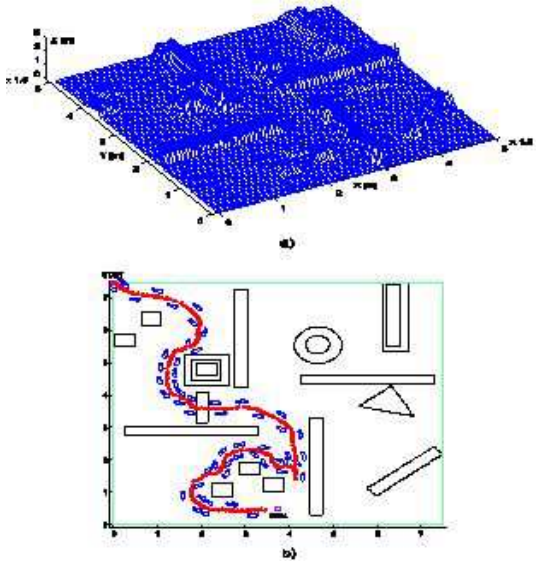

Figure 8. Example of an intelligent autonomous locomotion in an unknown environment with presence of static obstacles; a) CAD-model of the environment, b) Obstacle avoidance and target trajectory prediction with the footprints depicting gait.

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V. LOCAL AND REMOTE LABORATORIES IN THE EDUCATION

Nowadays and in the future all mobile robots will include one or more microprocessors / microcontrollers. The use of microprocessors / microcontrollers in a hardware design improves the design's capabilities as well as the design's implementation. Owing to this it is important that students of informatics, electronics and mechatronics have undergraduate experience with microcontrollers. These requirements present the university with a challenge in terms of sufficient laboratory establishment. Other important factors include the large number of students in the education process, the sometimes limited laboratory space and the financial (possibility) resources of the universities.

In an effective way we can use existing laboratories of informatics (LAN with PC-s) together with other techniques from the web (internet) and microcontroller trainer boards. Solutions over the internet open the possibilities for the distance learning. Open source distance learning software gives for the lecturers and students the chance for the distance administration, literature access, rapid material renovation, the use of tests. The main standing-point in creating laboratories is low level investment, using existing pieces of equipment together with the improvement of educational effectiveness. Including trainer boards and internet in the laboratories does not change the old functions of the informatics laboratories. This chapter presents a project to enhance the microcontroller/robotics education of informatics and electronics engineering students. Some courses provide preliminary knowledge for students who selected microcontroller / microprocessor based classes. For example the course in Architecture gives them hardware and assembly programming background.

In some obligatory and eligible courses students involve the design and development of microcontroller based technologies, for example in Robotics, Autonomous systems and Mechatronics. These courses include both lecture and laboratory components. In some cases in other courses students do interdisciplinary projects, or diploma works, also using microcontroller applications.

There are two aspects to teaching mobile robot architecture course, first the software (programming) and second the hardware (interfacing). Unlike in programming and architecture courses, in robot construction course students must understand deeply the connections between the software and hardware, so low level (assembly) programming, memory fetches, cycles per instructions, stacks, internal registers, accumulator, program counter, flags, timers, I/O lines etc.

Interfacing techniques require some physical and also electrical knowledge from students in microcontroller - external equipment connections. Students must know some electrical laws: common grounds, voltage/current limitations, noise shielding, timing (delaying) problems. Other courses deal with physical / electrical questions, but the experience is, a microcontroller course needs to be reminded of them.

We do not forget the mechanical interfacing aspects, this field is always imperfect in educational process of students.

Laboratory types

The simplest laboratory is the classic informatics laboratory with 10 to 25 PC computers, set up with microcontroller simulation programs in network scheme. It is true that this solution is budget-priced, there are no problems with real physical and electrical factors. Often some mobile robot navigation software for the presentations are used. There are few pieces of simulation software with the ability for the simulation of the peripheries. If some characteristic interfaces are included in the program, student can observe the simulated ports and interfaces behavior. The great problem with the simulators is that the code is correct, so the simulation results are correct, but because it is not working in real time, for the real activities is response time of code too slow or but too fast. After the programming of real system they will not work correctly.

A better solution is the trainer board supported laboratory, old, classical laboratory with PC-s is expanded with evaluation (trainer) boards. Printed circuit board with microcontroller and necessary hardware gives for the student theoretical and practical knowledge, and testing the solutions (program codes) parallel on simulator and real system. Application of mechanical parts for mobile robots (drives and motors, platforms, sensors and actuators) guided the students to the realization of a full, usable mobile robot. Adding the web properties to the second type of laboratory opens new capacities in mobile robot architecture courses. This type of laboratory opens the distance learning manner, all instruments, trainer boards, software equipments are controlled and observed through the net. So the experiments are flexible, the setup process is fast and satisfy all distance requirements.

Equipment configuration for microcontroller laboratory

The optimal number of workplaces is 10 to 15, one lecturer (instructor) in the laboratory can supervise the students' work efficiently. The primary role of this laboratory is the teaching and presentation of the microcontroller theory, I/O interfacing and programming. All workplaces are supplied with the same PC hosts, trainer boards and ICD (In Circuit Debugger) interfaces.

Laboratory equipment, which is used in few fields must have some special as well as universal parameters:

- Flexibility in programming (Assembly or C),
- Debugging capacity, internal operation showing while executing a program,
- Ability of interfacing with other systems, standardized equipments,
- Ability of interfacing with other external systems, peripheries and
- Robustness.

Hardware type of laboratory equipments

After an in-depth analysis of some microcontroller families we chose the PIC type of controllers. There are a large number of very good and operative development pieces of equipment with PIC controllers on

the market. Of a high account of parameter comparison we have selected a complex system, PIC16F877 Trainer board from Chipcad [8]. This board is supplied with required peripheries for the microcontroller course needs, these I/O pieces of equipment are also parts of mobile robots. Microchip [xxx] developed a complex software package MPLAB for program development, testing and programming. The connection between the PC host and Trainer board is via the Microchips ICD2 (In circuit debugger) (Figure V..).

Figure 9. The entire development system with PC host and Trainer board connecting through Microchips in-circuit debugger ICD2 [7].

PIC16F877 Trainer board is a single board microcomputer based on PIC16F877 (and other type of PIC) microcontrollers. This is a consummate developmental tool in education, industry and other fields, also it is able to fill a part in industrial applications.

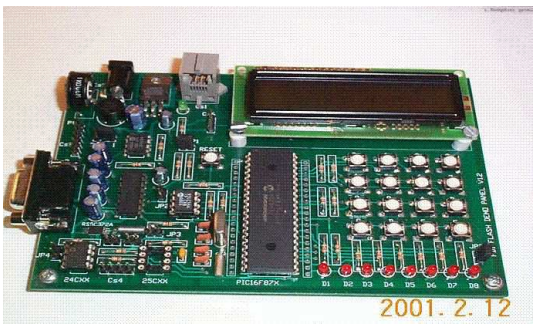

Figure 10. PIC16F877 Trainer board with 16F877 microcontroller .

Some technical characteristics from the board are:

- General purpose I/O ports,
- Interrupt logic,
- Timers,
- A/D converter,
- USART,
- I^2C bus and
- capture/compare/PWM module.

Main peripheries of board are (Figure V.):

- 4×4 matrix keyboard
- LCD module
- 8 LED diodes
- RS232 interface
- I^2C bus
- serial EEPROM
- analog input
- Analog output
- PIC port expansion
- ICD connector
- LDR-key connector

VI. Conclusion

The modern laboratory construction was created in accordance with the requirements of the Bologna process demands. Teaching microcontrollers for robotics applications is feasible for compulsory courses as well as voluntary courses. This laboratory equipment is also appropriate for other microcontroller applications. Applications of internet tools allow building very operative remote controlled laboratories for the teaching of mobile robot architecture.

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VII. ADVANTAGES OF WIRELESS SENSOR NETWORKS IN GREENHOUSE ENVIRONMENT

This paper describes the implementation and configuration of the wireless sensor network using the Sun SPOT platform. Sun SPOT is a small electronic device made by Sun Microsystems. They have a wide variety of sensors attached to it. Sun SPOTs are programmed in a Java programming language, with the Java VM run on the hardware itself. It has a quite powerful main processor running the Java VM "Squawk" and which serves as an IEEE 802.15.4 wireless network node. The SPOT has flexible power management and can draw from rechargeable battery, USB host or be externally powered. The Sun SPOT is designed to be a flexible development platform, capable of hosting widely differing application modules. As it is well known, greenhouses have a very extensive surface where the climate conditions can vary at the different points.

Introduction

Wireless sensor networks consist of tiny devices that usually have several resource constraints in terms of

energy, processing power and memory. In order to work efficiently within the constrained memory, many operating systems for such devices are based on an event-driven model rather than on multi-threading. Continuous advancements in wireless technology and miniaturization have made the deployment of sensor networks to monitor various aspects of the environment increasingly possibilities. Wireless Sensor Networks have recently received a lot of attention within the research community since they demand for new solutions in distributed networking. A common scenario associated with these networks is that tiny nodes, equipped with several sensors and hardware for wireless communication, are deployed randomly and in large numbers within a certain area. In order to report the data they gather in their proximity to an interested application or user, nodes connect to their neighbors and send valuable information on a multihop path to its destination.

The concept of wireless sensor networks is based on a simple equation:

Sensing + CPU + Radio = Thousands of potential applications

As soon as people understand the capabilities of a wireless sensor network, hundreds of applications spring to mind. It seems like a straightforward combination of modern technology. However, actually combining sensors, radios, and CPU's into an effective wireless sensor network requires a detailed understanding of the both capabilities and limitations of each of the underlying hardware components, as well as a detailed understanding of modern networking technologies and distributed systems theory.

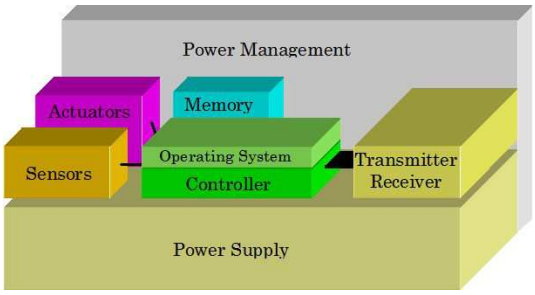

Figure 11. Sensor Node Architecture.

Wireless sensor networking is one of the most exciting technologies to emerge in recent years. Advances in miniaturization and MEMS-based sensing technologies offer increases by orders of magnitude in the integration of electronic networks into everyday applications. Traditional microcontroller design strategies have not reached the best possible power consumption, especially for the specialized application set of sensing networks. Power efficiency is a prime concern in wireless sensors, whether powered by a battery or an energy-scavenging module. Trends in miniaturization suggest that the size of wireless sensors will continue to drop, however there has not been a corresponding drop in battery sizes.

Greenhouse climate problems

The dynamic behavior of the greenhouse microclimate is a combination of physical processes involving energy transfer (radiation and heat) and mass balance (water vapour fluxes and CO_2 concentration). These processes depend on the outlet environmental conditions, structure of the greenhouse, type and state of the crop, and on the effect of the control actuators. The main ways of controlling the greenhouse climate are by using ventilation and heating to modify inside temperature and humidity conditions, shading and artificial light to change internal radiation, CO_2 injection to influence photosynthesis, and fogging/misting for humidity enrichment. Crop growth is mainly influenced by the surrounding environmental climatic variables and by the amount of water and fertilizers supplied by irrigation. This is the main reason why a greenhouse is ideal for cultivation, since it constitutes a closed environment in which climatic and fertirrigation variables can be controlled to allow an optimal growth and development of the crop. The climate and the fertirrigation are two independent systems with different control problems. Empirically, the requirements of water and nutrients of different crop species are known and, in fact, the first automated systems were those that controlled these variables.

As the problem of greenhouse crop production is a complex issue, an extended simplification consists of supposing that plants receive the amount of water and fertilizers that they require at every moment. In this way, the problem is reduced to the control of crop growth as a function of climate environmental conditions.

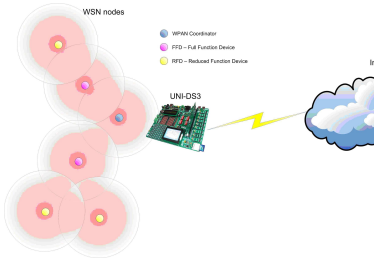

Figure 12. Schematic of the operational sensor network.

The applications for WSNs are many and varied. They are used in commercial and industrial applications to monitor data that would be difficult or expensive to monitor using wired sensors. They could be deployed in wilderness areas, where they would remain for many years (monitoring some environmental variable) without the need to recharge/replace their power supplies. They could form a perimeter about a property and monitor the progression of intruders (passing information from one node to the next). There are a many uses for WSNs. Typical applications of WSNs include monitoring, tracking, and controlling.

Some of the specific applications are habitat monitoring, object tracking, nuclear reactor controlling, fire detection, traffic monitoring, etc. In a typical application, a WSN is scattered in a region where it is meant to collect data through its sensor node.

Conclusions

The WSN-based controller has allowed a considerable decrease in the number of changes in the control action and made possible a study of the compromise between quantity of transmission and control performance. The limit of the level crossing sampling has presented a great influence on the event based control

Figure 13. Tomato plants in greenhouse

performance where, for the greenhouse climate control problem, the system has provided promising results.

Acknowledgements

This research was partially supported by the TAMOP-4.2.2/08/2008-0008 program of the Hungarian National Development Agency.

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Department of Foundations of Computer Science

The research performed in the Department of Foundations of Computer Science lies in the intersection of algebra, logic and computer science. The main themes are automata and formal languages, tree automata and term rewriting, weighted tree automata, logics on words and trees, finite model theory, fixed point operators in computer science, and axiomatic questions.

I. FIXED POINTS IN COMPUTER SCIENCE

We studied categorical models that give rise to solutions of recursion schemes [1, 3], the expressive power of recursion schemes [2, 4, 5], and complete descriptions of the equational properties of fixed point operations [11]. The papers [9, 10] provide applications of fixed point theory to fuzzy languages and weighted tree automata.

II. TREE AUTOMATA, TERM REWRITING AND LOGICS ON WORDS AND TREES

We studied logical aspects of automata and tree automata. In the papers [12–18, 20–22], we gave algebraic and game theoretic characterizations of various logics on words and trees, including linear and branching time temporal logics, and extensions of first-order logic by Lindström quantifiers. In [19], we gave a complete axiomatization of regular tree languages.

In [38, 39], we investigated macro pebble tree transducers. We showed that three different versions of the circularity problem for pebble macro tree transducers are decidable. Moreover, we proved several composition and decomposition results and showed that the type checking problem for pebble macro tree transducers is decidable.

In [46], we showed that there are finitely many descendants of any recognizable tree language L for all linear monadic term rewrite systems, and we gave these descendants through finitely many linear monadic term rewrite systems. In [47], we considered the ranked alphabet consisting of a binary symbol. Then we gave a rewrite system R effectively preserving recognizability on any ranked alphabet obtained by adding finitely many nullary symbols, and losing recognizability on the ranked alphabet obtained by adding one unary and one nullary symbol. In [48], we showed that some basic properties of murg term rewrite systems are undecidable. In [49], we compared the computing powers of a given deterministic bottom-up tree transducer and a given ground term rewrite system. In [50], we gave a weak quasi-decision procedure for deciding whether the range of a bottom-up tree transducer is recognizable, and in [51] we showed that it is decidable for any extended ground term rewrite system R whether there is an equivalent ground term rewrite system S.

III. WEIGHTED AUTOMATA AND SEMIRINGS

In the papers [6–8, 23–28], we carried out research on the axiomatic foundation of weighted automata. We identified several structures for this purpose such as Conway and iteration semirings [6–8, 27, 28], Conway and iteration semiring-semimodule pairs [25, 26]. We derived several key results of the theory of automata in the axiomatic settings.

IV. WEIGHTED TREE AUTOMATA AND TREE TRANSDUCERS

In [29], we used simulation to characterize equivalence of weighted tree automata. In [34], we gave a summary on several important results for weighted tree automata and weighted tree transducers. In [35], we characterized the syntactic $K\Sigma$-algebras of recognizable tree series and showed that all subdirectly irreducible $K\Sigma$-algebras are syntactic. In [36], we proved that a tree series is recognizable by a tree automaton over a multioperator monoid iff it appears as the composition of a relabeling tree transformation, a recognizable tree language, and a tree series computed by a one-state weighted tree automaton of the same type. In [37], we presented a KLEENE theorem on the equivalence of recognizability and rationality for tree series over distributive multioperator monoids. In [40], we proved that tree series recognizable by weighted tree walking automata over a commutative semiring K form a strict subclass of the class of recognizable tree series over K.

V. HIGHER DIMENSIONAL AUTOMATA

In the papers [42, 44, 45], we studied languages of higher dimensional words (elements of free algebras with several independent associative operations) and their acceptors, called parenthesizing automata.

VI. OTHER

In [30], we gave estimations of the state complexity of several operations on finite automata, such as operations induced by boolean functions. In [31–33], we opened a new direction in the study of infinitary languages by introducing context-free grammars generating languages of countable words.

The iterated shuffle is a frequently used operation to describe sequential execution histories of concurrent processes. In [43], necessary and sufficient conditions have been derived for regularity and context-freeness of the iterated shuffle of languages belonging to several simple classes of regular languages.

In [41], we gave new upper bounds for the length of the shortest i-directing word of an i-directable nondeterministic automaton for $i = 1, 2, 3$. For $i = 1, 2$ our bounds are asymptotically tight. These questions, introduced by Burkhardt in 1976, are motivated by the well-known Černý conjecture which is still open since 1964.

ACKNOWLEDGEMENTS

The above research has been supported by the AUTOMATHA programme of the European Science Foundation, the grants K 75249 and T046686 from the National Foundation of Hungary for Scientific Research (OTKA), the grants 68öu2 and 77öu9 of the Austrian-Hungarian Action Fund, the MTA-JSPS (Hungarian-Japanese) cooperative programme

no. 101, the MTA-CNRS (Hungarian-French) project and the TÁMOP-4.2.2/08/1/2008-0008 programme of the Hungarian National Development Agency.

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OTHER ACTIVITIES

I. EDITED BOOKS

In the period 2006–2009, the members of the Department of Foundations of Computer Science edited or co-edited the following books and special journal issues.

1. A. Bertoni, Z. Ésik, J. Karhumäki, Eds.: The art of rationality. In honour of Professor Christian Choffrut on the occasion of his 60th birthday. *Theoretical Computer Science*, 356(2006), no. 1–2, 262 pages.
2. Z. Ésik, Ed.: Automata and Formal Languages 2005, Special issue of *Acta Cybernetica*, Volume 17, No.4, 2006, 663–841.
3. Z. Ésik, Ed.: Automata and Formal Languages 2005, Special Issue, *Theoretical Computer Science*, Volume 366, Number 3, 2006, 181–315.
4. Z. Ésik, C. Martin-Vide, V. Mitrana, Eds.: Recent Advances in Formal Languages and Applications, Studies in Computational Intelligence 25, Springer-Verlag, 2006, VIII + 373 pages.
5. Z. Ésik, Ed.: Computer Science Logic 2006, proceedings, LNCS 4207, Springer-Verlag, 2006, XII + 626 pages.
6. E. Csuhaj-Varjú, Z. Ésik, Eds.: Fundamentals of Computation Theory 2007, LNCS 4639, Springer, 2007.
7. E. Csuhaj-Varjú, Z. Ésik, Eds.: Automata and Formal Languages, proceedings of the 2008 conference, Balatonfüred, Computer and Automation Institute, Hungarian Academy of Science, 2008.
8. Z. Ésik, R. Ramanujam, Eds.: Selected Papers of the Conference "Computer Science Logic 2006" Szeged, Hungary, 2006 *Logical Methods in Computer Science*, 2009.
9. E. Csuhaj-Varjú, Z. Ésik, Eds.: Automata and Formal Languages, *Acta Cybernetica*, Vol. 19, No. 2, 441–565, 2009.
10. Z. Ésik, Z. Fülöp, Eds.: Automata, Formal Languages, and Related Topics, Dedicated to Ferenc Gécseg on the occasion of his 70th birthday, University of Szeged, 2009.
11. E. Csuhaj-Varjú, Z. Ésik, Eds.: Fundamentals of Computation Theory. Special issue devoted to papers presented at FCT 07, *Theoretical Computer Science*, Volume 411(2010), Issues 4–5.
12. E. Csuhaj-Varjú, Z. Ésik, Eds.: Automata and Formal Languages, special issue devoted to AFL 2008, *Int. J. Foundations of Computer Science*, to appear in 2010.

II. ORGANIZED CONFERENCES

In the period 2006-2009, the Department of Foundations of Computer Science has organized the following conferences and workshops:

1. Annual Conference of the European Association for Computer Science Logic, **CSL'06**, Szeged, Hungary, September 25–29, 2006.
2. Logic and Combinatorics, Satellite Workshop of CSL'06, Szeged, Hungary, September 23–24, 2006.
3. Algebraic Theory of Automata and Logic, Satellite Workshop of CSL'06, Szeged, Hungary, September 30 and October 1, 2006.

4. 16th International Symposium on Fundamentals of Computation Theory, **FCT'07**, Budapest, Hungary, August 27–30, 2007.
5. 12th International Conference on Automata and Formal Languages, **AFL'08**, Balatonfüred, Hungary, May 27–30, 2008.

Department of Image Processing and Computer Graphics

More information on the current research projects of the Image Processing and Computer Graphics Department can be found online at `http://www.inf.u-szeged.hu/ipcg/projects/index.html`.

I. DISCRETE TOMOGRAPHY

Discrete Tomography (DT) deals with the reconstruction of discrete valued functions from their line integrals along certain directions called projections. The function itself usually represents a two-dimensional cross-section of an object consisting of a small number of homogeneous materials, while the projections can be regarded as the results of some imaging methods (like, e.g., X-ray, gamma, or neutron imaging). Among others, typical applications arise in nondestructing testing, electron micorscopy, and digital angiography. For several reasons, in all of these applications the number of available projections is at most about 10 (often only 2 or 4). This usually yields ambiguous reconstruction, i.e., the result image of a classical reconstruction method can be quite dissimilar to the original one. Another problem is that the reconstruction problem is in most cases NP-hard. Therefore, in DT more sophisticated methods are needed that can guarantee accurate and fast reconstruction despite the fact that there are just a few available projections. Such methods can be developed by cleverly using the prior knowledge that the image to be reconstructed can contain only a small number of known intensity values.

RECONSTRUCTION WITH GEOMETRICAL PRIORS

One way to reduce ambiguity and to avoid intractability is to suppose that the binary image (also called discrete set) to be reconstructed belongs to a certain class of images satisfying some geometrical properties (connectedness, convexity, etc.). The main challenge here is to find geometrical properties that drastically reduce the number of possible solutions of the same reconstruction problem but still keep the reconstruction process tractable.

Our work focuses on the possible extensions and improvements of former results using two projections: uniqueness and reconstruction of line-convex directed polyominoes [3], fast reconstruction of Q-convex sets [14], and reconstruction of hv-convex discrete sets consisting of more than one components [5, 9].

On the other hand, we study also the reconstruction from four projections and develop exact and heuristic methods to solve this problem [4, 6].

RECONSTRUCTION BY OPTIMIZATION WITH APPLICATIONS IN NONDESTRUCTIVE TESTING

The reconstruction process can also be formulated as an optimization task where the aim is to find the global minimum of the objective functional

$$\Phi(f) = \sum_{\vartheta} ||[\mathcal{R}f](\vartheta) - P_{\vartheta}||^2 + \gamma||f - f_0||^2,$$

where P_{ϑ} denotes the input projection of angle ϑ, f is the image function that approximates the solution, $[\mathcal{R}f](\vartheta)$ denotes the projection of the image f taken at angle ϑ, $||.||$ is the Euclidean norm, and $\gamma \geq 0$ is a regularizing parameter. f_0 is a prototype function that has the same domain and range as f, and is similar to the expected reconstruction result. Such a model has the advantage that one can incorporate prior information of the image to be reconstructed into the second term on the right hand side. Moreover, it also can handle incorrect measurements of projections. The regularazing parameter γ stands for controlling whether prior information or the projections are more reliable in a certain reconstruction task.

Such optimization problems can be solved, e.g., by simulated annealing (SA). A lot of work has been done at our department in this field, mostly concentrating on applications of neutron and X-ray tomography [1, 2, 13, 17]. The same technique was applied to solve some reconstruction problems in the case of so-called fan-beam projections [20, 21].

SA is not the only way to solve the above optimization problem. We also compared SA to a dc-programming method from the viewpoint of reconstruction efficiency. It turned out that (for the images used in that comparison) there is no significant difference of accuracy and running time between the two methods [22].

A branch-and-bound approach was also presented in [10] to reconstruct images similar to a given one, from their horizontal and vertical projections.

EMISSION DISCRETE TOMOGRAPHY

Recently, a new field of DT called *Emission Discrete Tomography* (EDT) has been studied. In this model the function to be reconstructed represents an object emitting some radiation surrounded by a homogeneous material having certain absorption. Thus, the projections are depending not only the emission but the absorption, too. We have studied the problem of uniqueness in the EDT model and the reconstruction of hv-convex discrete sets from two projections. We found that this latter problem is solvable in polynomial time, at least for a certain absorption coefficient. Our results on EDT are summarized in [12, 19].

MACHINE LEARNING IN DISCRETE TOMOGRAPHY

In DT many reconstruction methods have been developed which can exploit prior knowledge of the image to be reconstructed. However, it always has been supposed that the prior information is given explicitly. We apply feature selection methods and machine learning techniques (like decision trees, neural networks, nearest neghbour approaches) to extract important projection components of a given object, and to detect geometrical or complex topological properties of the objects to be reconstructed, purely from their attributes [15]. We also develop advanced reconstruction methods suitable to use the learnt (uncertain) prior information [11].

DIRECT FRAMEWORK AND BENCHMARK SETS

DIscrete REConstruction Techniques (DIRECT) is a toolkit for testing and comparing 2D/3D reconstruction methods of discrete tomography. The

toolkit involves generating projections of discrete objects, running reconstruction methods, and visualization of their results. Most of the reconstruction techniques developed at our department are implemented in this framework. The DIRECT toolkit is located at

`http://www.inf.u-szeged.hu/~direct/`

with a full access for registered users.

Based on the generation methods of [7, 8] we also offer benchmark collections of *hv*-convex discrete sets for analysing the performance of reconstruction algorithms. The benchmark sets are publicly available at

`http://www.inf.u-szeged.hu/~pbalazs/benchmark`

CONFERENCES ORGANIZED

The Workshop on Discrete Tomography and Its Applications was held in June 2005 in New York City with the co-organization of Attila Kuba. Based on the talks a book was edited that came out in 2007 [16], in which 6 from the 15 chapters are written by the members of our group, solely or partially. Further informations on the conference are available at

`http://www.dig.cs.gc.cuny.edu/`

The 13th Conference on Discrete Geometry for Computer Imagery was held in Szeged in October 2006. As part of the conference program a session was devoted to the topic of DT. Our research group has also publications in the conference proceedings [18]. The homepage of the conference can be found at

`http://www.inf.u-szeged.hu/dgci`

FUNDATION

Our research was mainly funded by the OTKA T048476 project entitled "New Directions in Discrete Tomography and Its Applications in Neutron Radiography" which finished in 2008 with excellent degree. Part of the work was also supported by the TÁMOP-4.2.2/08/1/2008-0008 program of the Hungarian National Development Agency and by the János Bolyai Research Scholarship of the Hungarian Academy of Sciences.

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II. GEOINFORMATICS

TERRAIN MODELLING

Thin plate spline interpolation is a widely used approach to generate a digital elevation model (DEM) from contour lines and scattered data [1]. We propose a high resolution processing method that ensures maximum utilization of information in the source data. The multigrid relaxation principle is used to speed up convergence. A crucial point of this procedure is the algorithm generating a low resolution matrix R from the original matrix Z with a reduction factor q. To solve the problem, a new contour thinning method is given that produces significant reduction of elevation bias in the terrain [2]. Sketch of the algorithm is as follows.

A qualifier code is attached to each element of Z and R respectively, with four possible values: C0 denotes a free point, the value of which will be calculated by relaxation; C1 denotes a "weak" contour point; C2 denotes a normal contour point; C3 identifies a single elevation point.

Step 1. A buffer zone of width $q/2$ is generated for points C2 and C3 in Z, the result is denoted by Z^+ (Figure 14).

Step 2. An initial q-reduced matrix S is calculated by tiling Z^+ into $q \times q$ squares and the average of all defined elements is calculated for each tile. Qualifier codes of reduced elements are determined using certain thresholds (Figure 15).

Step 3. R is calculated from S using a "chessboard algorithm", for the details see [2] (Figure 16).

Our method has been tested and compared with some commercial systems for watershed analysis [3].

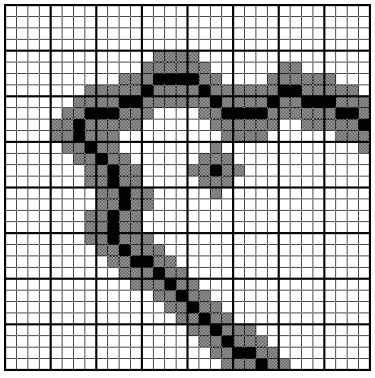

Figure 14. Example of a Z^+ matrix containing a contour line and a single elevation point with buffer zone ($q = 4$)

A DATA MODEL FOR MAP INTERPRETATION

The problem of map interpretation arises when a map is given as an unstructured set of vector data, originated for instance from automatic vectorization of a scanned map. Here interpretation means the recognition of simple and complex map objects.

It is a natural way to use some graph representation for a vectorized drawing. Some papers define attributed graphs, region adjacency graphs or other kinds of relational graphs where nodes represent shape primitives and edges correspond to relations between

			C2	C1		C1	
	C1	C2		C1	C2	C1	C2
		C1		C3			
		C2					
		C1	C1				
			C1	C1			
				C1	C1		

Figure 15. Qualifier codes in the S matrix (generated from Z^+ of Figure 14)

			C2			C1	
		C2			C2		C2
				C3			
		C2					
			C1				
				C1			
					C1		

Figure 16. The R matrix calculated from S

primitives. Another approach is to build a topological model in a relational database [4]. Our data model, named DG (Drawing Graph), combines graph based and topological approaches to handle vector data uniformly during the whole interpretation process [5]. The model can be used also to store and handle structured map data in a database.

Basic element of the model is the *DG-object*. A set Z of objects, describing the current state of interpretation, is called *DG-document*. Z consists of two disjoint subsets:

- Z_n denotes the set of normal objects; they are used to describe the current drawing.
- Z_s denotes the set of sample objects, giving an a priori knowledge description. For instance, sample objects can describe a symbol library of the map legend or vector fonts of a given language.

Each object may have *references* to other objects using their id's. Two types of references can be distinguished. A "contains" reference means that the current object involves the referred object as a component. A "defined by" reference means that the current object is a transformed version of a referred sample object. Such references are mainly used to describe recognized instances of sample objects.

The DG model contains three basic object types:

- A *NODE object* represents a point with coordinates. Normally, a NODE has no references to other objects.
- An *EDGE object* is a straight line section given by "contains" references to the endpoints.
- A *PAT (pattern) object* represents a set of arbitrary DG-objects given by "contains" references to its components.

The object type NODE has an important subtype, termed *TEXT*. Basically it represents a recognized inscription on the drawing with "defined by" reference to a vector font. Generalizing this idea, a TEXT object can be used to describe a transformed instance of any other sample object.

Initially the DG-document contains only sample objects coding prototypes of symbols and characters to be recognized. Interpretation usually starts with some raw vectorization process, as a result a NODE-EDGE graph description of the drawing is inserted in the DG-document. The processing is performed as a sequence of recognition steps, each step may consist of three phases:

1. *Hypothesis generation.* PAT objects are created in the DG-document.
2. *Verification of hypotheses* can be made by the user or by a higher level algorithm: PATs of false hypotheses are marked as "rejected" while correct ones as "accepted".
3. *Finalization.* Rejected hypotheses are dropped and accepted ones are processed by some algorithm, possibly making irreversible changes in the underlying data.

The DG model has been applied to interpret Hungarian cadastral maps. Main processing phases involve raw vectorization, creating topology, dashed line recognition, text recognition, recognizing connection signs, recognizing small circle symbols, drawing correction and recognizing buildings and parcels, as detailed in [5].

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III. SURGICAL PLANNING AND BIOMECHANICAL ANALYSIS

The surgical repair of fractured bones is often a difficult task, and the fixation of these bones has to be planned very carefully. This is why trauma surgeons may use a Computer Aided Surgery (CAS) system to improve surgical accuracy.

Our goal in this project is to develop a suitable CAS system that is also capable of performing biomechanical tests. The program can simulate the biomechanical behavior of possible surgical solutions and calculate its deformations and material stresses. These calculations are based on Finite Element Analysis (FEA). Using these results the surgeon is able to see the week points of the fixation before the surgery. The surgeon can test several surgical plans and based on the biomechanical results he can pick the most promising one.

SURGICAL PLANNING SYSTEM

Figure 17 shows the main parts of the surgical planning system.

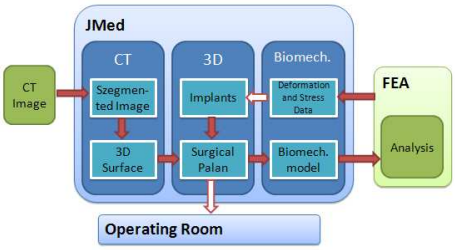

Figure 17. Overview of a surgical planning system.

The system gets its data from CT images. The first step is the segmentation [1] where the differentiation is done between various bone fragments and the background (see Fig. 18). Next, the segmented surface is approximated [3, 4] with a triangle mesh, followed by a surface simplification [2] which reduces the number of triangles in the mesh.

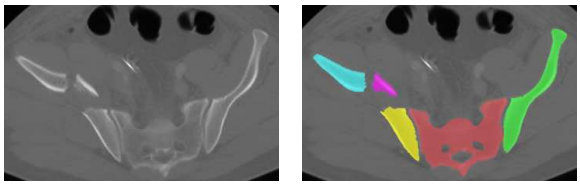

Figure 18. Left: CT slice of a patients pelvic region. Right: the same slice after segmentation.

This surface mesh contains all the geometrical information needed by the surgical planning module. In this module there are two main tasks: fracture reduction and implant insertion.

During fracture reduction the bone fragments are moved and rotated back to their original or healthy positions. Figure 19 shows our example pelvis before and after the reduction step. In [5] we presented two Iterative Closest Point (ICP) based methods for semi-automatic fracture reduction. The first used surface-pairs for the alignment, and required accurate description of the fractured surfaces. The second method used the healthy side - if available - for registration.

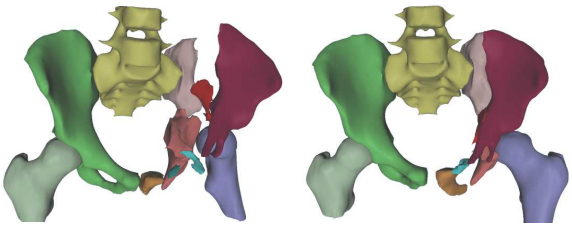

Figure 19. Before (left) and after (right) fracture reduction.

The system under development contains a sophisticated user interface (UI) for the insertion of various screw and plate implants (see Fig. 20 left.)

To simulate the biomechanical behavior of the surgical plan the geometrical model has to be converted into a mechanical model. The FEA mesh is generated from the triangle mesh used for rendering. The addition of load and boundary conditions is handled by the user interface of the planning module.

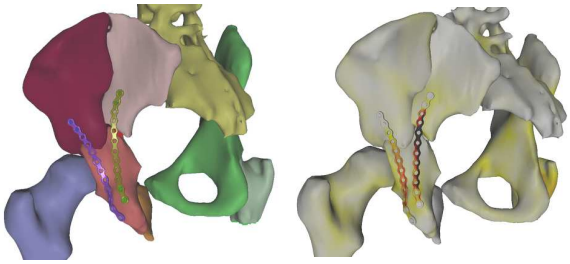

Figure 20. Left: surgical plan of a fractured pelvis. Two plates and 8 screws are visible. Right: result of the biomechanical analysis, deformation and material stress are shown.

The finite element analysis is performed by external software. The results of the analysis, namely the deformation under the load and the material stress are presented in our system, see Fig. 20 right.

CONCLUSION

A novel system was presented to help the surgeon in planning orthopedic operations.

With this system a virtual biomechanical lab was created and various FEA studies of jaw, face, pelvis, hip, spine (see Fig. 21), knee, and wrist (see Fig. 22) were carried out. The tool can be used by the surgeon to create surgical plans for fractured bone fixation and to predict the biomechanical stability of the plan before the operation takes place.

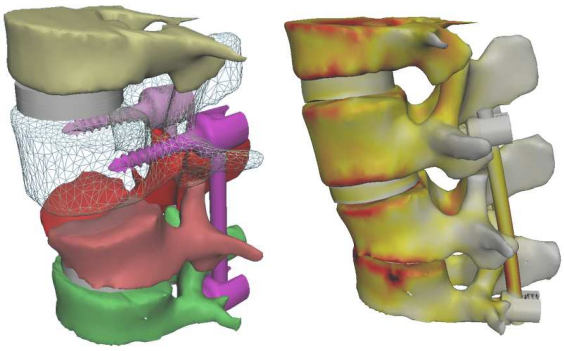

Figure 21. Spine study.

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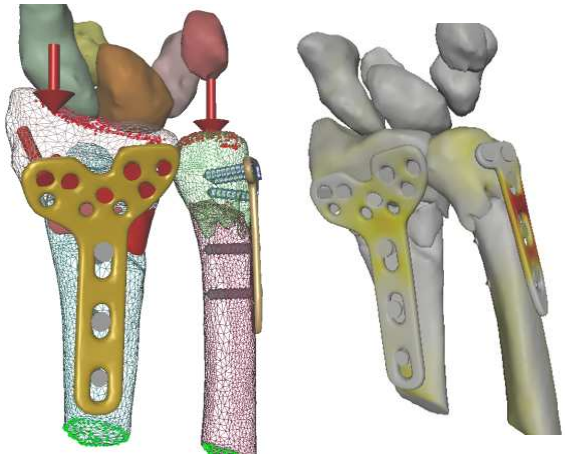

Figure 22. Wrist study.

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IV. IMAGE SEGMENTATION USING THE 'GAS OF CIRCLES' SHAPE PRIOR

The gas of circles (GOC) model is a tool to describe a set of circles with an approximately fixed radius. The model is based on the recently introduced higher-order active contour (HOAC) framework. For certain ranges of the HOAC parameters, the model creates stable circles with an approximately fixed radius instead of networks. We developed an alternative probabilistic formulation of the gas of circles using markov Random Fields (MRF).

The 'gas of circles' model assigns high probability to regions in the image domain consisting of some number of approximately circular connected components, each of which has approximately the same, specified radius, and that are more than a certain distance apart. There are three equivalent formulations of the model: higher-order active contours (HOACs) [2], phase fields [3], and Markov random fields [1]. In the next three subsections, we explain the three formulations, since each provides some insight into the model, and the equivalences between them.

CONTOUR REPRESENTATION

In the contour formulation, a region R is represented by its boundary ∂R, which is an equivalence class (under diffeomorphisms of their domain) of zero or more closed parameterized curves. The HOAC energy for the GOC model is [2]:

$$E_c(\partial R) = \lambda_c L(\gamma) + \alpha_c A(\gamma) - \frac{\beta_c}{2} \int_{T \times T'} dt\, dt'\, n \cdot n'\, G(\gamma - \gamma')\,, \quad (4)$$

where the parameterized curve γ with domain T is an arbitrary member of the equivalence class of parameterized curves corresponding to ∂R, and where L and

A are the boundary length and interior area functionals. The last term of Eq. (4) controls the geometry of the region, where n represents an (un-normalized) normal vector to the boundary, and where here and elsewhere, primed and unprimed maps are evaluated at primed and unprimed points of their domain. In this paper, the *interaction function* G takes the following form, plotted on the left in Fig. 23:

$$G(z) = \begin{cases} \frac{1}{2}\left(2 - \frac{|z|}{d} - \frac{1}{\pi}\sin\left(\frac{\pi(|z|-d)}{d}\right)\right) & \text{if } |z| < 2d, \\ 1 - H(|z| - d) & \text{otherwise,} \end{cases} \tag{5}$$

where d controls the range of interaction and H is the Heaviside step function. Horvath *et al.* showed in [2] that if the parameter triple $(\lambda_c, \alpha_c, \beta_c)$ satisfies certain constraints, circular regions of a given radius r will be local minima of the energy, and thus stable, thereby yielding the HOAC GOC model.

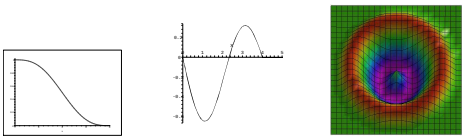


Figure 23. Left: a slice of the interaction function $G(z)$ for $d = 2$. Middle and right: a slice and a 2D plot of the corresponding geometric kernel $\mathcal{G}$.

PHASE FIELD REPRESENTATION

The phase field framework represents a region R by a real-valued function $\phi : \mathcal{D} \to \mathbb{R}$ on the image domain $\mathcal{D}$, and a threshold t: $R = \zeta_t(\phi) = \{x \in \mathcal{D} : \phi(x) \geq t\}$. The phase field energy E_f corresponding to the contour energy E_c is [4]:

$$E_f(\phi) = \int_{\mathcal{D}} \frac{D_f}{2}|\nabla\phi|^2 + \lambda_f\left(\frac{\phi^4}{4} - \frac{\phi^2}{2}\right) + \alpha_f\left(\phi - \frac{\phi^3}{3}\right) - \frac{\beta_f}{2}\int_{\mathcal{D}\times\mathcal{D}'} \nabla\phi\cdot\nabla'\phi'\, G(x-x'). \tag{6}$$

The (many-to-one) map ζ_t from phase fields to regions means that the probability distribution on phase fields ϕ induced by taking E_f as a Gibbs energy defines a probability distribution on regions, and thus, by composition with ∂, on boundaries. The zeroth-order saddle point approximation to this latter distribution is found by maximizing the probability, and hence minimizing E_f, over functions ϕ corresponding to a given region R under ζ_t. (This procedure also ensures that MAP estimates will be preserved by ζ_t.) Now, the function ϕ_R that minimizes E_f for a fixed region R takes the values $+1$ inside R and -1 outside R, away from the boundary ∂R, while changing smoothly from -1 to $+1$ in a narrow interface region around ∂R. Substitution of ϕ_R into E_f then gives an energy of the form Eq. (4), thus showing the equivalence, and providing relationships between the parameters, of the two models. The constraints on the parameters of the HOAC GOC model ensuring stability for circles of the desired radius, can thus be translated to the phase field version [2, 3], thereby yielding the phase field HOAC GOC model.

For the sequel, it is convenient to integrate the non-local term in Eq. (6) by parts twice:

$$-\frac{\beta_f}{2}\int_{\mathcal{D}\times\mathcal{D}'} \nabla\phi\cdot\nabla'\phi'\, G(x-x') = \frac{\beta_f}{2}\int_{\mathcal{D}\times\mathcal{D}'} \phi\,\phi'\, \underbrace{\nabla^2 G(x-x'))}_{\mathcal{G}(x-x')}. \tag{7}$$

The linear operator $\mathcal{G}$, plotted in Fig. 23, acts directly on the phase field ϕ as a *geometric kernel*.

BINARY MRF REPRESENTATION

As can be seen from Eq. (6), a phase field model can be viewed as a real-valued, continuum Markov random field. Naturally, in order to make computational (or even theoretical) sense of such a model, we have to impose a frequency cut-off, *i.e.* we have to discretize the domain of ϕ, leading to a discrete image domain $\mathcal{S} \subset \mathbb{Z}^2$ instead of $\mathcal{D} \subset \mathbb{R}^2$. In addition, however, the form of E_f means that probability is concentrated around configurations in which the field takes the values ± 1 except in a narrow interface region. It therefore makes sense computationally to restrict the allowed values of the field to ± 1, *i.e.* to restrict to binary-valued fields $\omega : \mathcal{S} \to \mathbb{B}$, where $\mathbb{B} = \{-1, +1\}$.

The map ζ_t, now supposed to act on functions on $\mathcal{S}$, provides a many-to-one map from phase fields on $\mathcal{S}$ to binary fields, and it can be used to push forward the probability distribution on phase fields to one on binary fields. The zeroth-order saddle point approximation to the integral involved is found in the same way as before, except that now the energy must be expressed in terms of the binary field.[1]

Once this discretization and binarization have been performed, one has a binary MRF [1]. The resulting Gibbs energy is

$$U(\omega) = \alpha\sum_s \omega_s + \frac{D}{2}\sum_s\sum_{s'\sim s}(\omega_s - \omega_{s'})^2 + \frac{\beta}{2}\sum_{s,s'} F_{ss'}\,\omega_s\,\omega_{s'}, \tag{8}$$

where $s \in \mathcal{S}$ denotes lattice sites (or pixels) and $\sim$ is the nearest neighbor relation. The model parameters are related to the phase field model as follows: $\alpha = \frac{2\alpha_f}{3}$, $\beta = \beta_f$, while $D = \frac{0.82 D_f}{4}$ incorporates the integral over pairs of boundary lattice cells. $F_{ss'}$ is a discrete approximation of $\mathcal{G}$ [1], which also determines the size of the neighborhood: $\{s' \in \mathcal{S} : |s - s'| < 2d\}$ as shown in Fig. 24. The singleton potential $\alpha\omega_s$ corresponds to an area term: a lower α favors larger regions, and vice versa, while the doubleton potential $D(\omega_s - \omega_{s'})^2$ acting over the nearest neighborhood of s ensures smoothness by penalizing boundary length. Finally, the *long-range* potentials $F_{ss'}$ enforce the geometric constraints yielding stable circles. From Fig. 24, it is clear that the *long-range* potentials favor the same label when $|s - s'| < d'$ (*attractive* case) and different labels when $d' < |s - s'| < 2d$ (*repulsive* case), where $d' \simeq d$ is the zero of $\mathcal{G}$.

Once again, the stability constraints on the parameters can be translated, from the HOAC model to the phase field model to the binary field model, thereby yielding the MRF GOC model [1].

[1] Note that the sets of regions in the image of ζ_t in the HOAC and binary field cases are not exactly the same, since the frequency cut-off is different; being a cut-off in Fourier space in the first case, and a spatial discretization in the second.

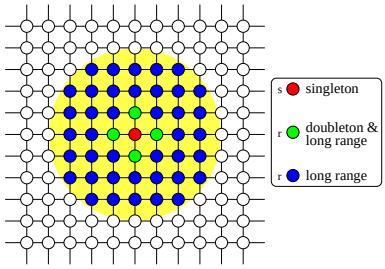


Figure 24. MRF neighbourhood.

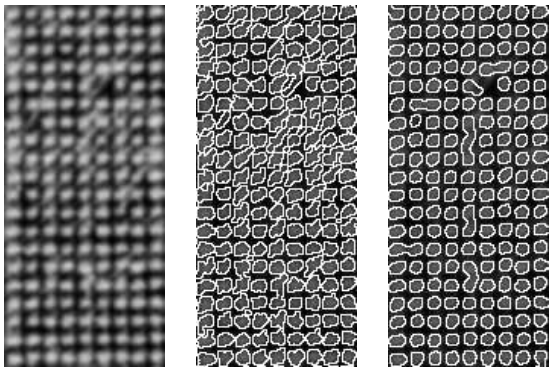


Figure 25. From left to right: image of poplars ©IFN (0.71, 0.075, 0.18, 0.075); the best result with a classical active contour $(35000, 100, 500)$; result with the 'gas of circles' HOAC model $(1200, 20, 100, 82, 3.5, 3.5)$.

CONCLUSION

We have constructed a new binary segmentation model that includes prior information about the shape of the region to be segmented, in this case, that it be composed of an arbitrary number of circles of a certain radius. In addition to classical homogeneity terms, the model includes terms that encourage inhomogeneity at long ranges, in order to capture nonlocal geometric properties. A probabilistic MRF model was derived in a principled fashion from a continuous 'gas of circles' phase field model. It is 'equivalent' to the continuous model in a well-defined way, thereby guaranteeing that stability conditions in the phase field model remain valid in the new model. Experimental tests on various synthetic and real images confirm the performance of the 'gas of circles' model.

COLLABORATION

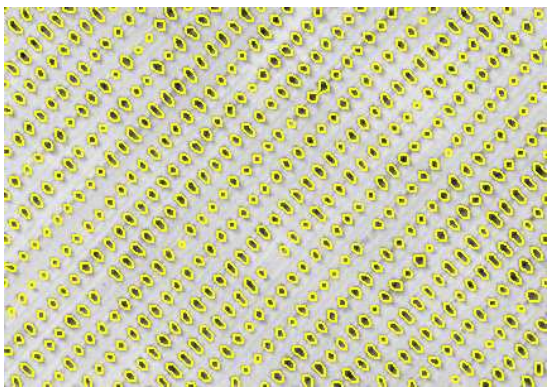
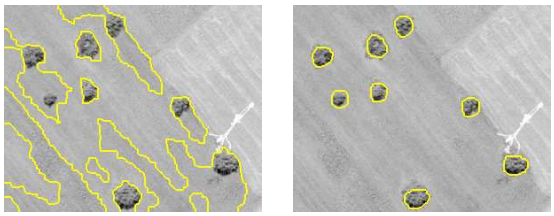


Figure 26. Tree detection result of the gocMRF model on an aerial image of a regularly planted pine forest.



Classical MRF gocMRF

Figure 27. Aerial image of sparsely planted trees. The classical MRF fails because the intensities of the foreground and background are similar making separation ambiguous.

This work is a joint research with ARIANA research group of INRIA Sophia Antipolis, France.

ACKNOWLEDGEMENT

This work was sponsored by a Hungarian-French Bilateral Grant PAI Balaton (F-3/04), EU project MUSCLE (FP6-507752), Hungarian Scientific Research Fund – OTKA T046805 and a János Bolyai Research Fellowship of the Hungarian Academy of Sciences. Péter Horváth was having his scholarship through the Doctoral School of the University of Szeged, Hungary and the Ministry of Foreign Affaires, France.

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V. ESTIMATION OF LINEAR SHAPE DEFORMATIONS

Registration is a crucial step in almost all image processing tasks where images of different views or sensors of an object need to be compared or combined. Typical application areas include visual inspection, target tracking, super resolution, shape modeling, object recognition, or medical image analysis. In a general setting, one is looking for a transformation which aligns two images such that one image (template) becomes similar to the second one (observation). The classical way to solve this registration problem is to find correspondences between the two images and then determine the transformation parameters from these landmarks usually utilizing an iterative optimization procedure. Here we propose novel approaches where

the exact transformation is obtained as the solution of either a polynomial or a linear system of equations using covariant functions.

Let us denote the points of the *template* and the *observation* by $\mathbf{x}, \mathbf{y} \in \mathbb{P}^2$ respectively (*i.e.* we use homogeneous coordinates). $\mathbf{A}$ is the unknown non-singular linear transformation that we want to recover. We can define the identity relation as follows

$$\mathbf{A}\mathbf{x} = \mathbf{y} \quad \Leftrightarrow \quad \mathbf{x} = \mathbf{A}^{-1}\mathbf{y}. \tag{9}$$

If we can observe some image features (*e.g.* gray-level of the pixels [5]) that are invariant under the transformation $\mathbf{A}$ then the following equality also holds

$$g(\mathbf{x}) = h(\mathbf{A}\mathbf{x}) \quad \Leftrightarrow \quad g(\mathbf{A}^{-1}\mathbf{y}) = h(\mathbf{y}). \tag{10}$$

Furthermore, the above equations still hold when an *invariant function* $\omega : \mathbb{R}^n \to \mathbb{R}^n$ is acting on both sides of the equations. Indeed, for a properly chosen ω

$$\omega(\mathbf{x}) = \omega(\mathbf{A}^{-1}\mathbf{y}), \quad \text{and} \tag{11}$$
$$\omega(g(\mathbf{x})) = \omega(h(\mathbf{A}\mathbf{x})) = \omega(h(\mathbf{y})). \tag{12}$$

The basic idea of the proposed approach is to generate enough linearly independent equations by making use of the relations in Eq. (9)–(12). Furthermore, we can get rid of the need for point correspondences by integrating both sides of the equations over the corresponding segmented domains.

Recently, similar ideas have been successfully applied by our collaborating partners at BGU to graylevel image registration [5,6], where one can make use of rich radiometric features to build a system of linear equations. However, these approaches cannot be used in the binary case due to the missing radiometric information. Therefore the main challenge of the proposed research is to find a way to construct a **direct** method to estimate linear deformations **without** making use of feature correspondences or complex optimization algorithms. We propose two ways to tackle this fundamental problem.

SOLUTION VIA A POLYNOMIAL SYSTEM

The first one makes use of Eq. (11) and constructs a system of polynomial equations

$$\int \omega(\mathbf{x}) d\mathbf{x} = \frac{1}{|\mathbf{A}|} \int \omega(\mathbf{A}^{-1}\mathbf{y}) d\mathbf{y}. \tag{13}$$

Obviously, the choice of ωs is crucial as our goal is to construct a system which can be solved. It is easy to see that a polynomial system, which is certainly straightforward to solve, is obtained when $\omega(x) = x^i$. From a geometric point of view, for $\omega(x) \equiv x$ Eq. (13) simply matches the center of mass of the *template* and *observation* while for $\omega(\mathbf{x}) = [x_1^i, x_2^i, 1]^T$ Eq. (13) matches the center of mass of the shapes obtained by the nonlinear transformations ω (see Fig. 28).

$\omega(\mathbf{x}) = \mathbf{x}$ $\quad \omega(\mathbf{x}) = [x_1^2, x_2^2, 1]^T$ $\quad \omega(\mathbf{x}) = [x_1^3, x_2^3, 1]^T$

Figure 28. The effect of the *invariant functions* (ω) acting directly on the coordinates.

(a) (b) (c)

Figure 29. Gaussian density function fitted over the binary shape yields a consistent coloring. (a) Original binary image; (b) 3D plot of the Gaussian density function over the binary shape; (c) Gaussian density as a grayscale image.

BINARY OBJECT REPRESENTATION

The polynomial system of equations in Eq. 13 is derived in the continuous space. However, digital image space provides only limited precision for these derivations and the integral can only be approximated by a discrete sum over the pixels. There are many approaches for discretization of a continuous function.

Our first method expects a discrete image created by sampling the continuous function at uniform grid positions, leading to a binary representation [2–4].

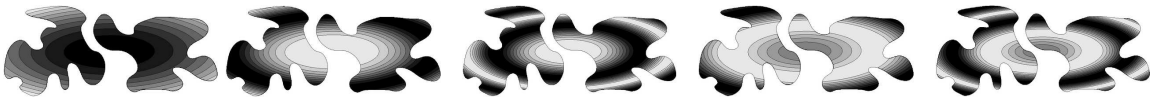
FUZZY BORDER REPRESENTATION

We extended our method by investigating the case when the segmentation method is capable of producing fuzzy object descriptions instead of a binary result [7]. It has been shown via synthetic tests that the information preserved by using fuzzy representation based on *area coverage* (see Fig. 31) may be successfully utilized to improve precision and accuracy of the registration method. In real applications we need a segmentation method that provides fuzzy results. With an intention to show the applicability of the approach, but to not focus on designing a completely new fuzzy segmentation method, we derived pixel coverage values from an Active Contour segmentation, which provides a crisp parametric representation of the object contour. From such a representation it is fairly straightforward to compute pixel coverage values.

Figure 31. Binary (left) and area coverage based fuzzy representation (right) of a filled arc

SOLUTION VIA A LINEAR SYSTEM USING COVARIANT FUNCTIONS

The second solution [1] is based on Eq. (12). The advantage of this approach is that it yields a linear system of equations which is numerically much more stable. The key idea is to construct two *covariant functions* satisfying Eq. (10). Once this is achieved, we can construct a linear system using Eq. (12) to solve for the unknown transformation $\mathbf{A}$. Since we do not have any radiometric information, this is a quite challenging task as we have to define these functions based on the only available geometric information. For example, we can consider the points of the *template* as a sample from a normally distributed random variable $X \sim N(\mu, \Sigma)$. It is well known, that for any linear



(a) $\omega(x) = x$ (b) $\omega(x) = \cos(x)$ (c) $\omega(x) = \cos(2x)$ (d) $\omega(x) = \sin(x)$ (e) $\omega(x) = \sin(2x)$

Figure 30. The effect of the *invariant functions* (ω) acting on the colored image in Fig. 29. Level lines are overlayed on the original graylevel images for easier evaluation.

transformation, when $Y = \mathbf{A}X$ then Y has also a normal distribution

$$X \mapsto Y \sim N(\mu', \Sigma') = N(\mathbf{A}\mu, \mathbf{A}\Sigma\mathbf{A}^T),$$

furthermore

$$p'(\mathbf{y}) = \frac{1}{|\mathbf{A}|} p(\mathbf{x}),$$

where p' and p are the Gaussian density functions. It is clear that p and p' are *covariant* and the Jacobian can also be computed as $|\mathbf{A}| = \sqrt{|\Sigma'|/|\Sigma|}$. Obviously, the above relation is only valid when $\mathbf{A}$ is positive definite. The parameters of the probability densities $N(\mu, \Sigma)$ and $N(\mu', \Sigma')$ can be easily estimated as the sample means and covariances (*i.e.* the mean and covariance of the point coordinates). From a geometric point of view, the mean values μ and μ' represent the center of mass of the *template* and *observation* respectively, while Σ and Σ' capture the orientation and eccentricity of the shapes. Fig. 29 shows a binary shape and the fitted Gaussian density. Note that the densities p' and p can be further reduced to the corresponding Mahalanobis distances g and h

$$g(\mathbf{x}) = (\mathbf{x} - \mu)^T \Sigma^{-1} (\mathbf{x} - \mu)$$

and

$$h(\mathbf{y}) = (\mathbf{y} - \mu')^T \Sigma'^{-1} (\mathbf{y} - \mu').$$

New equations can then be generated by making use of appropriate *invariant functions* $\omega : \mathbb{R} \to \mathbb{R}$. Thus we get

$$\int \mathbf{x}\omega(g(\mathbf{x}))d\mathbf{x} =$$

$$\int \mathbf{x}\omega(h(\mathbf{A}\mathbf{x}))d\mathbf{x} = \frac{1}{|\mathbf{A}|} \int \mathbf{A}^{-1}\mathbf{y}\omega(h(\mathbf{y}))d\mathbf{y}.$$

Theoretically any *invariant function* could be applied. For example the following set of functions gave us good results (see Fig. 30): x, $\cos(x)$, $\cos(2x)$, $\sin(x)$ and $\sin(2x)$.

CONCLUSION

We have presented a novel framewrok for binary image registration. The fundamental difference compared to classical image registration algorithms is that our model works without any landmark, feature detection or optimization. It uses all the information available in the input images, but there is no need for an established correspondence between them.

COLLABORATION

Part of this work is a joint research with

- Department of Electrical and Computer Engineering, Ben-Gurion University of the Negev, Israel
- Faculty of Engineering, University of Novi Sad, Serbia
- Centre for Image Analysis, Swedish University of Agricultural Sciences, Uppsala, Sweden

ACKNOWLEDGEMENT

This research was partially supported by

- Hungarian Scientific Research Fund (OTKA – K75637)
- PhD Scholarship of the Doctoral School in Mathematics and Computer Science of the University of Szeged
- Predoctoral fellowship of the Foundation for Education and Research in Informatics
- CEEPUS

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Figure 32. Some registration results with the overlaid contour are presented in the context of various real application.

VI. RECOVERING DIFFEOMORFIC SHAPE DEFORMATIONS WITHOUT CORRESPONDENCES

We propose a novel framework to estimate the parameters of a diffeomorphism that aligns a known shape and its distorted observation. Classical registration methods first establish correspondences between the shapes and then compute the transformation parameters from these landmarks. Herein, we trace back the problem to the solution of a system of nonlinear equations which directly gives the parameters of the aligning transformation. The proposed method provides a generic framework to recover any diffeomorphic deformation without established correspondences. It is easy to implement, less sensitive to the strength of the deformation, and robust against segmentation errors. The method has been applied to several commonly used transformation models. The performance of the proposed framework has been demonstrated on large synthetic datasets as well as in the context of various applications.

REGISTRATION FRAMEWORK

In the general case, we want to recover the parameters of an arbitrary $\varphi : \mathbb{R}^2 \to \mathbb{R}^2$ *diffeomorphism* which aligns a pair of shapes. Let us denote the point coordinates of the *template* and *observation* by $\mathbf{x} = [x_1, x_2]^T \in \mathbb{R}^2$ and $\mathbf{y} = [y_1, y_2]^T \in \mathbb{R}^2$ respectively. The following identity relation is assumed between the point coordinates of the shapes:

$$\mathbf{y} = \varphi(\mathbf{x}) \quad \Leftrightarrow \quad \mathbf{x} = \varphi^{-1}(\mathbf{y}), \tag{14}$$

where $\varphi^{-1} : \mathbb{R}^2 \to \mathbb{R}^2$ is the corresponding inverse transformation. Note that φ^{-1} always exists since a diffeomorphism is a bijective function such that both the function and its inverse have continuous mixed partial derivatives. Suppose that shapes are represented by their characteristic function $\mathbb{1} : \mathbb{R}^2 \to \{0, 1\}$, where 0 and 1 correspond to the background and foreground respectively. If we denote the *template* by $\mathbb{1}_t$ and the *observation* by $\mathbb{1}_o$, the following equality also holds

$$\mathbb{1}_o(\mathbf{y}) = \mathbb{1}_o\big(\varphi(\mathbf{x})\big) = \mathbb{1}_t(\mathbf{x}), \tag{15}$$

since $\mathbf{x}$ and $\mathbf{y}$ are corresponding point coordinates.

Classical landmark based approaches would now set up a system of equations from Eq. (14) using point correspondences. However, we are interested in a direct approach without solving the correspondence problem. As a consequence, we cannot directly use Eq. (14)–(15) because we do not have established point pairs. However, we can multiply these equations and then integrate out individual point correspondences yielding

$$\int_{\mathbb{R}^2} \mathbf{y}\mathbb{1}_o(\mathbf{y})d\mathbf{y} = \int_{\mathbb{R}^2} \varphi(\mathbf{x})\mathbb{1}_t(\mathbf{x})\,|J_\varphi(\mathbf{x})|\,d\mathbf{x}, \tag{16}$$

where the integral transformation $\mathbf{y} = \varphi(\mathbf{x})$, $d\mathbf{y} = |J_\varphi(\mathbf{x})|\,d\mathbf{x}$ has been applied. The Jacobian determinant $|J_\varphi| : \mathbb{R}^2 \to \mathbb{R}$

$$|J_\varphi(\mathbf{x})| = \begin{vmatrix} \frac{\partial \varphi_1}{\partial x_1} & \frac{\partial \varphi_1}{\partial x_2} \\ \frac{\partial \varphi_2}{\partial x_1} & \frac{\partial \varphi_2}{\partial x_2} \end{vmatrix} \tag{17}$$

gives the measure of the transformation at each point. Note that in the case of affine (*i.e.* linear) transformations, the partial derivatives of the distortion are constants, hence the Jacobian is also constant and the transformation measure can be simply computed as the ratio of the shape areas. This property has been explored in [1]. Herein, however, the transformation is nonlinear causing the Jacobian to become a non-constant function of the coordinates.

Since multiplying with the characteristic functions essentially restricts the integral domains to the foreground regions $\mathcal{F}_t = \{\mathbf{x} \in \mathbb{R}^2 | \mathbb{1}_t(\mathbf{x}) = 1\}$ and $\mathcal{F}_o = \{\mathbf{y} \in \mathbb{R}^2 | \mathbb{1}_o(\mathbf{y}) = 1\}$, we obtain the following finite integral equation:

$$\int_{\mathcal{F}_o} \mathbf{y}d\mathbf{y} = \int_{\mathcal{F}_t} \varphi(\mathbf{x})\,|J_\varphi(\mathbf{x})|\,d\mathbf{x}. \tag{18}$$

The diffeomorphism φ can be decomposed as

$$\varphi(\mathbf{x}) = [\varphi_1(\mathbf{x}), \varphi_2(\mathbf{x})]^T, \tag{19}$$

where $\varphi_1, \varphi_2 : \mathbb{R}^2 \to \mathbb{R}$ are coordinate functions. Hence Eq. (18), which is in *vector form*, can be decomposed into a system of two equations using these coordinate functions:

$$\int_{\mathcal{F}_o} y_i d\mathbf{y} = \int_{\mathcal{F}_t} \varphi_i(\mathbf{x})\,|J_\varphi(\mathbf{x})|\,d\mathbf{x}, \quad i = 1, 2. \tag{20}$$

The parameters of φ are the unknowns of these equations. Usually, φ has more than two unknown parameters therefore a system of two equations is not enough to recover φ.

CONSTRUCTION OF THE SYSTEM OF EQUATIONS

First of all, let us notice that the identity relation in Eq. (14) remains valid when a function $\omega : \mathbb{R}^2 \to \mathbb{R}$

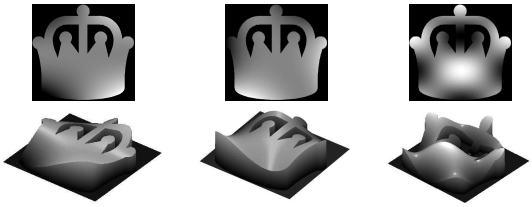

Figure 33. The effect of various ω functions. **Top**: the generated coloring of a binary shape. **Bottom**: the corresponding volumes.

is acting on both sides of the equation [1–3]. Indeed, for a properly chosen ω

$$\omega(\mathbf{y}) = \omega(\varphi(\mathbf{x})) \quad \Leftrightarrow \quad \omega(\mathbf{x}) = \omega(\varphi^{-1}(\mathbf{y})). \tag{21}$$

Thus the following integral equation is obtained from Eq. (18)

$$\int_{\mathcal{F}_o} \omega(\mathbf{y}) d\mathbf{y} = \int_{\mathcal{F}_t} \omega\big(\varphi(\mathbf{x})\big)\, |J_\varphi(\mathbf{x})|\, d\mathbf{x}. \tag{22}$$

The basic idea of the proposed framework is to generate sufficiently many linearly independent equations using a set of nonlinear ω functions. Let the number of parameters of φ denoted by k and let $\{\omega_i\}_{i=1}^{\ell}, \omega_i : \mathbb{R}^2 \to \mathbb{R}$ denote the set of adopted nonlinear functions. In order to solve for all unknowns, we need at least k equations, hence $\ell \geq k$. We thus obtain the following system of equations

$$\int_{\mathcal{F}_o} \omega_i(\mathbf{y}) d\mathbf{y} = \int_{\mathcal{F}_t} \omega_i\big(\varphi(\mathbf{x})\big)\, |J_\varphi(\mathbf{x})|\, d\mathbf{x}, \qquad i = 1, \ldots, \ell, \tag{23}$$

where each ω_i function provides one new equation. Note that the generated equations provide no new information, they simply impose additional linearly independent constraints. The solution of the system gives the parameters of the aligning transformation. Intuitively, each ω_i generates a consistent coloring of the shapes as shown in Fig. 33. From a geometric point of view, Eq. (18) simply matches the center of mass of the *template* and *observation* while the new equations in Eq. (22) match the volumes over the shapes constructed by the nonlinear functions ω_i (see Fig. 33).

Figure 34. Registration results. **Top:** *templates*. **Bottom:** the corresponding registration results. The first image pair shows the segmented regions used for registration.

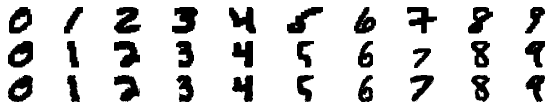

Figure 35. Sample images from the MNIST dataset and registration results using a thin plate spline model. First and second rows show the images used as *templates* and *observations* while the last row show the registration results obtained by the proposed method.

CONCLUSION

Experimental results show that the proposed method provides good alignment on both real and synthetic images. Furthermore, its robustness has been demonstrated on a large synthetic dataset as well as on real images. Although our method clearly dominates state of the art correspondence-based methods, it has to be noted that, being calculated from the whole object, our equations are sensitive to partial occlusions. On the other hand, a common limitation of classical approaches is that they assume a deformation close to identity in order to establish reliable correspondences. Therefore we see our contribution as a complementary method rather than a replacement for all previous registration algorithms. Its superiority can be fully exploited in applications where occlusion can be kept at a minimum (*e.g.* medical imaging or industrial inspection), while feature-based methods can be more efficient when occlusions are common (*e.g.* surveillance). A rigorous theoretical analysis on selecting an optimal $\{\omega_i\}$ set has also been carried out and our findings have been confirmed experimentally. A unique feature of the proposed framework is that it can be used not only with standard transformations but also with application-specific deformation models.

ACKNOWLEDGEMENT

This research was partially supported by

- Hungarian Scientific Research Fund (OTKA – K75637)
- PhD Scholarship of the Doctoral School in Mathematics and Computer Science of the University of Szeged
- Predoctoral fellowship of the Foundation for Education and Research in Informatics
- TAMOP-4.2.2/08/1/2008-0008 program of the Hungarian National Development Agency
- ContiTech Fluid Automotive Hungária Ltd.

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VII. SKELETINIZATION BY THINNING IN 3D

Skeleton is a region–based shape feature to represent the general form of an object. Skeletonization (i.e., skeleton extraction from binary objects) in 3D has become a very challenging task in various medical and engineering applications. Thinning is a frequently used technique for producing a reasonable approximation to the skeleton or extracting skeleton-like features (i.e., centerline or topological kernel).

SKELETON AS A SHAPE FEATURE

Shape is a fundamental concept in computer vision. It can be regarded as the basis for high–level image processing stages concentrating on scene analysis and interpretation. There are basically two different approaches for describing the shape of an object:

- using the boundary that surrounds it and
- using the occupied region.

Boundary–based techniques are widely used but there are some deficiencies which limit their usefulness in practical applications especially in 3D. Therefore, the importance of the region–based shape features shows upward tendency. The local object symmetries represented by the skeleton certainly cannot replace boundary–based shape descriptors, but complement and support them.

The skeleton is a region–based shape feature that has been proposed by Blum as the result of the Medial Axis Transform. A very illustrative definition of the skeleton is given using the prairie–fire analogy: the object boundary is set on fire and the skeleton is formed by the loci where the fire fronts meet and quench each others. The formal definition of the skeleton has been stated by Calabi: the skeleton of an object is the locus of the centers of all the maximal inscribed hyperspheres. The continuous skeleton of a solid 3D box is illustrated in Fig. 36.

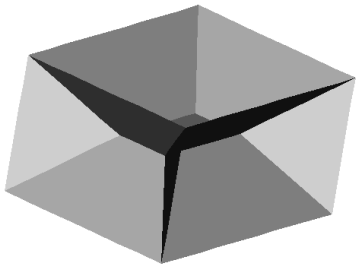

Figure 36. Example of 3D skeleton. The original object was a solid box. Note, a skeleton in 3D generally contains surface pathes (i.e., branched 2D manifolds).

SKELETONIZATION TECHNIQUES IN DISCRETE SPACES

During the last two decades skeletonization in the digital image raster has been an important research field. There are two major requirements to be complied with. The first one is geometrical. It means that the "skeleton" must be in the "middle" of the object and invariant under geometrical transformations. The second one is topological requiring that the "skeleton" must be topologically equivalent to the original object.

There are three major discrete skeletonization methods:

- based on distance transformation,
- thinning, and
- based on Voronoi–diagram.

The first method is to find the maximal inscribed hyperspheres. It requires the following 3–step process:

1. The original binary picture is converted into another one consisting feature and nonfeature elements. The feature elements belong to the boundary of the discrete object.
2. The distance map is generated where each element has a value that approximates the distance to the nearest feature element.
3. The detection of ridges (local extremas) as the centers of maximal inscribed hyperspheres.

Unfortunately, the result of the distance transformation depends on the selected distance and the ridge extraction is a rather difficult task. The distance map based method fulfils the geometrical requirement if a good approximation to the Euclidean distance is applied, but the topological correctness is not guaranteed.

The thinning process is to simulate the fire–front propagation: a layer by layer erosion is executed until the "skeleton" is left. The iterative process is shown in Fig. 37. The topological aspect is taken care by thinning. On the other hand the geometrical requirement correctness (i.e., invariance under arbitrary rotations) is not guaranteed.

The Voronoi diagram of a discrete set of points (called generating points) is the partition of the given space into cells so that each cell contains exactly one generating point and the locus of all points which are nearer to this generating point than to other generating points. It is shown that the skeleton of an object which is described by a set of boundary points can be approximated by a subgraph of the Voronoi diagram of that generating points.

Both requirements can be fulfilled by the skeletonization based on Voronoi diagrams but it is regarded as an expensive process, especially for large and complex objects.

We prefer thinning, since it:

- preserves topology,
- makes easy implementation possible (as a sequence of local Boolean operations),
- can produce different types of skeleton-like shape features (see fig. 38),
- takes the least computational costs, and
- can be executed in parallel.

THINNING METHODOLOGIES

A 3D binary picture is a mapping that assigns value of 0 or 1 to each point with integer coordinates in the 3D digital space denoted by $\mathbb{Z}^3$. Points having the value of 1 are called black points, while 0's are called white ones. Black points form objects of the picture. White points form the background and the cavities of the picture. Both the input and the output of a picture operation are pictures. An operation is reduction if it can delete some black points (i.e., changes them to white) but white points remain the same. There is a fairly general agreement that a reduction operation is *not* topology preserving if any object in the input picture is split (into two or more ones) or completely deleted, if any cavity in the input picture is merged with the background or another hole, or if a cavity is created where there was none in the input picture. There is an additional concept called hole in 3D pictures. A hole (that doughnuts

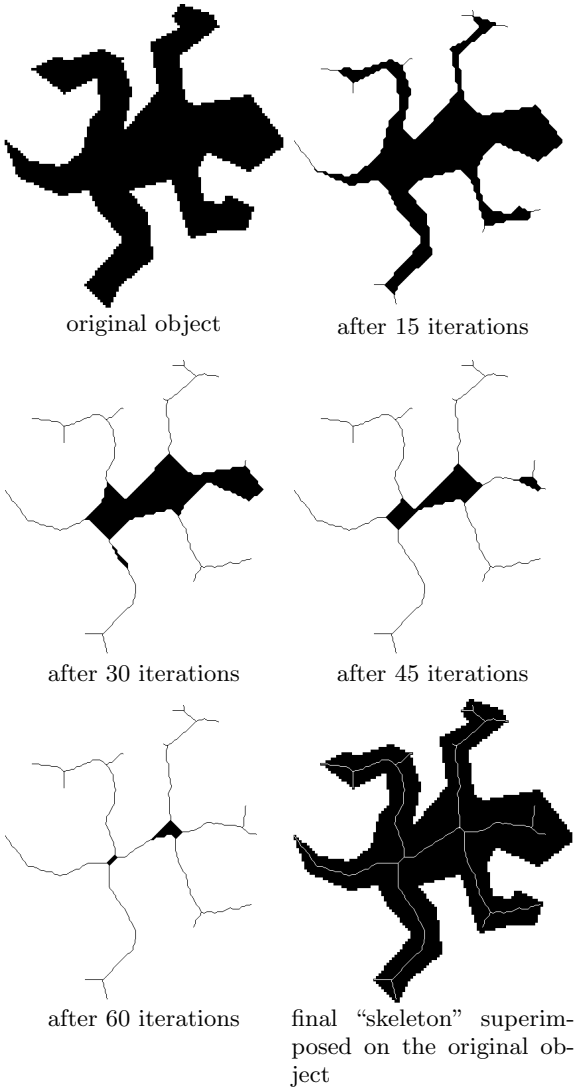

Figure 37. Example of thinning in 2D. The size of the test image is 430×460

have) is formed by 0's, but it is not a cavity. Topology preservation implies that eliminating or creating any hole is not allowed.

Thinning must be a topology–preserving reduction. Existing 3D thinning algorithms can be classified from several points of view. One of them is the classification on the produced skeletons: surface-thinning algorithms result in medial surfaces, curve-thinning ones can produce medial lines, and shrinking algorihms extract topological kernels.

Since the fire front propagation is by nature parallel, most of the existing thinning algorithms are parallel (i.e., all border points satisfying the deletion condition of the actual phase of the process are deleted simultaneously) [1–8]. Despite of this fact, we have proposed two sequential thinning algorithms [9, 10].

APPLICATIONS

Thinning is a common preprocessing operation in raster–to–vector conversion or in pattern recognition. Its goal is to reduce the volume of elongated objects. Some important applications have been appeared in medical image processing, too [11–15].

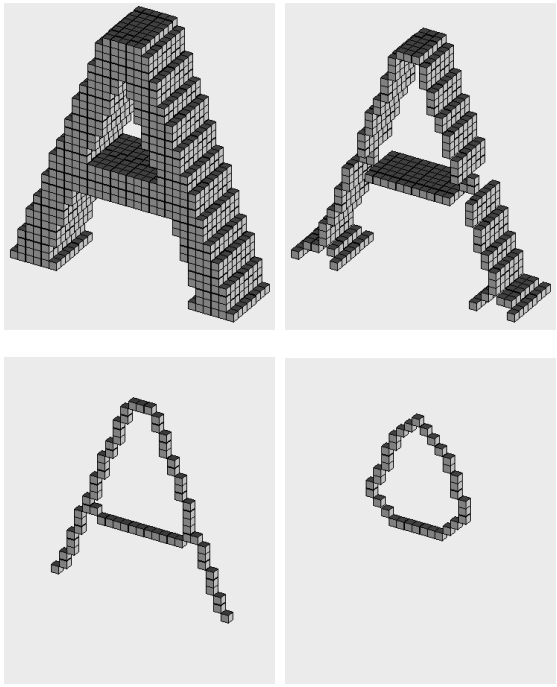

Figure 38. Different types of 3D "skeletons". The original elongated object (upper left), its medial surface produced by a surface thinning algorithm (upper right), its medial line (bottom left) extracted by a curve thinning algorithm, and its topological kernel (i.e., a minimal structure being topologically equivalent to the original object) created by a shrinking algorithm(bottom right). (Each small cube represents an object voxel.)

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VIII. RETINA IMAGE ANALYSIS

Images of the eye ground not only provide an insight to important parts of the visual system but also reflect the general state of health of the entire human body. Preventive medicine and large scale screenings become more and more important due to the high treatment costs, or simply because at an advanced stage, disease treatment may no longer be possible. This is also the case with glaucoma, wherein the significant loss of optic nerve fibers leads to irreversible vision loss, making glaucoma one of the most common causes of blindness. The objective of our current research is to devise robust automatic methods usable in screening applications for risk analysis and early detection of glaucoma.

We focus on a novel automated classification system for glaucoma, based on image features derived from color fundus photographs. These images are acquired by a digital fundus camera that, in contrast to other modalities, is a low priced imaging device widely available and commonly applied for basic eye examinations, which makes it one of the most capable devices for screening applications and clinical trials. Although digital color fundus images were already considered, for example, for automated analysis of diabetic retinopathy, in glaucoma evaluation they are mostly used for visual inspection only. Most existing computer aided analysis of retina images for glaucoma evaluation are based on some kind of image segmentation, which is mostly done manually or by semi-automated methods. The drawback of hard, segmentation-based techniques is that small errors in localization and/or delineation may lead to significant errors in the measurements and consequently in diagnosis.

Our new data-driven approach requires no manual assistance and does not depend on explicit structure segmentation and measurements. First, disease independent variations are reduced/eliminated from the images. Nonuniform illumination is corrected by a polynomial surface fitting technique, size differences are compensated for by cropping and appropriate scaling, and blood vessels are eliminated by image inpainting. The features extracted from the preprocessed images comprise of raw pixel intensities, coefficients of the FFT of the image, and coefficients of a B-spline representation of the image. These high-dimensional feature vectors are compressed via PCA before classification with SVMs takes place in a two-stage classification scheme. In Stage 1, probabilistic SVM classifiers separately trained for each feature type will act on the PCA compressed feature vectors. Their output values are taken as a new (low-dimensional) input feature vector for the Stage 2, 'combining' SVM classifier, that outputs one single probabilistic glaucoma index what we call Glaucoma Risk Index (GRI).

Several hundred images were randomly selected from the Erlangen Glaucoma Registry that contains thousands of records of multi-modal fundus images from a long-term screening study. Diagnosis was made by an ophthalmologist based on a complete ophthalmological examination. Our technique achieves an accuracy of detecting glaucomatous retina fundus images comparable to that of human experts. Additionally, the "vessel-free" images and intermediate output of the methods are novel representations of the data for the physicians that may provide new insight into and help to better understand glaucoma.

ACKNOWLEDGMENTS

The work reported here has been mostly carried out at the Chair of Pattern Recognition, University of Erlangen-Nuremberg, Germany, headed by Prof. Joachim Hornegger. The collaboration between the German and Hungarian partners was in part supported by the Alexander von Humboldt-Foundation, the German Academic Exchange Service (DAAD), the Hungarian Scholarship Board (MÖB), the Erlangen Graduate School in Advanced Optical Technologies (SAOT), and the German Research Foundation (DFG) in context of Collaborative Research Center 539 subproject A4 (SFB 539 A4).

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IX. MEDICAL IMAGE SEGMENTATION AND ANALYIS

In the period of 2006–2009, several scientific publications and patents were published on the methods and results of our prior research projects. One project aimed at segmentation of pelvic organs, such as the kidneys, liver, spleen, prostate, and bladder, and parts of the visual system from CT images for radiotherapy planning. The other project applied segmentation of tubular structures in the human body and skeletonization to assess diseases such that the laryngotracheal stenosis, infra-renal aortic aneurysm, and also detecting polyps in the colon via virtual dissection.

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CONFERENCE ORGANIZATION

In the period 2006-2009 the Department of Image Processing and Computer Graphics has organized the following conferences and workshops:

1. 13th International Conference on Discrete Geometry for Computer Imagery, October 25-27, 2006, Szeged, Hungary.
2. Summer School in Image Processing, SSIP, Szeged, 2007
3. Conference of PhD Students in Computer Science, Szeged, 2008

Between the years 2006 and 2009 the people of the Department served in program committees of 35 international conferences.

OTHER SCIENTIFIC SERVICE

Several members of the faculty work as editors in international scientific journals; they play significant roles in major scientific organizations and serve in program committees of major conferences.

Some of those journals: **Acta Cybernetica**, Central European Journal of Operations Research, Grammars, **IEEE Transactions on Image Processing**, Informatica, Pure Mathematics and Application, **Theoretical Computer Science**, Theoretical Informatics and Applications, Optimization Letters,

and Oriental J. of Mathematics, **Discrete Applied Mathematics**.

Organizations in which the Institute is represented: European Association for Theoretical Computer Science, European Association for Computer Science Logic, Gesellschaft für Angewandte Mathematik und Mechanik, International Federation of Information Processing, **Institute of Electrical and Electronics Engineers**, **International Association for Pattern Recognition**, and Association for Computing Machinery.

Department of Software Engineering

I. AD-HOC MOBILE AND MULTIMEDIA NETWORKS

Wireless Networks

In recent years wireless networks have begun to replace wired networks in areas where they are more cost effective than their wired counterparts. Also, the rapid development and spread of mobile devices has encouraged the spread of wireless networks as well, since wireless networking is the only viable solution in the case of mobile devices. We carried out our study in the area of wireless mesh networks, by looking at the state-of-the-art developments. We successfully deployed a working mesh network in Mórahalom during the Collaboration@Rural integrated project funded by the EU 6th Framework Programme. A tool developed by the department provides additional management functionality to make WMN setups more maintainable. Our tool enables the dynamic collection of various pre-defined and customizable mesh node parameters via Telnet, SSH and SNMP protocols and visualizes the given topology and configuration information on a custom Google Maps-based web interface. The tool provides the means for saving snapshots of collected network information that can be used for later investigations. Another interesting aspect that can help make the maintenance of mesh nodes more cost effective is the ability to fall back on working configurations in the case of failure. This capability allows the nodes to be accessed even in the case of failure by providing a default fallback state for the node that can be used in extreme situations.

The quality of a network is crucial for several services, especially sensitive multimedia services like audio and video streaming services. By measuring the Quality of Service parameters of networks we can monitor different quality-related properties of the network and assess the applicability of the network for specific purposes. Our WMN monitoring tool is capable of monitoring, calculating and estimating such QoS parameters so we can provide useful quality information about the mesh network in real time. In addition, we created a modular Java framework capable of analysing network simulator trace files. Using this framework we were able to compare various video stream quality control algorithms. These algorithms are responsible for maintaining stream flow (and controlling the bit rate, buffer usage, etc.) by reducing video quality or changing less important parameters of the stream. The framework was developed in a joint project together with Nokia-Siemens Networks.

Network Simulation, Testing and Efficiency Management

To improve the network topology discovery capabilities of the cNIS framework, our department developed a variety of plugins. We developed plugins to provide support for ethernet, VLANs, Etherchannel, the Cisco Discovery Protocol, Link Layer Discovery Protocol, Spanning Tree Protocol, Multiple Spanning Tree Protocol, VLAN Trunking Protocol and others that have not yet been incorporated into the cNIS. We carried out a study of peer-to-peer (P2P) networks as well. It is well known that the BitTorrent file sharing protocol is responsible for a significant portion of the Internet traffic. A large amount of work has been devoted to reducing the footprint of the protocol in terms of the amount of traffic, but its flow level footprint has not yet been studied in detail. We argued in a paper that the large amount of flows that a BitTorrent client maintains will not scale beyond a certain point. To overcome this problem, we examined the flow structure via realistic simulations. We found that only a few TCP connections are frequently used for data transfer, while most of the connections are used mostly for signalling. This makes it possible to separate the data and signalling paths. We proposed that, as the signalling traffic provides small overheads, it should be transferred on a separate dedicated small degree overlay while the data traffic should utilize temporary TCP sockets that are active during the data transfer. Through simulations we showed that this separation has no significant effect on the performance of the BitTorrent protocol, while we can drastically reduce the number of actual flows [20].

In recent years peer-to-peer technology has been adopted by Internet-based malware as a fault tolerant and scalable communication medium for self-organization and survival. It has been shown that malicious P2P networks would be nearly impossible to uncover if they operated in a stealth mode, that is, using just a small constant number of fixed overlay connections per node for communication. While overlay networks of a small constant maximal degree are generally considered to be unscalable, we argued in a paper that it is possible to design them to be scalable, efficient and robust. This is an important finding from a security point of view: we showed that stealth mode P2P malware which is very difficult to discover with state-of-the-art methods is a plausible threat. We presented algorithms and theoretical results that support the scalability of stealth mode overlays, and realistic simulations using an event-based implementation of a proof-of-concept system. Besides P2P botnets, our results are also applicable in scenarios where relying on a large number of overlay connections per node is not feasible because of the cost or the limited number of communication channels available [2].

State-of-the-art approaches for the detection of P2P botnets are on the one hand mostly local and on the other hand tailored to specific botnets involving a great amount of human time, effort, skill and creativity. Enhancing or even replacing this labour-intensive process with automated and, if possible, local network monitoring tools is clearly extremely desirable. To investigate the feasibility of automated and local monitoring, we presented an experimental analysis of the traffic dispersion graph (TDG) — a key concept in P2P network detection — of P2P overlay maintenance and search traffic as seen at a single autonomous system (AS). We focused on a feasible scenario where an imaginary P2P botnet uses some basic P2P techniques to hide its overlay network. The simulations were carried out on an AS-level model of the Internet. We showed that the visibility of P2P botnet traffic at any single AS (let alone a single router) can be very lim-

ited. While we strongly believe that the automated detection and mapping of complete P2P botnets is possible, our results imply that it cannot be achieved by a local approach: it will inevitably require very close cooperation among many different administrative domains and it will require state-of-the-art P2P algorithms as well [3].

Applications of Semantically Structured Information

Ontologies are intended to be used when the information contained in the documents needs to be processed by applications as opposed to the situations when the content only needs to be presented to humans. OWL is a model and language specially created for representing ontology information in a well defined manner. Researchers at the Department of Software Engineering have studied these ontologies and their applicability to various subjects requiring a machine-processable representation of complex data relationships.

HIGH-LEVEL CONTEXT INFORMATION IN MOBILE NETWORKS

One such area is mobile network-based services. In co-operation with Nokia Siemens Networks, the department investigated the usability of ontologies for representing high-level user profile information in mobile networks. In this case data was provided by a network-oriented user profile generation system that aggregates and refines the data originating from the underlying network. The generation system has the potential of allowing network operators and service providers to use user profile data for better, personalized and tailored services

We studied the state-of-the-art mobile ontologies and proposed extensions to the OWL-based mobile ontology framework developed in the SPICE integrated project funded by the EU. We refined the concept of a framework for context-aware service frontends that seek to detect high level user context information.

PERVASIVE COMPUTING

Another application area of ontology-based knowledge representation is in the theory of Pervasive Computing. The dramatic growth of the amount of information created by computer systems and the increasing need to access relevant information anywhere at any time are becoming an increasing challenge to cognitive capacity of human users. This is an immediate result of the design goal of providing transparent access to all available information that guides the development of today's information and communication technology. Therefore, instead of providing the right information at the right time, current computer systems are geared towards providing all the available information at any time. This requires humans to explicitly and repeatedly specify the context of the required information in great detail.

The overall problems resulting from this type of information access are exacerbated by the fact that an ever-increasing number of users are accessing information on-the-move through portable computer systems such as PDAs and cellular phones. Due to their shape and size, such systems cannot be equipped with input devices such as keyboards that are suitable for manually entering large amounts of context information. Hence, these systems are becoming increasingly ill-suited for providing users with efficient mobile access to sought-for information.

The vision of Pervasive Computing seeks to address these problems by providing seamless and distraction-free support for user tasks with devices that are invisibly embedded into the environment.

While there are various approaches towards enabling the vision of Pervasive Computing, existing approaches mostly focus on concepts to realize smart spaces, such as smart meeting rooms or offices. However, truly seamless support for user tasks requires the development of one system that provides a single and unified 'image' to its human users. This requires the integration of multiple smart spaces with each other and with the information systems infrastructure that exists today.

In order to model device capabilities and resources in an extendable way that can support the ongoing evolution of technology, we employed ontologies. [4]

SECURITY CONSTRAINTS REPRESENTATION

In complex software systems that cross even organizational boundaries, the representation of security constraints is a non-trivial challenge. Each co-operating party has its own well established policies for security issues. Also, different software systems use different security models that have to be synchronized to each other. During inter-organizational collaboration all of these security constraints have to be satisfied at the same time. Furthermore, in several cases regulatory rules must be applied to the security of the whole collaborating ecosystem. These strict requirements imply the need for a clear model for representing security-related issues in areas, such as authentication, authorization and accounting. In the CONVERGE project (funded by the 7th EU Framework Programme) we designed a security model based on state-of-the-art technology that is capable of fulfilling the above-mentioned requirements. In this model the representation of security-related information is crucial. In CONVERGE, ontologies are used together with other standard knowledge description models specifically designed for the representation of security-related topics, like XACML and SAML [5].

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II. OPEN SOURCE DEVELOPMENT AND EMBEDDED SYSTEMS

Introduction

Nowadays, and according to the trends, in the future embedded systems and devices will become more common. Their market is about 100 times that of the desktop market, and it is expected to grow exponentially over the next decade.

Embedded systems are everywhere these days and they permit the creation of systems with a functionality that cannot be provided by human beings. Example application areas include consumer electronic products (e.g. CD players, microwave ovens), telecommunications (e.g. mobile phones), medical systems (e.g. pacemakers), traffic control (e.g. intelligent traffic lights), driving and car control (e.g. ABS), airborne equipment (e.g. fly-by-wire), and plant control (e.g. packaging machines, wafer steppers).

Due to their importance, the researchers of the department are working on several areas related to embedded systems. These research topics were suggested by industrial partners, and most of the results are utilized immediately in real products.

Interestingly, the open source development methodology is quite common in the domain of embedded systems. Hence, most of the projects conducted by the department in this domain, even those which are motivated by industrial partners, are available as open source software.

Optimizing for Energy

One of the big design challenges for mobile devices is the optimal usage of the typically very limited energy resources. Within the framework of the Bilateral German-Hungarian Collaboration Project on Ambient Intelligence Systems (BelAmI), we have been investigating the possibilities of reducing the energy consumption of software with the help of compilers since late 2005. The evaluation of software optimisation techniques requires the ability to accurately measure the power consumption of a system. The most trivial solution is to perform measurements on real hardware. However, in some scenarios (e.g., where automatic collection and evaluation of large amount of results is required), hardware measurements can be overly expensive or impractical. In these situations an accurate simulation tool can and should be used. This is why we created a cycle-accurate energy simulator tool for the ARM v5TE architecture-based XScale processor cores [10, 13, 14]. Power dissipation graphs showing the accuracy of the resulting simulator compared to real measurement are given in Figure 39.

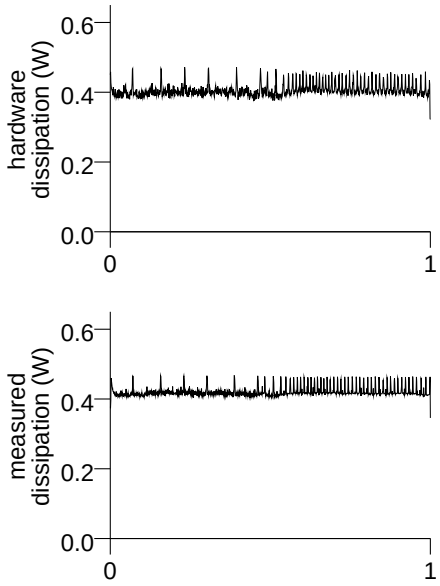

Figure 39. Measured and simulated power dissipation.

	JFFS2	UBIFS
Indexing on flash	None	B+ tree with wandering algorithm
Indexing in memory	Chained list, containing information about every node, information always kept in memory	TNC (Tree Node Cache), an extension of B+ tree algorithm, optimized specially for flash
Write operation	Write through (write data immediately)	Write back (do caching at writing)

Table 1. Main differences between JFFS2 and UBIFS

Flash File System Improvements

Embedded systems mostly use flash memory as storage devices. The embedded systems which are complex enough to run a real operating system (in open source environment it is Linux), need a special flash file system to store their base (root) file system. Using an ordinary file system would wear out the flash prematurely.

The most effective and most popular open-source flash file system is JFFS2. To make it more powerful we improved its compression performance, and speed (we speeded up its mount/boot time by 5-10 times). Our improvements [2] were partially sponsored by Nokia Finland, and the results were approved by the open-source community. Now it is the official part of the JFFS2 filesystem and the Linux kernel, and a part of several industrial products such as Nokia 770, N800 and N810 and small Linux server of Realm called Blackdog.

Unfortunately JFFS2 has reached its limit: it was designed over 5 years ago, and it cannot be tuned for a flash memory bigger than 512M. The problems are in the design of the filesystem, so the development of a new generation of this filesystem was necessary. This development is partially sponsored by Nokia, and the name of the new file system is UBIFS [3]. It is now part of the Linux kernel, and it is used in the Nokia N900 smart phone. The main differences between JFFS2 and UBIFS are summarized in Table 1.

ECG Application Development

The above developments are close to the system level. To validate their effectiveness, we commenced an application development project on Nokia 770 in 2006,

Figure 40. The Nokia770-based mobile ECG application.

which was based on open-source techniques.

We colaborated with Meditech Ltd., an ECG manufacturer company, to build a pilot ambient assisted living application. We improved the functionality of their mobile ECG device (called CardioBlue) with some useful features using a Nokia 770 device: it displays ECG diagrams, extends the capacity of CardioBlue, configures CardioBlue, etc. This application [4, 11] is capable of transfering real-time ECG data to a remote PC as well, hence it makes remote medical consultation possible. 2006. Figure 40 shows a typical setup of the application.

Browser Engine Improvements

In 2008, researchers and students of the department began investigating how the user experience of web browsing could be enhanced on embedded, mobile systems. The result was that we became involved in the development of the widely used WebKit browser engine [8], which forms the basis of several desktop (e.g., Safari and Chrome) and mobile (e.g., in iPhone, Symbian S60, and Android) web browsers.

The team investigated and experimented with several browsing-related topics, but focused mainly on JavaScript engines. We studied memory management, the parallelization of JavaScript execution [15], and the effect of coding guidelines on the performance of JavaScript applications [12]. A major result of the developers of the department is the implementation of a JavaScript just-in-time (JIT) compiler for the ARMv5 and ARMv7 architectures. As a result of the developments made for WebKit, and for being active community members [9], several members of the team have been promoted to committer status in the project.

DRUPAL Developments

Drupal is a free and open source modular framework and Content Management System (CMS) written in PHP. It is used as a "back end" system in various types of websites, ranging from small personal blogs to large corporate and political web sites. Since 2007, each semester there has been an optional course for 30-40 students, and also ongoing research studies in this area. Most of the results have been contributed to the community.

We also have R&D projects based on Drupal. The most important one is the information system of the Metabolism Laboratory of the University of Szeged at the Department of Paediatrics. This system makes it possible to submit blood sample data via the Internet and provide the authorized doctors with online access to the measurement results. Now the information system [7] which is based on Drupal, is used by 220 active users in over 40 hospitals in East Hungary.

II.1. Conferences

The staff of the department is active in organizing community and academic events. From 2005 to date, we have organized the national Software Freedom Day. In 2009, the event was extended to a Free Software Conference [5] with more than 30 presenters and 300 visitors. We also took part in the organization of Drupalcon Szeged 2008 [1], which was held in late August 2008 and had 500 attendees. Besides this, our colleagues participated in the organization of the Demo Day on Ambient Assisted Living in Practice [6]

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III. SOFTWARE QUALITY ASSESSMENT AND IMPROVEMENT

Software quality assessment and improvement relies heavily on reverse engineering, which is "the process of analyzing a subject system to (a) identify the system's components and their interrelationships and (b) create representations of a system in another form at a higher level of abstraction" [1]. We refer to the extracted information as *facts* about the software system. The form of the extracted facts in terms of a set of entities with attributes and relationships is described by *schemas*. A *model* is an embodiment of the schema which models a concrete software system.

We developed a process and a framework to facilitate fact extraction and to create various outputs from the models to aid software quality assessment and improvement.

Software Quality Supervision

Several tools and methods for source code quality assurance based on static analysis finally reached a state when they are applicable in practice and recognized by the industry. However, most of these tools are used in an isolated manner and very rarely as organic parts of the quality assurance process. Furthermore, little or no help is provided in interpreting the outputs of these tools. We developed a tool called *SourceInventory*, a system for source code-based software quality assessment and monitoring, which is able to collect, store and present measurement data including metrics, coding problems and other kinds of data like bug numbers and test coverage information. It helps software developers, architects and managers to take control over their software's quality by performing continuous code scans, fault detection, coding style verification, architecture violation detection, and automatic report generation considering metric baselines [6].

Metrics-based Bug Prediction

In our experiments we examined the general relationship between object-oriented metrics and the fault-proneness of classes. We analyzed a large open-source program called Mozilla, calculated 58 object-oriented metrics for Mozilla at the class level [10], collected the reported and corrected bugs from the bug tracking system of Mozilla and associated them with the classes. We applied logistic regression to examine which metrics could be used to predict the fault proneness of the classes. We found that 17 of the 58 object-oriented metrics were useful predictors, but to a different extent. The CBO (Coupling Between Object classes) metric was the best, but it was only slightly better than NOI (Number of Outgoing Invocations) and RFC (Response Set for a Class), which proved useful as well.

We also examined the metrics in terms of their categories and we found that coupling metrics were the best predictors for finding bugs, but the complexity and size metrics also gave good results. On the other hand, in tests all the inheritance-related metrics were statistically insignificant [11].

High cohesion is a desirable property of software, as it positively impacts understanding, reuse, and maintenance. Currently proposed measures for cohesion in Object-Oriented (OO) software reflect particular interpretations of cohesion and capture different aspects of it. Existing approaches are largely based on using the structural information from the source code, such as attribute references in methods, to measure cohesion. We propose a new measure for the cohesion of classes in OO software systems, based on the analysis of the unstructured information embedded in the source code, such as comments and identifiers. The measure, named the Conceptual Cohesion of Classes (C3) is inspired from the mechanisms used to measure textual coherence in cognitive psychology and computational linguistics. We present the principles and the technology that stand behind the C3 measure. A large case study on three open source software systems is presented, which compares the new measure with an extensive set of existing metrics and uses them to construct models that predict software faults. The case study shows that the novel measure captures different aspects of class cohesion compared to any of the existing cohesion measures. In addition, combining C3 with existing structural cohesion metrics proves to be a better predictor of faulty classes when compared to different combinations of structural cohesion metrics [4].

Coupling is also an important property of software systems, which directly impacts program comprehension. In addition, the strength of coupling measured between modules in software is often used as a predictor of external software quality attributes such as changeability, ripple effects of changes and fault-proneness. We present a new set of coupling measures for Object-Oriented (OO) software systems measuring conceptual coupling of classes. Conceptual coupling is based on measuring the degree to which the identifiers and comments from different classes relate to each other. This type of relationship, called conceptual coupling, is measured through the use of Information Retrieval (IR) techniques. The proposed measures are different from existing coupling measures and they capture new dimensions of coupling, which are not captured by the existing coupling measures. We investigate the use of the conceptual coupling measures during change impact analysis. We report the findings of a case study in the source code of the Mozilla web browser, where the conceptual coupling metrics were compared to nine existing structural coupling metrics and proved to be better predictors for classes impacted by changes [9].

Object-oriented metrics are becoming evermore popular and they are used in many different areas of software development. Many researchers have showed in practice that object-oriented metrics can be efficiently used for quality assurance. For example, a lot of experimental results confirm that some of the object-oriented metrics (like *coupling*, *size*, and *complexity*) are able to predict the fault-proneness of classes. Quality assurance experts usually accept that actively applying metrics can help their work. On the other hand, developers tend not to use metrics because they do not know about them, or if they do know about them, they do not really know how to use them. Hence we devised a *Survey* to ask developers with different levels of experience about the use of metrics. Our hypothesis was that developers with different levels of experience might have significantly different views about the usefulness of metrics.

In the *Survey* four metrics (*size*, *complexity*, *coupling*, and *code duplication*) were examined. The *Survey* asked questions about the participants' experience and skills, then it asked questions about how the participants would probably use these metrics for software testing or program comprehension, and at the end the relative importance of the metrics was assessed.

The main result of the *Survey* is a list which contains those cases where the views about the metrics from developers having different experience significantly differ. We think that getting to know the developers' views better can help us to create better quality models based on object-oriented metrics [12].

Detecting Code Clones

Although source code cloning (copy&paste programming) represents a significant threat to the maintainability of a software system, problems usually start to arise only when the system evolves. Most of the related research papers tackle the question of finding code clones in one particular version of the software only, leaving the dynamic behavior of the clones out of consideration. Eliminating these clones in large software systems often seems absolutely hopeless, as there might exist several thousands of them. Alternatively, tracking the evolution of individual clones can be used to identify those occurrences that could really cause problems in the future versions.

We developed an approach for mapping clones from one particular version of the software to another one, based on a similarity measure. This mapping is used to define conditions under which clones become suspicious (or "smelly") compared to their other occurrences. Accordingly, these conditions introduce the notion of dynamic clone smells. The usefulness of these smells is validated on the Mozilla Firefox internet browser, where the approach was able to find specific bugs that resulted from neglecting earlier copy&paste activities [3].

Mining Design Patterns

Recovering design pattern [2] usage in source code is a very difficult task. Several tools are described in the literature for this purpose, but there is little work invested in evaluating them. The main reason for this is the lack of an approved benchmark for these tools. We developed a benchmark, called **DEEBEE** (**DE**sign pattern **E**valuation **BE**nchmark **E**nvironment), for evaluating and comparing design pattern miner tools. It is programming language, tool, pattern and software independent, and it is open to the community and freely available. Currently, the benchmark database contains the results of three tools: Columbus (C++), Maisa (C++), and Design Pattern detection Tool (Java). The tools were evaluated on reference implementations of patterns and on open source software (Mozilla, NotePad++, JHotDraw, JRefactory and JUnit). Additionally, instances recovered by researchers are added from NotePad++ as well. Some recovered patterns are already verified by experienced developers. This work is the first step in building a large reference database of design pattern usage in open source software and we expect that researchers will join us in this effort [5], [7], [8].

Conference Organization and Editorial Work

Rudolf Ferenc was a co-chair of the *IEEE 13th European Conference on Software Maintenance and Reengineering (CSMR 2009)* and co-editor of the special issue of the *Journal of Software Maintenance and Evolution: Research and Practice, incorporating Software Process: Improvement and Practice* Journal for CSMR 2009.

Árpád Beszédes is a founding member of the Hungarian Testing Board, which was founded in 2007 as the official member board of the International Software Testing Qualifications Board (ISTQB).

Acknowledgements

The mentioned research tasks were supported by the János Bolyai Research Scholarship of the Hungarian Academy of Sciences and the Hungarian national grants OTKA K-73688 and TECH 08-A2/2-2008-0089.

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IV. PROGRAM ANALYSIS

In the program analysis area we investigated problems on different levels with different goals. Both theoretical and practical research results have been achieved, some of them with industrial relevance. Furthermore, our group has a long term research agenda. We also took part in organizing international conferences and in other professional activities.

In the topic of change impact analysis the main goal was to develop an innovative change impact analysis software-suit. We presented a system for source code-based software quality assessment and monitoring which helps software developers, architects and managers to take control over their software's quality. An existing technology and some tools were adapted suitable for quality assessment based on source code analysis in industrial environment. We introduced a method for designing test cases based on high level functional specifications and presented dynamic and static techniques for impact set computation, and explored them in terms of recall and precision and we compared them with existing techniques.

In the area of enterprise applications, a framework has been developed to predict critical failures in large-scale telecommunication software systems in industrial environment. In other work we propose two techniques that compute dependencies between procedures and database tables. In the low level dependency analysis area we revealed and analyzed the dependencies among macro-related program points using the so-called macro slices, we extended the approach for the combination with existing C/C++ language slicers and reported its benefits in terms of the completeness of the resulting slices.

An efficient algorithm to compute dynamic slices has been implemented in the GCC/GDB environment. We investigated the concept of union slices and verified on real-world Java programs their usefulness as a replacement to static slices. In the area of compiler technology we gave an overview about implementing different code factoring algorithms on the IPA, Tree, Tree SSA and RTL passes of GCC. In other work, we focused on the protection of source code by means of obfuscation and discussed the adaptation of a control flow transformation technique (control flow fattening) to the C++ language.

Change Impact Analysis

Testing-based software quality assurance often does not provide an appropriate level of efficiency and reliability. To aid this problem, different kinds of static verification techniques can be applied, like code metrics and code inspection. Many quality assessment methods that are based on static source code analysis has already been proposed, yet these can be used is particular industrial environment - in which often proprietary programming languages are used - only after appropriate adaptation. We present experiences [2] in adapting an existing technology and tools suitable for quality assessment based on source code analysis. The technology has demonstrated its success and usability in industrial environment; being capable of comprehensive and continuous quality monitoring of large and complex software systems involving proprietary technologies.

The research field of change impact analysis plays an important role in software engineering theory and practice nowadays. Not only because it has many scientific challenges, but it has many industrial applications too (e.g., cost estimation, test optimization), and the current techniques are still not ready to fulfill the requirements of industry. Typically, the current solutions lack a whole-system view and give either precise results with high computation costs or less precise results with fast algorithms. For these reasons, they are not applicable to large industrial systems where both scalability and precision are very important. We present a project whose main goal is to develop an innovative change impact analysis software-suit based on recent scientific results and modern technologies [1]. The suite will use hybrid analysis techniques to benefit from all the advantages of static and dynamic analysis. In addition, it will be able to determine the dependencies at system level of software systems with heterogeneous architecture. The software is being developed by FrontEndART Ltd. while the theoretical and technological background is provided by the Department of Software Engineering at the University of Szeged. The project is funded by the Economic Development Operational Programme, New Hungary Development Plan.

Analysis of High Level Models

We introduced a method for designing test cases based on high level functional specifications - business process models [3]. Category Partition Method (CPM) is used to automatically create test frames based on possible paths, which are determined by business rules. The test frames can then be used in the process of test case design, together with filtering and prioritization also given as CPM rules. We present the details of the adaptation of CPM, together with first experiences from applying the method in an industrial context.

High Level Efficient Dependency Analysis

Many of the existing techniques for impact set computation in change propagation and regression testing are approximate for the sake of efficiency. A way to improve precision is to apply dynamic analysis instead of static ones. The state-of-the-art dynamic impact analysis method is simple and efficient, but overly conservative and hence imprecise. We introduce the measure of Dynamic Function Coupling (DFC) [6] between two functions or methods, which we use to define a more precise way of computing impact sets on function level with a scalable rate of recall. The intuition behind our approach is that the 'closer' the execution of a function is to the execution of another function in some of the runs of the program, the more likely they are really dependent on each other. So, impact sets may be computed based on this kind of coupling. We provide experimental data to support the validity of the concept, which essentially show that the impact set of a function consisting of only strongly DFC-coupled functions has twice the precision compared to the conservative method.

We introduce Static Execute After (SEA) relationship [5] among program components and present an efficient analysis algorithm. Our case studies show that SEA may approximate static slicing with perfect recall and high precision, while being such less expensive and more usable. When differentiating between explicit and hidden dependencies, our case studies also show that SEA may correlate with direct and indirect class coupling. We speculate that SEA may find applications in computation of hidden dependencies and through it in many maintenance tasks, including change propagation and regression testing.

We further explored Static Execute After (SEA) dependencies in the program and their dual Static Execute Before (SEB) dependencies [4]. It empirically compares the SEA/SEB dependencies with the traditional dependencies that are computed by System Dependence Graph (SDG) and program slicers. In our case study we used about 30 subject programs that were previously used by other authors in empirical studies of program analysis. We reported two main results. The computation of SEA/SEB is much less expensive and much more scalable than the computation of the SDG. At the same time, the precision declines only very slightly, by some 4% on average. In other words, the precision is comparable to that of the leading traditional algorithms, while intuitively a much larger difference would be expected. We discussed whether based on these results the computation of the SDG should be replaced in some applications by the computation of the SEA/SEB.

Analysis of Enterprise Application in use

The possibility of automatically predicting runtime failures in large-scale distributed systems such as critical slowdown is highly desirable, since this way a significant amount of manual effort can be saved. Based on the analysis of execution logs, a large amount of information can be gained for the purpose of prediction. Existing approaches - which are often based on achievements in Complex Event Processing - rarely employ intelligent analyses such as machine learning for the prediction. Predictive Analytics on the other hand, deals with analyzing past data in order to predict future events. We have developed a framework [7] for our industrial partner to predict critical failures in their large-scale telecommunication software system. The framework is based on some existing solutions but include novel techniques as well. We overview the methods and present initial experimental evaluation.

Observing failures and other – desired or undesired – behavior patterns in large scale software systems of specific domains (telecommunication systems, information systems, online web applications, etc.) is difficult. Very often, it is only possible by examining the runtime behavior of these systems through *operational logs* or *traces*. However, these systems can generate data in order of gigabytes every day, which makes a challenge to process in the course of predicting upcoming critical problems or identifying relevant behavior patterns. We can say that there is a gap between the amount of information we have and the amount of information we need to make a decision. Low level data has to be processed, correlated and synthesized in order to create high level, decision helping data. The actual value of this high level data lays in its availability at the time of decision making (e.g., do we face a virus attack?). In other words high level data has to be available real-time or near real-time. The research area of *event processing* deals with processing such data that are viewed as events and with making alerts to the administrators (users) of the systems about relevant behavior patterns based on the rules that are determined in advance. The rules or patterns describe the typical circumstances of the events which have been experienced by the administrators. Normally, these experts improve their observation capabilities over time as they experience more and more critical events and the circumstances preceding them. However, there is a way to aid this manual process by applying the results from a related (and from many aspects, overlapping) research area, *predictive analytics*, and thus improving the effectiveness of event processing. Predictive analytics deals with the prediction of future events based on previously observed historical data by applying sophisticated methods like machine learning, the historical data is often collected and transformed by using techniques similar to the ones of event processing, e.g., filtering, correlating the data, and so on. We have examined both CEP and PA research areas and offer a survey on terminology, research achievements, existing solutions, and open issues. Discussed the applicability of the research areas to the telecommunication domain, primarily based on articles published in international conferences and journals, but considering other sources of information as well, like technical reports, tools or web-logs. As a result of the investigation a technical report is created.

Determining dependencies between different com-

ponents of an application is useful in lots of applications (e.g., architecture reconstruction, reverse engineering, regression test case selection, change impact analysis). However, implementing automated methods to recover dependencies has many challenges, particularly in systems using databases, where dependencies may arise via database access. Furthermore, it is especially hard to find safe techniques (which do not omit any important dependency) that are applicable to large and complex systems at the same time. We propose two techniques [8] that can cope with these problems in most situations. These methods compute dependencies between procedures or database tables, and they are based on the simultaneous static analysis of the source code, the database schema and the SQL instructions. We quantitatively and qualitatively evaluate the methods on real-life data, and also evaluate them on some of their potential applications.

Low Level Dependency Analysis

The expressiveness of the C/C++ preprocessing facility enables the development of highly configurable source code. However, the usage of language constructs like macros also bears the potential of resulting in highly incomprehensible and unmaintainable code, which is due to the flexibility and the "cryptic" nature of the preprocessor language. This could be overcome if suitable analysis tools were available for preprocessor-related issues, however, this is not the case (for instance, none of the modern Integrated Development Environments provides features to efficiently analyze and browse macro usage). A conspicuous problem in software maintenance is the correct (safe and efficient) management of change. In particular, due to the aforementioned reasons, determining efficiently the impact of a change in a specific macro definition is not yet possible. We describe a method for the impact analysis of macro definitions, which significantly differs from the previous approaches. We reveal and analyze the dependencies among macro-related program points using the so-called macro slices. [11]

Slicing C programs has been one of the most popular ways for the implementation of slicing algorithms; out of the very few practical implementations that exist many deal with this programming language. Yet, preprocessor related issues have been addressed very marginally by these slicers, despite the fact that ignoring (or handling poorly) these constructs may lead to serious inaccuracies in the slicing results and hence in the comprehension process. The accurate slicing method for preprocessor related constructs has been combined with existing C/C++ language slicers - providing a more complete comprehension of these languages. Benefits are presented in terms of the completeness of the resulting slices [10] [9].

Dynamic Slicing

Program slicing is a program analysis technique initially introduced to assist debugging, based on the observation that programmers mentally form program slices when they debug and understand programs. Namely, only those statements need to be investigated that actually influenced the erroneous value, and eventually, these statements constitute the backward dynamic program slice. An efficient algorithm to compute such slices has been implemented in the GCC/GDB environment, which adds a new slice command to retrieve the slice for a given program entity. A background on program slicing is given [12], followed by the details of implementation. The dependences are computed after 'gimplification' in GCC, while STABS format is used to transfer them to GDB. The initial experimental results are presented as well.

Static program slicing is often proposed for software maintenance-related tasks. Due to different causes static slices are in many cases overly conservative and hence too large to reduce the program-part of interest meaningfully. We further investigate [13] the concept of union slices, which are defined as the unions of dynamic slices computed for the same (static) slicing criteria, but for different executions of the program. We verified on real-world Java programs their usefulness as a replacement to static slices. For this we investigate the sizes of a number of backward and forward dynamic and union slices, also by comparing them to the corresponding static slices. Our results show that the union slices are precise enough (backward slices are 5-20% of the program and forward slices are 5-10%, the corresponding static slices being 25-45%), and that with the saturation of the overall coverage given many different executions, union slices also reach a steady level and typically do not grow further by adding new test cases.

Compiler Technology

Today as handheld devices (smart phones, PDAs, etc.) are coming to be increasingly popular, the storage capacity becomes more and more important. One way to increase capacity is to optimize static executables on the device. This resulted that code-size optimization gets bigger attention nowadays and new techniques are observed, like code factoring which is still under research. GNU GCC as the most common compiler in the open source community has many implemented algorithms for code-size optimization, but currently the compiler is still weak in these methods, which can be turned on using the '-Os' flag. We gave an overview about implementing different code factoring algorithms (local factoring, sequence abstraction, interprocedural abstraction) on the IPA, Tree, Tree SSA and RTL passes of GCC [14]. The correctness of the implementation has been checked, and the results were measured on different architectures with GCC's official Code-Size Benchmark Environment (CSiBE) as real-world system. These results showed that on the ARM architecture we could achieve maximum 61.53% and 2.58% average extra code-size saving compared to the '-Os' flag of GCC.

Protecting a software from unauthorized access is an ever demanding task. Thus we focus on the protection of source code by means of obfuscation and discuss the adaptation of a control flow transformation technique called control flow fattening to the C++ language [16] [15]. In addition to the problems of adaptation and the solutions proposed for them, a formal algorithm of the technique is given as well. A prototype implementation of the algorithm presents that the complexity of a program can show an increase as high as 5-fold due to the obfuscation.

Conference Organization and other Professional Activities

In this period we made lots of efforts to organize several international conferences, the work is still in progress. The group contributed in the following events:

- CSMR 2010
  (`http://www.sait.escet.urjc.es/csmr2010/`)
  Árpád Beszédes - Workshop Chair
- ETOOS 2010
  (`http://etoos2010.sed.hu/`)
  Árpád Beszédes - Co-Chair
- ICSM 2010
  (`http://icsm2010.upt.ro/`)
  Árpád Beszédes - Industrial Co-Chair
- ESEC/FSE 2011
  (`http://2011.esec-fse.org/`)
  Árpád Beszédes - Local Organization; László Vidács - Web chair

We took part in organizing events of the Software Technology Forum (`http://www.inf.u-szeged.hu/stf/`), including the editorial work of the 25th anniversary proceedings.

R & D Projects

Our group took part in several Hungarian and international research and development projects with industrial partners (for example 4dsoft, FrontEndART Ltd., GriffSoft Ltd., DEAK) as a subcontractor.

Our work was supported, in part, by the Hungarian national grant OTKA K-73688.

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Research Group on Artificial Intelligence

SPEECH TECHNOLOGY

During the period 2007-2010 our speech technology team focused on both practical and theoretical aspects of speech recognition. As regards the practical side, we improved the speech dictation system developed in the previous years by extending its capabilities with speaker normalization and adaptation features. In the more theoretical direction, we experimented with novel acoustic modeling techniques such as the tandem scheme and the application of fuzzy operators to the hypothesis probability calculation. In 2009 the institute won the TAMOP 4.2.2 grant on sensor network-based data collection. Our team will contribute to this project be developing noise-robust speech recognition algorithms for the speech data recorded via the sensors. This work, however, has just been commenced.

I. REFINEMENT OF THE MEDICAL DICTATION SYSTEM

During the years 2004-2006 the Department of Informatics at the University of Szeged and the Laboratory of Speech Acoustics of the Budapest University of Technology and Economics cooperated in a project (IKTA-056/2003) which resulted in a speech database and a prototype medical dictation system. Although the project ended, we made several further refinements to the recognition system. Most importantly, we made a thorough investigation on how the system's recognition performance is affected by various types of mismatches between the training and testing conditions, such as the gender of the speakers and the microphone used. We tried to minimize the performance drop caused by the mismatch by applying speaker adaptation. We found that speaker adaptation can bring about quite a significant improvement when the training and testing acoustic conditions differ. Our results with the medical dictation system were summarized in two journal papers [2, 7].

II. FUZZY OPERATORS IN SPEECH RECOGNITION RESEARCH

In conventional acoustic models such as the hidden Markov model the local acoustic probabilities are combined by simple multiplication. Mathematically, this corresponds to the assumption that these local pieces of information are independent. Though this assumption of independence leads to a convenient mathematical formulation, and it also behaves quite well in practice, this assumption is false, owing to the continuous motion of the vocal chords, the tongue, the mouth and so on. Hence, it is natural to expect that the model can be improved further by replacing the product operator with a more general binary operation on the interval $[0, 1]$. This led us to the utilization of standard triangular norm families taken from fuzzy logic theory, which fulfil two important criteria: they have multiplication-like properties (like having unit 1, sink 0, being associative and commutative), and usually they have a parameter which allows the simple control of their behaviour. Due to their similarity with the product operator their application was quite straightforward as well. We found that, among the standard triangular norm families, especially the Schweizer-Sklar and the Dombi ones behaved well in practice, outperforming the basic multiplication operator.

Next we looked for a more general operator to apply, and we found the General Dombi Operator a suitable choice. This triangular norm has all the kind of properties we required earlier, but it also has the potential of more precise tuning as it includes many standard triangular norms as special cases, and supplies a smooth transition between them via its two adjustable parameters. However, it also required special treatment as setting two parameters is much harder than doing it with just one. To address this task, we turned the speech recognition problem into an optimization one and applied a standard optimization package to find a local optimum point. With the parameter values found this way in the medical dictation task we were able to reduce the error rates by a surprisingly large amount (see Table 2). The achieved improvements suggest that it is indeed worth applying a general triangular norm in speech recognition [10].

Finally an attempt was made to see if the triangular norms could be modelled in a more general way. To do this we concentrated on the *additive generator* of the triangular norms, for which an application-oriented estimation method was introduced [5]. Namely, we introduced the *logarithmic generator*, which makes the given t-norm work directly on the cost values (i.e. $-\log p$) instead of the p probability values, as in a typical speech recognition environment these are used to avoid underflowing. This logarithmic generator was estimated piecewise linearly, keeping the steepness values constant between certain intervals. The bounds of these n intervals (the *control points*) were positioned using the result of a histogram in such a way that roughly the same number of uses fell into each interval, making each steepness value just as important. After arranging the steepness values in the form of a vector $\overline{m}$, the whole speech recognition problem could be treated as an optimization task for $\overline{m}$, maximizing the recognition accuracy. The results of the experiments (see Table 2) confirm that it is possible to reduce the error rates this way even more than it was possible via the Generalized Dombi Operator, leading to relative error reduction scores of 64.20% and 50.00% for word accuracy and correctness, respectively. Moreover, this method could also be applied in other areas as well where fuzzy norms are used, thus its use is not limited to this particular problem, or even to speech recognition.

III. EXPERIMENTS WITH THE TANDEM ACOUSTIC MODEL

We performed a lot of tests with the HMM/ANN hybrid acoustic modeling technology [20]. The basic difference between this and the standard HMM scheme

Method	Acc.	Corr.
Product (baseline)	96.76%	98.38%
Dombi t-norm	97.57%	98.84%
Generalized Dombi operator	98.49%	98.95%
Logarithmic generator, $n = 8$	98.27%	98.84%
Logarithmic generator, $n = 16$	98.84%	99.19%

Table 2. The best word accuracy and correctness values obtained with fuzzy operators.

is that here the probabilities are modelled by Artificial Neural Networks (ANNs) instead of the conventional Gaussian mixtures (GMM). As ANNs seem to be more capable of modelling the observation context than GMMs, hybrid models are usually trained over longer time windows. A more recent version of this technology combines the ANN and the conventional GMM machine learning algorithms, and hence it is called the "tandem" method. In this scheme the output of the neural net is used as a feature set of a standard HMM recognizer. The main advantage of this approach is that this way the recognizer does not require any sort of modification, in contrast to the HMM/ANN hybrid method.

A further advantage of the two-stage or "tandem" structure is that the neural net applied in the first stage can be trained to detect anything that might be useful for the recognition, not only phones. A possible alternative is to use the net to detect the presence of articulatory features (AFs). These features are supposed to be more language-universal than phones. Moreover, an articulatory feature detection system – a multi-layer perceptron (MLP) net that was trained on 2000 hours of English speech – is freely available on the Web. This gave us the idea to try to combine these *English* ANN-based feature detectors within a tandem system which – in the second stage – is trained to recognize *Hungarian* speech. A comparison was made with a fully Hungarian system and a phone-based English-Hungarian cross-lingual system. The results show no significant difference between the configurations [6]. However, when the English phone MLP was adapted to the Hungarian data, we manage to outperform all our previous results. Table 3 summarizes the word accuracy, phone correctness and phone accuracy values obtained with the various configurations.

Feature set: PLP	WACC	PhACC
+ Hungarian phone MLP	97.5%	62.6%
+ English AF MLP	97.2%	61.8%
+ English phone MLP	96.5%	62.2%
+ Adapted phone MLP	**98.1%**	**64.9%**

Table 3. Word and phone recognition performance obtained with the mono-lingual and cross-lingual MLP-based tandem features. The best result in each column is shown in bold face.

The second scenario where we tried the tandem modelling approach was the recognition of audio books [9]. Our main motivation for these experiments was that the material of audio books represent quasi-optimal data for speech recognition: there is only one speaker with careful pronunciation, and the recordings are made in a studio, under perfect conditions. Hence, the results obtained on such a data set reflect a sort of upper limit for the possibilities of the technology, because in a real-life situation the recognition conditions are always worse. Table 4 shows the results obtained with various configurations of the tandem system, in parallel with the performance on the real-life MTBA telephone-speech database. As can be seen, the recognition of the audio book is much easier, and the best result on the MTBA database is just slightly better than the worst result on the audio book. The best result – 86.33%, obtained with a phone-bigram and discriminative training – is pretty close to the scores measured with humans on the task of recognizing nonsensical speech [3].

	MTBA	Audio book
Conventional HMM	53.37%	72.18%
Tandem HMM	65.09%	79.49%
Tandem+bigram	69.67%	83.62%
Tandem+bg.+discr.tr.	73.93%	86.26%

Table 4. Phone recognition performances obtained on the MTBA database and on the audio book.

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NATURAL LANGUAGE PROCESSING

Natural language processing research (primarily information extraction) started at the University of Szeged in 1998, and by now, the group has become one of the leading workshops of Hungarian computational linguistics. The Hungarian Computational Linguistics Conferences have been organized by the group since 2003 and the international Fourth Global WordNet Conference (GWC2008) was held in Szeged as well. The Group is engaged in processing Hungarian and English texts. Its general objective is to develop language-independent or easily adaptable technologies. `http://www.inf.u-szeged.hu/rgai/nlp`

Information extraction seeks to automatically obtain useful information, correlations from raw texts. It proves most expedient when lengthy texts are to be scanned in order to find the necessary information. In the case of a suitably sized training database, the amount of human labour required can be radically reduced by means of machine learning algorithms. Applications include the following important fields: information extraction from business news, biological publications, medical reports and from the Internet (e.g. forums, blogs).

IV. NAMED ENTITY RECOGNITION

During the 2007-2009 period a language-independent named entity recognition algorithm and software tool was developed. A Named Entity is a phrase in the text which uniquely refers to an entity of the world. It includes proper nouns, dates, identification numbers, phone numbers, e-mail addresses and so on. As the identification of dates and other simpler categories are usually carried out by hand-crafted regular expressions we focus on proper names like organizations, persons, locations, genes or proteins. `http://www.inf.u-szeged.hu/rgai/NER`

The identification and classification of proper nouns in plain text is of key importance in numerous natural language processing applications. It is the first step of an IE system as proper names generally carry important information about the text itself, and thus are targets for extraction. Moreover Named Entity Recognition (NER) can be a stand-alone application as well and besides IE, Machine Translation also has to handle proper nouns and other sort of words in a different way due to the specific translation rules that apply to them.

Our NER system won the I2B2 international open challenge on medical record anonimisation in 2007. The anonymization of medical records is of great importance in human life sciences because a de-identified text can be made publicly available for non-hospital researchers as well, to facilitate research on human diseases. Our group developed a novel, machine learning-based iterative de-identification model that can automatically remove personal health information (PHI) from discharge records to make them conform to the guidelines of the Health Information Portability and Accountability Act.

V. MEDICAL NATURAL LANGUAGE PROCESSING

In the field of the automatic processing of medical texts we worked on a model that can automatically extract the information related to certain diseases from medical reports. ICD-9-CM codes are used for billing purposes by health institutes and are assigned to clinical records manually following clinical treatment. Since this labeling task requires expert knowledge in the field of medicine, the process itself is costly and is prone to errors as human annotators have to consider thousands of possible codes when assigning the right ICD-9-CM labels to a document. Our machine learning based approach automatically extends the available hand-crafted rules of the ICD coding guide according to the labelled corpus. Automating the assignment of ICD-9-CM codes for radiology records was the subject of a shared task challenge organized by the Computational Medicine Center (CMC) in Cincinatti, Ohio in 2007. Our system won that challenge. `http://www.inf.u-szeged.hu/rgai/mednlp`

Classifying patient records if they have a certain disease is a similar task to ICD coding. The Obesity Challenge in 2008, organized by the Informatics for Integrating Biology and the Bedside (I2B2), asked participants to construct systems that could correctly replicate the textual and intuitive judgments of the medical experts on obesity and its co-morbidities based on narrative patient records. An approach similar to the one used in the ICD coder was applied here, i.e. it was an extended dictionary-lookup-based system, which also took into account the document structure and the context of disease terms for classification. To achieve this, we used statistical methods to pre-select the most common (and most confident) terms and abbreviations then evaluated outlier documents to discover infrequent terms and spelling variants.

VI. BIOLOGICAL INFORMATION EXTRACTION

Achievements in biological research worldwide manifest themselves in the form of patents, publications (at present, the MedLine database in itself contains over 12 million publications). This exponentially growing set of documents contains a lot of useful information, which is, however, "hidden" in the text. The objective of computational linguistics (text mining) is to extract these pieces of information automatically. The target information is usually biological entities (genes, proteins, DNA etc.) and the relationships among them. `http://www.inf.u-szeged.hu/rgai/bionlp`

For reliable information extraction, the disambiguation of biological and other terminologies is the primary preprocessing step. Its importance comes from the fact that in the language use of special fields or communities, certain words are integrated into the language of the particular field as a technical term assuming a specific sense. See e.g. the human gene name *MMP-25*, which research teams use to indicate three different genes. Therefore, the disambiguation of such expressions and the recognition of various linguistic forms and attitudes, such as speculation (conditional), negation, past or future are of key importance for efficient processing and IE applications, since the very objective of IE is to collect facts and data from textual documents.

VII. WEB MINING

During 2007-2009 the group worked on several R&D applications which target the textual documents of the Web. For instance, scientific social network analysis seeks to discover global patterns in the network

of researchers working in a particular field. Common approaches use bibliographic/scholarly data as the basis for this analysis. In the Textrend project, we look for the potential of exploiting other resources as an information source, such as the homepages of researchers. The information on homepages may be present in a structured or natural text form. We focused on the detection and analysis of full text regions of the homepages as they may contain a huge amount of information while it requires more sophisticated analysis than that for structured ones. `http://www.inf.u-szeged.hu/rgai/homepagecorpus`

Free text tagging is the task of assigning a few natural language phrases to documents which summarize them and semantically represent their content. The tags are useful for organizing, retrieving and linking different contents. We developed an automatic free text tagging solution for the online news archive of the Hungarian [origo] news portal. The 370 thousand articles in the news archive could not be tagged by neither the community of readers nor the team of journalists. We showed that free-text-tagging could be carried out by an automatic system achieving a satisfactory accuracy of 77.5 percent. `http://www.inf.u-szeged.hu/rgai/tagging`

VIII. LANGUAGE RESOURCES

Machine Learning approaches require manually constructed language resources with high precision. `http://www.inf.u-szeged.hu/rgai/nlp_download` The Hungarian WordNet project ended in 2007, resulting in the Hungarian ontology that conforms with the WordNet standard, and the ground for further Hungarian word sense disambiguation research was created. As an acknowledgment of our research efforts, the annual conference of the Global WordNet Association took place in Szeged in 2008, and we played an active part in its organization.

By converting the Szeged Treebank into syntactically annotated dependency trees, we aimed at creating the first manually annotated dependency corpus for Hungarian. In order to be able to convert the originally phrase-structured Treebank into a dependency corpus, constituent trees were automatically converted into dependency relations. As automatic machine conversion is not expected to produce perfect, flawless results, this phase was followed by manual control, when linguists checked the files and modified them if necessary. So far, the business news, newspaper articles, legal texts and texts on informatics subcorpora have been annotated, the annotation of literary texts being in progress. Further on, we would also like to implement a dependency parser for Hungarian, for which this corpus can be used as a learning database. The development of the Hungarian dependency corpus opens the door to multilingual applications as well. On the other hand, applying dependency trees has advantages in several fields of computational linguistics: corpora in dependency-tree format may be used successfully in both machine translation and information extraction.

Besides these huge Hungarian language resources, several smaller corpora were also constructed in the past three years which support the development of NLP applications. For example, the BioScope corpus consists of medical and biological texts annotated for negation, speculation and their linguistic scope. This was done to allow a comparison between the development of systems for negation/hedge detection and scope resolution. The corpus is publicly available for research purposes. The corpus consists of texts taken from 3 different sources in order to ensure that it captures the heterogeneity of language use in the biomedical domain.

The dataset dedicated to Opinion Mining in Hungarian was gathered from the posts of the forum topic of the Hungarian government portal dealing with the referendum about dual citizenship. We downloaded all the 1294 forum posts from the three-month-long period preceding the referendum and these were annotated by two independent linguists. Annotators were told to label forum posts independently according to the most likely vote their composer would give. Based on this, we determined three categories of comments, i.e. irrelevant, supporting and rejecting ones. However, preliminary results showed us that a significant proportion of the posts belonged to another class, namely those stating that they would intentionally vote invalidly because they did not like the idea of asking such a question in a referendum. So, finally we had to classify the posts into four groups (irrelevant, supporting, rejecting and invalid).

We also manually annotated a corpus of homepages of researchers for scientific social information. It has been extensively annotated, has a hierarchical label structure and is freely available (along with the HTML annotation tool) for research purposes. Later, as a case study, we chose one particular scientific social information type and sought to extract information tuples concerning the previous and current affiliations of the researcher in question.

IX. R&D PROJECTS

During 2007-2009 we participated in several R&D projects granted by the Hungarian government:

- The Hungarian WordNet project (GVOP-19/50/1U108) was completed in 2007, resulting in a Hungarian ontology that conforms with the EuroWordNet standard.
- The Hungarian-English translator engine project (NKFP-19/50/1W051) was completed in 2007, and the resulting translator can be tested at www.webforditas.hu.
- The psychological text analysis project (NKFP-19/50/1W075) ended in 2008. Our team was responsible for processing the texts using tools of language processing technology.
- The "TUDORKA7" (OM-00145/2007) project was carried out in 2008. The Department of Informatics of SZTE contributed to the development of text-mining tools for VPOP by supporting information extraction tools and expertise.
- The "Textrend" (OM-00006/2008) project started in 2008 and will last for three years, its goal being to construct a decision-support system for economic and governmental use via the application of trend analyser and text mining tools.
- The project with the codename "MASZEKER" (NTP/2 OM-00309/2008) started in 2009 and will last for four years. Its chief aim is to develop a new type of search engine that is built on novel, semantics-based strategies.

- The "BELAMI" Hungarian-German bilateral project (OMFB-737/05) on ambient intelligence ran between 2005 and 2008; in 2008 we won the application to continue the project, and as a part of it our researchers will develop text mining algorithms.

Our team is participating in the European FP7 project entitled "Common Language Resources and Technologies Infrastructure". Its aim is to unify the formalism of all European language technology databases. This project should start in the near future.

X. PUBLICATIONS

In the past three years we have published 44 papers, 1 book chapter and 2 PhD theses in the area of language technology. Here we list just the most important ones, for a full list of publications please visit: `http://www.inf.u-szeged.hu/rgai/nlp_publications`.

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PEER-TO-PEER ALGORITHMS AND SELF-ORGANIZING SYSTEMS

XI. INTRODUCTION

During the past decade the Internet has undergone an impressive growth and has reached very high levels of penetration into homes and businesses. This has lead to a radical shift in the possibilities it offers and new applications such as (illegal) file sharing and collective computation have appeared. Many of these applications, mostly due to legal pressure, have obtained a truely *peer-to-peer* (P2P) character, in that they are fully decentralized, extremely fault tolerant and scalable.

These systems and their success have contributed to revitalizing the interest of the scientific community in fully decentralized, scalable, robust distributed systems, since they have many legitimate applications as well, such as content distribution networks, sensor networks, network monitoring, distributed data mining, and so on.

In the following we brielfy summarize the main results we achieved in the past three years in this area.

XII. MAIN RESULTS

We continued to work in the area of gossip protocols in the context of a number of applications. Some of our earlier research topics have been extended, finalized, and completed, as well as published in journal articles [8, 9].

Global optimization was a novel topic, done in cooperation with the European Space Agency in the context of an Ariadna project [3, 4]. Here we proposed P2P optimization algorithms and compared them with a fully distributed version of a branch-and-bound technique, and also proposed distribued hyper-heuristics.

We have analyzed the peer sampling service we introduced earlier from a novel point of view taking into account message delay and message loss [12].

We proposed algorithms for the synchronization of heartbeats in a P2P overlay network, based on biological inspiration: the spontaneous synchronization behavior of fireflies [1]. The resulting synchronization is illustrated in Figure 41. For more details please refer to [1].

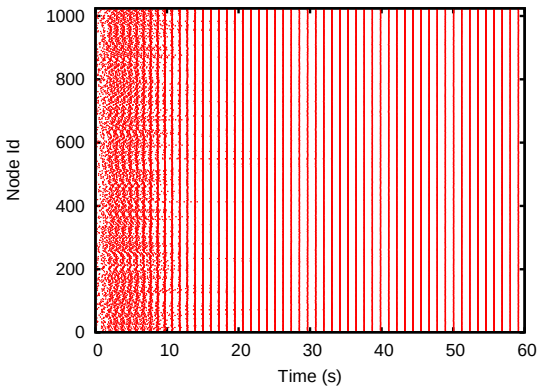

Figure 41. Synchronization of 1000 nodes

We have proposed a local algorithm for evolving specified shapes in mobile wireless devices (robots or resque teams, etc) [2]. Figure 42 illustrates the behavior of the algorithm when started from an evenly distributed random configuration. The main idea is that all agents know their relative position on the final confoguration, and they iteratively and locally optimize their own position relative to the other nodes they can communicated with. For more details please consult [2].

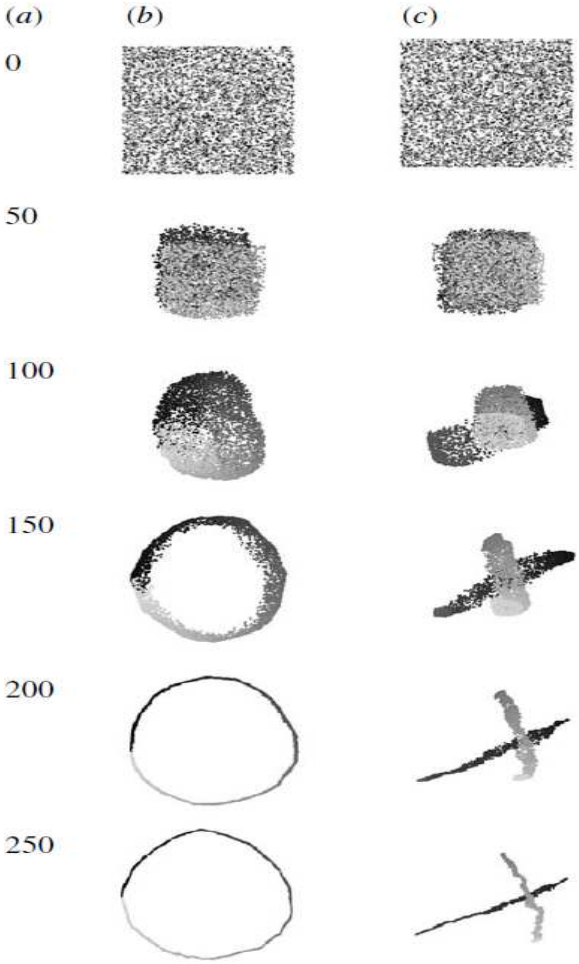

Figure 42. Convergence to specified configurations (number of cycles shown on left)

In addition to the above topics we have investigated a number of additional problems. These include synchronous power iteration [7], where the dominant eigenvector of a distributedly stored matrix is calculated in an iterative and asynchronous way (tolerating message delay and failures). We have also investigated the problem of botnet detection, and in relation to this, some algorithmic and theoretical problems related to small degree overlay networks [5, 6]. Finally, an algorithm was proposed for calculating the order-rank of nodes in an efficient and distributed way [11].

XIII. PEERSIM

The P2P simulator PeerSim continues to be developed and an increasing number of researchers use it regularly [10]. No major updates have been performed on the core, but several extension packages have been produced as well as new releseases of the software.

XIV. CONFERENCE ORGANIZATION AND EDITING

- The Fourth IEEE International Conference on Self-Adaptive and Self-Organizing Systems (SASO 2010), Budapest, Hungary, September 27-October 1 2010. General Co-Chair.
- Self-Organizing Systems Track, 12th International Symposium on Stabilization, Safety, and Security of Distributed Systems (SSS 2010), New York City, USA, September 20-22, 2010. Co-Chair.
- The Second IEEE International Conference on Self-Adaptive and Self-Organizing Systems (SASO 2008), Isola di San Servolo (Venice), Italy, October 20-24 2008. Publication Chair.
- The First IEEE International Conference on Self-Adaptive and Self-Organizing Systems (SASO 2007), Boston, Massachusetts, USA, July 2007. TPC co-chair.

XV. SELECTED PROGRAM COMMITTEES

1. IEEE Conference on Peer-to-Peer Computing (P2P) 2008, 2010
2. The 7th Intl. Conf. on Swarm Computing (ANTS) 2010
3. International Conference on Bio inspired Models of Network, Information and Computing Systems (BIONETICS) 2007–2010
4. European Conference on Parallel Computing (Euro-Par) 2008, vice chair of topic: Peer-to-Peer and Web Computing

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