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

2009–2012

Szeged, 2013

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), Dr. Károly Dévényi (management) and Dr. László Nyúl (hardware-software).

The Institute consists of six 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: Dr. Csanád Imreh
- 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
- Department of Technical Informatics, head of the department: Dr. Zoltán Gingl
- 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 bachelor, master, and doctoral (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.

UNDERGRADUATE 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 master 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 master 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 master 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 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.

Engineering Information Technology, MSc

The normal duration of the program is 4 semesters. The goal of the training is to produce informatics experts, who have firm theoretical basis and are able to expand their knowledge autonomously in a long run. They can work in a team or on their own in the field of applied informatics such as measurement technology instrumentation, analogue and digital electronics, sensor signal conditioning, signal processing, process control, and robotics. Furthermore, they possess the necessary cooperation and model making skills that are needed for solving the applied informatics problems arising in their fields. They are also able to conduct research work, 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 to 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, with an emphasis on theoretical aspects.

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.

It is composed of three subprograms: Theoretical Computer Science, Operations Research and Combinatorial Optimization, and Applications of Computer Science. The possible research topics include mostly come from 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 5-6 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

Ad-hoc mobile and multimedia networks. Static and dynamic analysis of software systems. Software quality models, assessment and improvement. Reverse engineering. Code coverage and testing. Open source software development. Browser engine development. Linux file system and GCC compiler optimization. Embedded systems. Process synthesis.

Department of Technical Informatics

Stochastic processes and applications, developing measurement and data acquisition systems, virtual instrumentation, remote laboratories, sensors and sensor networks, medical Instrumentation, HIL (Hardware In the Loop) modules, applications in education, pneumatic artificial muscle, robot navigation and localization, fuzzy control, industrial robotics, design of robot manipulators, CAD/CAM systems, CNC, ARM based embedded systems, intelligent buildings, remote surveillance, vibrations analytics, industrial communication and automatization, industrial monitoring systems, FPGA based digital circuit design.

Research Group on Artificial Intelligence

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

The members of the Institute of Informatics publish about 150 scientific papers in highly respected international journals/proceedings anually.

Partners

The Institute of Informatics has joint programs and research cooperation (e.g. CEEPUS,

SOCRATES/ERASMUS, DAAD) 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.
Belgium: Universite Libre de Bruxelles, Katholieke Universiteit Leuven, University of Antwerpen.
Bulgaria: University of Rousse.
Czech Republic: Charles University, Prague.
Denmark: University of Aalborg, The University of Copenhagen.
England: University College London, Coventry University, Durham 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, Centrum Wiskunde & Informatica, Amsterdam.
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, Universidad de Girona.
Sweden: Swedish University of Agricultural Science, Uppsala.
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/`

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, Oriental Journal of Mathematics, and 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, Informatics Europe, and Association for Computing Machinery.

V. RESOURCES

LIBRARIES

The Institute of Informatics has a library which holds about 5000 Hungarian and English volumes and subscribes over 200 scientific journals. The recently renewed University Library is also an invaluable resource for both our faculty and our students. It offers not only numerous scientific books, journals and databases, 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/`

Research by Departments

Department of Computational Optimization

The research of the Department of Computational Optimization includes the study of both continuous and discrete optimization methods and applications. Besides these, we work on various parts of discrete mathematics and the history of mathematics.

Three special issues of the Central European Journal on Operations Research have been coedited by Tibor Csendes during the reported period. The first one, [1] was devoted to the 50th anniversary of the Hungarian Method, the algorithm that solves the assignment problem. The volume was praised in the European J. on Operational Research by Harold W. Kuhn, who has invented the method.

The second special issue was based on the talks held at the XXVIII. Hungarian Operations Research Conference, Balatonőszöd, 2009. The third one is related in a similar way to a conference of the Slovenian Society INFORMATIKA – Section for Operations Research (SDI-SOR) held in Nova Goricia, 2009.

I. GLOBAL, a stochastic global optimization algorithm revisited

The refreshed global optimization code, that was originally meant for simple bound constrained nonlinear optimization problems, was extended to constrained global optimization problems in [4].

A numerically difficult parameter estimation problem arising from the field of digital angiography was solved in [9]. The main point was here actually the smoothing of original data and the reduction of the number of model parameters to a level that allowed valuable prediction, while the related model identification problem remained solvable, and robust against data perturbation.

Global was extensively tested on a noiseless nonlinear optimization testbed of the Vienna University [12]. The method was compared to leading edge blackbox optimization techniques, and although the algorithmic part of GLOBAL are already a few decades old, in some of the evaluation criteria it proved to be competitive with the other state-of-the art algorithms.

Gossip based strategies for global optimization were studied in [19]. The research was completed in the frame of an European Space Agency project.

II. Network optimization

A general introduction was given into verified numerical techniques for modelling real life systems, and for the verification of mathematical models in [5]. Interval inclusion functions were proposed as natural tools for the description of uncertainties, especially in environmental modelling.

Efficient estimation of loads in service networks was studied in [7]. The original problem was recognized in pos delivery services. Given a directed graph representing the flow of mail and packages, the question was how to measure efficiently the amount of mailed units in such a way, that while the final delivered amounts are estimated with a preset uncertainty, the total cost of the measurements remain limited. In the real life case, it is easy and cheap to count letters in some of the post offices that use electronic machinery for finding the next destination, while manual counting available in small post offices is expensive both in terms of time and money.

The paper [8] introduces PageRank based new network algorithms for extracting information from oriented graph descriptions that emerge in as wide fields as scientometrics and wine tasting. In both cases the new methods proved to be capable to capture relevant, objective information on the quality of scientific publications and wine tasters. In the example case of the seminal, Hungarian language paper of J. Egerváry, on which the famous Hungarian method is based, it turned out, that its value is way larger according to the new methodology than what was known on the basis of traditional citation analysis only.

III. Interval methods

The earlier interval arithmetic based branch-and-bound global optimization method was improved and newly implemented in Matlab [6], utilizing the advanced features of the Intlab package. The new algorithm was capable to demonstrate the good efficiency values documented earlier, with the exception of the CPU time. The Matlab implementation was 2-3 order of magnitude slower than the earlier C-XSC or Fortran based ones – due to the interpreter nature of the numerical testing oriented neighborhood. Still it is quite popular due to the easiness of the application, and it can be recommended for the first phase of optimization and modelling tasks. The first author of the paper, László Pál obtained his PhD title in the year 2011, in part based on these results. The publication [11] provides an introduction to interval arithmetic based nonlinear optimization methods in Hungarian together with a case study of their use for the sensor localization problems. The paper [10] discusses directly a reliable, verified algorithm for the solution of constraint satisfaction problems.

IV. Symbolic simplification of nonlinear optimization problems

The next research field we have investigated was oriented to the presolve methods for nonlinear optimization. Based on the known expressions of the objective function and the possible constraints, the suggested methodology proved to be capable to automatically recognize substitution possibilities that lead to alternative problem formulation being simpler or easier to solve. First we have presented a Maple based implementation [13], then another one programmed in Mathematica [15]. The latter algorithm was more successful since the substitution and interval inclusion function services were better. Basically all the know simplifyable cases were recognized and solved as expected. On on hand simplifyable nonlinear optimization problems are rare, on the other hand, the presented automatic presolve method brings such advantages that are otherwise unavailable for global optimization problems.

V. Computational results for dynamical systems

One of the most time consuming investigation of our department was that has just been submitted for publication on a long standing conjecture of Wright. The unproven statement was made in 1955 on a simple looking delay differential equation that is related to some financial and number theoretical problems. The paper [14] is now in the review phase, the referees will have some changes in the presentation, while all of them finds the results important and interesting for the SIAM Journal on Applied Dynamical Systems.

Although the research in this subject was started as early as eight years ago, our technique was able to prove the statement of conjecture only for over 99% of the parameter range in question See Figure 1. Still we think, the developed new verified estimation schemes for delay equations will be useful for other similar problems. Our next similar issue is the still unproven chaotic behaviour of the Mackey-Glass equation.

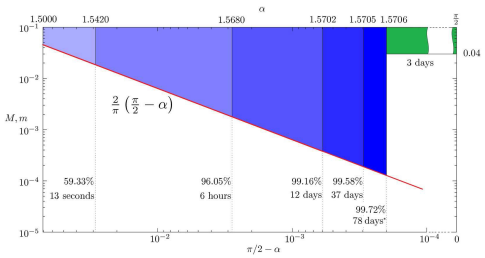

Figure 1. Illustration of the proven part of the Wright conjecture together with CPU times.

Finally Balázs Bánhelyi and Balázs Lévai studied reliable optimization techniques to find chaotic trajectories in the forced damped pendulum [16]. The latter simple mechanical system was proved to be chaotic by a research team involving two teachers of our department. The present result aimed to locate such starting points of the phase space, that ensure given preset properties of the solution trajectories.

VI. Industrial problems

We investigated the possibilities for implementing various global optimization approaches in a peer-to-peer environment, using gossip algorithms. Two rather different algorithms were compared: a branch-and-bound method and particle swarm optimization procedure. The results are presented in [17]. The second topic of investigation was the fully distributed implementation of a hyper-heuristics, that manages a pool of lower level algorithms and tries to adaptively combine or filter them to solve a given problem. The local Grid of European Space Agency (ESA) already applies such a hyper-heuristic called Digmo. We conducted an extensive study, and proposed various fully distributed versions of Digmo along with a number of original algorithms. The results of this test are presented in [18]. These works were completed in the frame of a European Space Agency project.

In the second problem, we were asked by an air conditioner service firm to develop a method which is capable to detect some types of machinery failure based on regularly collected signals of motions sensors attached to the device we are monitoring. The technique we developed consists of two major components: feature extraction and sample classification.

Finally we mention, that an automated design software of LED street lights has been developed based on optimization methods and parallel computing. We used NVIDIA's CUDA technology to implement a new version of the designer software with the parallel computation of the illuminance. Comparing the two implementations, we measured approximately a 13 times speedup, that can be experienced only in case of large designing tasks. In practice, this means that the 3-4 hours usual runtime can be reduced to 20-30 minutes.

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VII. ALGORITHMS ON GRAPHS

A new direction of research has been started in graph theory for about 15 years. It is the study of *Small World graphs* that includes social, transactional, technological etc. graphs. The discipline promises wide range of useful applications, while the same time requires the development of new approaches, methods.

We investigate various aspect of graph algorithms that make possible to build sophisticated models out of these graphs. In [3, 10] we discuss the problems of communities (overlapping clusters) of Small World graphs. We present new algorithms, give a unified view of community searching algoritmus, and evalutate the perfomance of those by using several criteria.

The possible change of communities are described and computed in [4]. The problem is to associate the communities of two graphs G_1 and G_2. Palla et al. also studied this problem, which worked well in some circumstances, but had two problems. First, it heavily depends on the properties of their community finding algorithm, the clique percolation method. The other problem is the incomplete classification; there are simply more types of possible events can happen that they examined. We constucted methods independent of the community finder, and applied a more refined classification which decreased percentage of obscure events. We also investigate the evolution of to large graphs, one is being a transaction graph of a bank, the other is a call graph derived from the logs of a telephone company.

The computation of the graph variables mentioned above were partly motivated from the results of [8]. Here we developed a credit default model based on the transaction graphs. The estimate the default probabilities we used a generalized version of the Domingos-Richardson cascade model. It is also pointed out that the success of such a model depends heavily on the estimation of edge infection probabilities.

In [5] we propose a method for estimating the edge infection probabilities in a generalized Domingos-Richardson model. The probabilities are considered as unknown functions of a priori known edge attributes. To handle this inverse infection problem, we divide the past data to learning and test sets. Then we try to assign edge probabilities such that the model results in infection patterns similar to the learning set, while we evaluate the overall process by the test set. Usually not the edge probabilities themselves are estimated, but their dependences on other available information, such as the previous behaviors of nodes. In our case these are vertex or edge attributes. Mathematically we face with various optimization problems, where the objective functions are known only implicitly. We study different measures of goodness, and develop algorithms for the optimization and investigate the possible best estimations given the boundary conditions.

Network analysis is an increasingly used research method in medicine. Network analysis is a research and interpretation model at the same time. Our article [6] outlines the various applications of network analysis in medicine and at its interdisciplinary boundaries. General introduction to the notions of small world graphs, cluster analysis, protein-protein interaction network and clinical opinion leaders are presented along with a overview of the field.

VIII. HYPERGRAPHS AND POSITIONAL GAMES

In [11] 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 $n \geq 8$).

The paper [1] 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.

In [2] we investigate a special form of degree games defined by D. Hefetz et al. Usually the board of a graph game is the edge set of K_n, the complete graph on n vertices. Maker and Breaker alternately claim an edge, and Maker wins if his edges form a subgraph with prescribed properties; here a certain minimum degree. In the special form the board is no longer the whole edge set of K_n, Maker first selects as few edges of K_n as possible in order to win, and our goal is to compute the necessary size of that board. Solving a question of Hefetz et al., we show, using the discharging method, that the sharp bound is around $10n = 7$ for the positive minimum degree game. More precisely, for $n \geq 4$, the necessary number of edges is $\lceil \frac{10}{7}n \rceil$, for $n \not\equiv 2 \pmod 7$, and $\lceil \frac{10}{7}n \rceil + 1$, for $n \equiv 2 \pmod 7$.

In [7] 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.

In the paper [9] we continue the study of Chooser-Picker and Picker-Chooser games. First of all, we show that both Picker-Chooser and Chooser-Picker games are NP-hard, which gives support to the paradigm that the games behave similarly while being quite different in definition. We also investigate the generalized pairing strategies for Maker-Breaker games, proving that the existence of such a strategy is a NP-complete problem in general. We apply these results to some well-studied games like the k-in-a-row or the "Snaky."

Acknowledgements

The research was partially supported by OTKA grants T049398 and K76099. The research was also partially supported by TÁMOP-4.2.2/08/1/2008-0008 TÁMOP-4.2.1/B-09/1/KONV-2010-0005.

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IX. History of Mathematics and Informatics

We worked on some books, book chapters and articles based on our research in History of Mathematics and Informatics. The main topics were the following:

- Circle packings [1–3, 9]
- Nonlinear Programming [4, 9]
- The two Bolyais [6, 14, 15, 18–20, 22, 31]
- The Riesz brothers [7, 10, 21, 25, 26, 32, 33]
- Jenő Egerváry [12, 13, 30]
- Migrations of Hungarian mathematicians in the 20th century [28]
- History of the University of Szeged [5, 8, 24]
- Biographies [11, 29] Manó Beke, János Bolyai, Tibor Gallai, Alfréd Haar, György Hajós, Pál Turán, György Pólya, Gusztáv Rados, Gyula Szőkefalvi Nagy
- Others
  - Paul Dirac [16]
  - John von Neumann Society [17]
  - László Vekerdi [23]
  - Renaissance mathematics [27]

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I. NATURAL LANGUAGE PROCESSING

Natural language processing research started at the University of Szeged in 1998, and by now, the group has become one of the leading workshops of Hungarian computational linguistics (`http://www.inf.u-szeged.hu/rgai/nlp`). The group is a collaboration of researchers from the Department of Computer Algorithms and Artificial Intelligence and from the Research Group on Artificial Intelligence.

The Hungarian Computational Linguistics Conferences have been organized by the group since 2003. The Group is engaged in processing Hungarian and English texts. Its general objective is to develop language-independent or easily adaptable technologies.

I.1. HUNGARIAN TEXT ANALYSIS

For end-user text mining/processing applications, it is essential to have a basic language resource kit, which is able to split texts into sentences and tokens and to assign morphological and syntactic analysis to them. Between 2008 and 2012, our group developed the `magyarlanc`, a basic language processing toolkit for Hungarian (`http://www.inf.u-szeged.hu/rgai/magyarlanc`). Hungarian is a morphologically rich and free word order language. Due to these characteristics of the language we had to completely reconsider several architectural issues of the language analysis tools developed for English.

`magyarlanc` consists of a sentence splitter and tokenizer, a morphological analyzer and a POS-tagger and it also includes a module for dependency parsing, which latter is unique in Hungarian language technology [1]. The components of the system are based on machine learning techniques (trained on the Szeged Corpus and Szeged Dependency Treebank) and were implemented in JAVA, which makes it possible to use it in a platform-independent way.

Figure 2 shows the output – i.e. tokens, morphological and syntactic analysis – of `magyarlanc` for a Hungarian sentence.

I.2. KEYPHRASE EXTRACTION

During the period of 2009–2012 a key research direction to deal with was the identification of keyphrases from natural language texts. We investigated the possible use of keyphrase extracion techniques on a wide variety of document genres (i.e. scientific publications, news documents and various types of product reviews). Besides experimenting with various domains, various end application utilizations of the extracted keyphrases were probed, e.g. in document visualization.

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. In [2] an automatic free text tagging solution was developed for the on-line news archive of the Hungarian [origo] news portal. The 370,000 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.

Our institute also participated at the Semeval-2010 shared task where the task was to extract keyphrases for scientific documents instead of news articles. Our proposed solution which regarded the task as a supervised classification problem and employed maximum entropy model with a rich feature set was ranked third by the official evaluation metric. Details with respect the feature engineering that was carried out can be found in [3]. In [4] we also dealt with the keyphrases of scientific documents and investigated how keyphrase extraction can benefit from named entity extraction and vice versa.

In [5] we gave a generalization of the concept of keyphrases and introduced a system for extracting the keyphrases responsible for the authors' opinion from product reviews. The datasets for two fairly different product review domains related to movies and mobile phones were constructed semi-automatically based on the pros and cons entered by the authors. The proposed system illustrated that the classic supervised keyphrase extraction approach – mostly used for scientific genre previously – could be adapted for opinion-related keyphrases as well. Besides adapting the original framework to this special task through defining novel, task-specific features (relying on SentiWordnet for instance), an efficient way of representing keyphrase candidates was also demonstrated. The paper also provided a comparison of the effectiveness of the standard keyphrase extraction features and that of the system designed for the special task of opinion expression mining.

Evaluation is a key issue in natural language processing tasks and even though there exist tasks – such as tokenization or morphological parsing – for which the level of ambiguity and subjectivity is essentially lower, it is still an open question to find a satisfactory solution for the (automatic) evaluation of certain tasks, such as keyphrase extraction. In [6] we presented the difficulties of finding an appropriate way of evaluating a highly semantics- and subjectivity-related task, namely opinionated keyphrase extraction.

I.3. UNCERTAINTY DETECTION

In computational linguistics, especially in information extraction and retrieval, it is of the utmost importance to distinguish between uncertain statements and factual information. In most cases, what the user needs is factual information, hence uncertain propositions should be treated in a special way: depending on the exact task, the system should either ignore such texts or separate them from factual information. In machine translation, it is also necessary to identify linguistic cues of uncertainty since the source and the target language may differ in their toolkit to express uncertainty (one language employs an auxiliary, the other employs just a morpheme). To cite another example, in clinical document classification, medical reports can be grouped according to whether the pa-

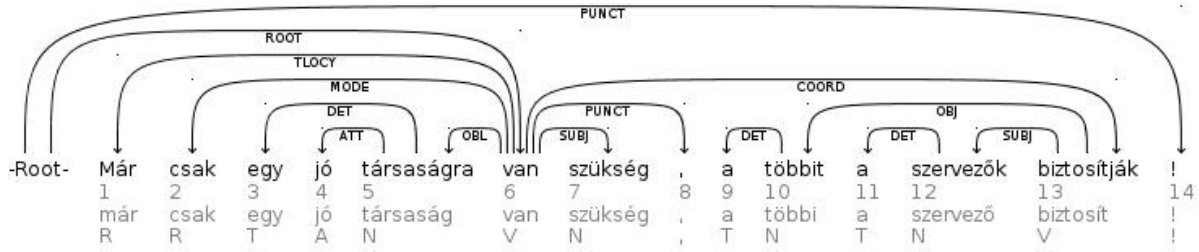

Figure 2. Dependency graph and morphological analysis of the sentence *Már csak egy jó társaságra van szükség, a többit a szervezők biztosítják*! "Now you just need a good company, everything else will be provided by the organizers."

tient definitely suffers, probably suffers or does not suffer from an illness.

The key steps of recognizing uncertain propositions in a natural language processing (NLP) application include the steps of locating lexical cues for uncertainty, disambiguating them (as not all occurrences of the cues indicate uncertainty), and finally linking them with the textual representation of the propositions in question. The linking of a cue to the textual representation of the proposition can be performed on the basis of syntactic rules that depend on the word class of the lexical cue, but they are independent of the actual application domain or text type where the cue is observed. However, the set of cues used and the frequency of their certain and uncertain usages are domain and genre dependent, which has to be addressed if we seek to craft automatic uncertainty detectors.

In order to give a comprehensive framework to research on uncertainty detection, we defined a language-independent classification of uncertainty phenomena based on theoretical background and empirical evidence, both from the fields of computer science and linguistics [7]. Based on the above classification, we also created and manually annotated benchmark databases for several types of uncertainty, e.g. the CoNLL-2010 Shared Task Corpora [9] and the Szeged Uncertainty Corpus [7]. Besides, we compared different approaches to determining the uncertain parts of a sentence by analyzing the differences between scope- or event-based uncertainty detection [8]. We also detected different types of semantic uncertainty in several types of English texts by domain adaptation techniques [7] and we also exploited uncertainty detection in the medical field when identifying the status of obesity and related diseases in patients [10].

I.4. MULTIWORD EXPRESSIONS

Multiword expressions (MWEs) are lexical units that that can be decomposed into single words, however, they exhibit special syntactic, semantic, pragmatic or statistical features. They are frequent in language use, in addition, in many cases they are similar to productive and compositional phrases at the surface level. Thus, they often pose a problem to NLP systems. However, for NLP applications like information extraction or machine translation it is essential to know that they count as one lexical unit, hence the identification of multiword expressions in texts is of outmost importance.

Multiword expressions can be divided into several groups based on the parts of speech of their components or based on their syntactic and semantic behavior. Among different groups of MWE, our investigations primarily focused on the automatic identification of nominal compounds and light verb constructions. A nominal compound is a lexical unit that consists of two or more elements that exist on their own and function together as a noun, and its meaning contains some additional element that cannot be calculated from the meaning of its parts (e.g. *high school*). Nominal compounds belong to the most frequent MWE-classes and they are productive, i.e. new nominal compounds are being formed in language use all the time, which yields that they cannot be listed exhaustively in a dictionary. Their inner syntactic structure varies: they can contain nouns, adjectives and prepositions as well. Light verb constructions are verb and noun combinations in which the verb has lost its meaning to some degree and the noun is used in one of its original senses (e.g. *have a walk*). Light verb constructions are semi-productive, that is, new light verb constructions might enter the language following some patterns. On the other hand, they are less frequent in language use and they are syntactically flexible, that is, they can manifest in various forms: the verb can be inflected, the noun can occur in its plural form and the noun can be modified.

In order to identify the above types of multiword expressions, we first developed several corpora in Hungarian as well as in English. The Szeged Treebank and the SzegedParalellFX corpora were manually annotated for Hungarian light verb constructions [16,17], and the Wiki50 corpus contains 50 Wikipedia articles manually annotated for several types of English MWEs and Named Entities (NEs) [15]. In these corpora, we were able to test our rule-based and machine learning based methods [12, 14] to identify multiword expressions, we empirically proved the beneficial effects of identifying MWEs and NEs in keyphrase extraction [11] and we also emphasized the domain specificity of the problem [13].

I.5. RESEARCH PROJECTS

The MASZEKER project (TECH_08_A2/2-2008-0092) started off in 2009 with the aim of developing a model-based semantic search system primarily for English and Hungarian patents and folklore texts. First, we adapted state-of-the-art natural language parsers (POS-tagger for English, dependency parser, NE-recognizer) to the features of the subtasks and domains in cooperation with our consortial partner, the Applied Logic Laboratory. Later, we developed the prototype of the syntactic parser for English patents, and implemented a dependency parser for Hungarian. Furthermore, a word sense disambiguation mod-

ule was built and a semantic lexicon was constructed for the semantic processing of patents. The efficiency of our methods was evaluated on a corpus of English patents, which contains manual annotation at several linguistic layers (e.g. shallow syntactic parsing, named entities). Besides, Hungarian ethnographic texts were manually POS-tagged and non-standard or misspelled words were replaced by the standard versions. In the last workphase of the project the final prototypes of the search engines for Hungarian folklore texts and English patents were implemented. The project ended with success in September 2012.

The TEXTREND project (OM-00006/2008) started in 2008, its goal being to construct a decision-support system for economic and governmental use via the application of trend analyser and text mining tools. Our group contributed to this goal by the research and implementation of several text processing tools, like the Hungarian linguistic preprocessor, automatic keyword extractor, people name disambiguator, Wikipedia vandalism detector. The project ended with success in November 2010.

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II. Research in fuzzy and pliant system

II.1. 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.

In their seminal treatment of multiattribute utility theory (MAU), Keeney and Raiffa show how certain conditions of independence among attributes yield the so called *multiplicative multiattribute utility function*

$$u_M(\mathbf{z}) = \frac{1}{k}\left(\prod_{i=1}^{n}(1+kk_iu_i(z_i))-1\right)$$

where $\mathbf{z} = (z_1, \ldots, z_n)$, $u_i \colon \mathbb{R} \to [0,1]$ are utility functions, z_i are evaluations, k_i is the weight of the ith criterion, and k is a scaling constant.

Use of the multiplicative model requires that the condition of mutual utility independence is satisfied. A subset of criteria to be independent of its complement. The criteria are said to be mutually independent if every subset of the criteria is utility independent of its complement. The multiplicative MAU model is able to represent fairly rich preference structures including nonlinearities in the attributes and interactions between attributes without restricting to unrealistic behavioral assumption. Furthermore it is quite tractable in practice. The assessment required for its calibration are neither prohibitive in number nor unduly difficult for the decision maker. In short, the multiplicative MAU model constitutes a good compromise of flexibility and practicality for application to real problems. It has been used in numerous applications. [1]

Our starting point is the multiplicative utility function which is extensively used in the theory of multicriteria decision making. Its associativity is shown and as its generalization a fuzzy operator class is introduced with fine and useful properties. As special cases it reduces to well-known operators of fuzzy theory: min/max, product, Einstein, Hamacher, Dombi and drastic. As a consequence, we generalize the addition of velocities in Einstein's special relativity theory to multiple moving objects. Also, a new form of the Hamacher operator is given, which makes multi-argument calculations easier. We examined the De Morgan identity which connects the conjunctive and disjunctive operators by a negation. It is shown that in some special cases (min/max, drastic and Dombi) the operator class forms a De Morgan triple with any involutive negation [3].

In this research we introduce extended fuzzy operators. We show that it is closely related to the Sugeno measure and to the multiplicative utility. The well-known Hamacher operator also belongs to this extended fuzzy operator class. We present a new form of the Hamacher operator. The sign of the parameters of this operator tells us whether it is a conjunctive or a disjunctive operator. After, we show the connection between the parameters when they build a DeMorgan class. As a special case we get the product, drastic and Einstein operators.

II.2. Pliant operator system

We study a certain class of strict monotone operators which build the DeMorgan class with infinitely many negations. We show that the necessary and sufficient condition for this operator class is $f_c(x)f_d(x) = 1$, where $f_c(x)$ and $f_d(x)$ are the generator functions of the strict t-norm and strict t-conorm. We give a new representation theorem of negation based on the generator function of the strict operator. On the other hand our starting point is study of the relationship for Dombi aggregative operators, uninorms, strict t-norms and t-conorms. We present new representation theorem of strong negations where two explicitly contain the neutral value. Then relationships for aggregative operators and strong negations are verified as well as those for t-norm and t-conorm using the Pan operator concept. We study a certain class of aggregative operators which build a self-DeMorgan class with infinitely many negation operators. We introduce the multiplicative pliant concept and characterize it by necessary and sufficient conditions.

In this research our starting point is a study of connection with Dombi aggregative operators, uninorms, strict t-norms and t-conorms. We present a new representation theorem of strong negations that explicitly contains the neutral value. Then the relationships for aggregative operators and strong negations are verified as well as those for the t-norm and t-conorm using the Pan operator concept. We introduce the multiplicative pliant concept and give the necessary and sufficient conditions for it. We study a certain class of weighted aggregative operators (representable uninorms) which build a self-DeMorgan class with infinitely many negations. We provide the necessary and sufficient conditions for these operators [4].

In fuzzy concepts the most powerful term is the membership function. Up until now the research community could not give an unambiguous definition of this term. In the pliant concept we give one which is connected to the operator system. Our starting point is that the fuzzy terms are so-called polar terms. In the table below we summarize some of the most common ones.

Pliant logic is a one generator function based operator system. In this system negation, conjunctive (t-norm), disjunctive (t-conorm) and aggregative operators are defined. In this contribution we define the implication operator and we show its main properties [7].

Hedges play an important role in fuzzy theory, although there are relatively few theoretical articles on them. In our study we construct unary operators related to negation operators inspired by intuitionistic logic. We give the general form of the necessity and possibility operators, then we prove some interesting identities relating to logical operators.

In our study we give a general form for modifiers that includes negation, different types of hedge and the sharpness operators. We show that the four operators have a common form in the Pliant system and they are called modifier operators. By changing the parameter value of a modifier we get the modalities, negation and the sharpness operators [5].

Hedges play an important role in fuzzy theory, although there are relatively few articles on them. Our aim is to provide a theoretical basis not only for hedges, but also for every type of unary operator. One of them is the negation operator,

which was presented in an article [9] concerning the DeMorgan class. In our study we develop unary operators related to other binary operators by demanding that they satisfy certain properties [6].

Modal operators play an important role in fuzzy theory, and in recent years researchers have devoted more effort on this topic. In our study, we construct modal operators in three different ways. The first is related to negation operators. The second was inspired by intuitionistic logic. The third is based on the distributive properties of the modal operators over conjunctive and disjunctive operators. We examine the simultaneous distributivity as well. All of these approaches give the same results for a certain class of operators. Next, we introduce graded modal operators. We also show that the modal operators are closely connected to Bayes' theorem.
Then we turn to hedges. Applying the distributivity property, we see that the modal operators are directly affected by the membership function. This influence is called hedging. Using the aggregation operator (representable uninorm), we can define the sharpness operator (using the second approach).
Lastly, we give a common form of all types of unary operators by using a special class of generator functions (negation, necessity and possibility operator, modifiers) called the kappa function and we characterise them using differential equations and functional equation. We show that a special class of the kappa function is related to the sigmoid function, and can be characterised by odds. We extend this kappa function to the $[a, b]$ interval [7].

In this research, we present a tool for describing and simulating dynamic systems. Our starting point is the aggregation concept, which was developed for multicriteria decision making. Using a continuous logic operator and a proper transformation of the sigmoid function, we build positive and negative effects. From the input data we can calculate the output effect with the help of the aggregation operator. Our approach is similar to the concept of the Fuzzy Cognitive Map. We shall introduce a new technique that is more efficient than the FCM method. The applicability of PCM is discussed and simulation results are presented [8].

We give a new representation theorem of negation based on the generator function of the strict operator. We study a certain class of strict monotone operators which build the DeMorgan class with infinitely many negations. We show that the necessary and sufficient condition for this operator class is $f_c(x)f_d(x) = 1$, where $f_c(x)$ and $f_d(x)$ are the generator functions of the strict t-norm and strict t-conorm [9].

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. In this research 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: we were able to reduce the error rate by 53.4% [10].

In this research we present a new approach to composing and decomposing functions. This technology is based on pliant concept. We use the proper transformations of conjunction of the sigmoid function to create an effect. We 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 present a solution that solves some of these problems. We introduce positive and negative effects. Their mathematical description can be realized by using continuous valued logic. We 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. [2]

II.3. Fuzziness measure in the Pliant system: The Vagueness measure

The basic idea of fuzzy sets is the introduction of the membership function, which replaces the classical characteristic function. It is an interesting question to learn how close the membership function is to the characteristic function, when we use a certain class of membership functions. This measure is called the fuzziness measure.

Below we shall present an operator-dependent fuzziness measure called the vagueness measure. We show that this measure satisfies the usual classical assumptions for the fuzziness measure. In addition, we show that there is a connection between this measure and the entropy function.

In our view, one of the most important concepts, because on this basis we can prove "convergence theorems" in the sense that "if there is less fuzziness in the input variables, then there will be less fuzziness in the result".

In the fuzzy literature we do not find such theorems, because membership functions, operators and fuzziness measures are unrelated so it seems hopeless to prove such convergence theorems.

In the Pliant concept we have the distending function instead of the membership function based on the Pliant operator, and now we define a vagueness measure by using the generator function of Pliant operator. On the basis of this consistent concept we can derive a convergence theorem.

First, we take a closer look at the fuzziness measure: Let $\mu(x)$ be the membership function and $d(\mu)$ be the fuzziness measure [11].

We introduce a new global thresholding algorithm which uses the image distribution function over the set of intensities. For a given threshold value, the method constructs the cumulative distribution functions of classes (object and background) and computes an entropy measure for a given threshold based on a vagueness measure that is also introduced. The effectiveness of this method is compared with other commonly used algorithms to demonstrate the usefulness of the proposed approach [12].

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III. Analysis of algorithms

III.1. Bin packing and scheduling problems

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 the online version we observe the items one by one and the algorithm has to pack the actual item into a bin without any information about the future items. The efficiency of online algorithms is usually measured by the competitive ratio where we give a worst case bound on the ratio of the algorithms' cost and the optimal offline cost.

In the class constrained 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 [14] we followed earlier work on this problem and studied the problem further in both offline and online scenarios. We presented an AFPTAS for the offline problem if k is considered as a constant. In the online case we gave an algorithm with asymptotic competitive ratio 2.63492, which performance is better than the performance of the best previously known algorithm.

In [13] we considered the class constrained 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 studied both the offline and the online variants of this problem. We first designed an optimal polynomial time algorithm for the offline problem. For the online problem we gave 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 analyzed the performance of the natural heuristic First-Fit.

In [10] we considered 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 studied 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 was considered as well.

In [4] we dealt with a very general packing problem: a given graph G is to be "packed" into a host graph H, and we are asked about some natural optimization questions concerning this packing. The input of the problem is a simple graph $G = (V, E)$ with lower and upper bounds on its edges and weights on

its vertices. The vertices correspond to items which have to be packed into the vertices (bins) of a host graph, such that each host vertex can accommodate at most L weight in total, and if two items are adjacent in G, then the distance of their host vertices in H must be between the lower and upper bounds of the edge joining the two items. Special cases are bin packing with conflicts, chromatic number, and many more. We gave some general structure statements, treated some special cases, and investigated the performance guarantee of polynomial-time algorithms both in the offline and online setting.

We also studied some scheduling problem. In [19] we investigated 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 presented 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 [17] we considered the problem with general machine cost functions. Furthermore we also studied 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 were given.

III.2. Online clustering type problems

In clustering problems, the goal is to partition a set of points into subsets known as clusters, while optimizing a given objective function. In the online version the points are presented to the algorithm one by one. The algorithm maintains a set of clusters, where a cluster is identified by its name and the set of points already assigned to it. Each point must be assigned to a cluster (in a valid way, according to the specific definition of each variant) at the time of arrival. One of the most important clustering problems is facility location, where the cost of a cluster is defined as the sum of a fixed setup cost and the total distance of the points of the cluster from its center. In [12] we considered a new version of the online facility location problem, where the algorithm is allowed to move the opened facilities in the metric space. We considered the uniform case where each facility has the same constant cost. We presented an algorithm which is 2-competitive for the general case and we proved that it is 3/2-competitive if the metric space is the line. We also proved that no algorithm with smaller competitive ratio than $(\sqrt{13}+1)/4 \approx 1.1514$ exists. We also presented an empirical analysis which showed that the algorithm gives very good results in the average case. In [9] we studied a one dimensional clustering problem where a cluster is a closed interval, and the cost of a cluster is the sum of a fixed set-up cost and its diameter (or length). We studied several variants, each having the two essential properties that a point which has been assigned to a given cluster must remain assigned to that cluster and no pair of clusters can be merged. In the strict variant, the diameter and the exact location of the cluster must be fixed when it is initialized. In the flexible variant, the algorithm can shift the cluster or expand it, as long as it contains all points assigned to it. In an intermediate model, the diameter is fixed in advance but the exact location can be modified. We gave tight bounds on the competitive ratio of any online algorithm in each of these variants. In addition, for each model we also considered the semi-online case where points are presented ordered by their location.

An another clustering application is the online data acknowledgment. If the communication channel is not completely safe, then the arrival of the packets must be acknowledged. In the data acknowledgment problem the goal is to determine the time of sending acknowledgments. In [18] we presented a new online algorithm for the solution of this problem. Our algorithm is a parameter learning extension of the alarming algorithms. The efficiency of the algorithm is investigated by an experimental analysis, and it is demonstrated that the new parameter learning algorithm has a significantly better performance than the classical algorithm. In [20] we extended our algorithm to the semi-online version where the algorithm has some extra information about the arrival time of the future packets.

III.3. Applications of pattern recognition techniques

In [6] and [11] we studied the online signature verification problem. This was a joint research with our Department of Technical Informatics. In [6] we presented a new method for online signature verification treated as a two-class pattern recognition problem. The method is based on the acceleration signals obtained from signing sessions using a special pen device. We applied a DTW (dynamic time warping) metric to measure any dissimilarity between the acceleration signals and represented our results in terms of a distance metric. Later in [11] based on an earlier proposed procedure and data, we extended our signature database and examined the differences between signature samples recorded at different times and the relevance of training data selection. We found that the false accept and false reject rates strongly depend on the selection of the training data, but samples taken during different time intervals hardly affect the error rates.

In [5], [7] and [8] we considered object classification in wireless sensor networks. Feature selection is a classical problem in the discipline of pattern recognition, for which many solutions have been proposed in the literature. In these papers we considered feature selection in the context of pattern classification in wireless sensor networks. One of the main objectives in the design of wireless sensor networks is to keep the energy consumption of sensors low. This is due to the restricted battery capacity of todays sensors. Assum-

ing that the features of a pattern recognition systems are acquired by the networks sensors, the objective of keeping the energy consumption of the sensors low becomes equivalent to minimizing the number of features employed in object classification. In fact, this objective is related with, but not identical to, classical feature selection, where one wants to optimize the recognition performance of a system by detecting and eliminating noisy, redundant, and irrelevant features. We introduced a general framework for pattern classification in wireless sensor networks that aims at increasing the lifetime of the underlying system by using a number of features as small as possible in order to reach a certain recognition performance. In these papers we studied several methods for the solution of this problem. In experiments with data from the UCI repository, we demonstrated the feasibility of our approach and compared a number of classical procedures for feature subset selection in the context of pattern classification in wireless sensor networks.

III.4. Other results

In [15] we studied the file caching problem, where the input is a sequence of requests for files out of a slow memory. A file has two attributes, a retrieval cost and an integer size. It is required to maintain a cache of size k, bringing each file, which is not present in the cache at the time of request, from the slow memory into the cache. This incurs a cost equal to the retrieval cost of the file. We studied two online variants of the problem, *caching with bypassing* and *caching with rejection*. If bypassing is allowed, a miss for a file still results in an access to this file in the slow memory, but its subsequent insertion into the cache is optional. In the model with rejection, together with each request for a file, the algorithm is informed with a rejection penalty of the request. When a file which is not present in the cache is requested, the algorithm must either bring the file into the cache, paying the retrieval cost of the file, or reject the file, paying the rejection penalty of the request. The goal function is the sum of total rejection penalty and the total retrieval cost. We designed both deterministic and randomized algorithms for both problems and determined their competitive ratio.

We also developed and analysed some algorithms in the area of logistics and chemical engineering. In [2] we introduced a new, pickup and delivery vehicle routing model where weight limits and also packing constraints are taken into account. In the model the vehicles have to transport 3-dimensional boxes from their pickup points into their delivery points. The boxes have weights and the vehicles has to satisfy a weight limit. We presented a heuristic algorithm for the solution of the problem. The efficiency of the algorithm is evaluated by an experimental analysis In [3] the packing part of this model was studied further. We designed and compared several heuristics algorithms for the solution of this problem.

In [16] we considered 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 overviewed the known reduction techniques for PNS problems and we presented a new reduction algorithm. The performance of this new algorithm was examined by an empirical analysis. In [1] we studied the reaction-pathway identification problem. The available algorithmic methods for this problem can be roughly grouped into two major classes, one based on graph theory and the other on linear algebra. Both classes of methods consider any chemical reaction system as a network of elementary reactions, thereby implying that the two classes are interrelated. This paper studied the linear algebraic concept termed direct mechanism introduced in the mid-eighties and the graph-theoretical concept termed structurally minimal pathway introduced two decades later. It has been formally proven that the two concepts are equivalent.

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III.5. CONFERENCE ORGANIZATION

The Conference on Hungarian Computational Linguistics (MSZNY) has been traditionally held in Szeged since 2003. In 2009, 2010 and 2011, the conference again provided a great opportunity for presenting the latest research achievements in the field of speech and language technology in front of a professional audience. Besides organizing the event, our colleagues actively participated in the scientific programme of the conference with several oral, poster or demo presentations each year. The websites of the conferences are available here: `http://www.inf.u-szeged.hu/mszny2009/`, `http://www.inf.u-szeged.hu/mszny2010/` and `http://www.inf.u-szeged.hu/mszny2011/`.

In 2010, our colleagues won the right to organize the shared task of that year's CoNLL conference. The challenge *Learning to detect hedges and their scope in natural language text* aimed at detecting hedge cues and their in-sentence scopes in biological texts and Wikipedia entries. Organizational tasks involved creating training and evaluation databases, defining evaluation metrics, editing of the conference proceedings and organizing the Shared Task sessions at the conference CoNLL-2010. 23 teams participated in the call from all over the world. The website of the Shared Task can be found here: `http://www.inf.u-szeged.hu/rgai/conll2010st/`.

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 studied themes are automata and formal languages, lexicographic orderings of languages, context-free languages of infinite words, tree automata, tree transducers and term rewriting, semirings, semimodules, weighted automata and weighted tree automata, logics on words and trees, finite model theory, fixed point operations in computer science, and axiomatic questions.

I. ITERATION THEORIES AND FIXED POINT OPERATIONS

Most computer scientists are aware of the fact that just about all their work is related to fixed points and fixed point operations. Prior work by Bloom, Ésik and others led to the notion of 'iteration theories' that capture the equational properties of fixed point operations in computer science. Iteration theories were studied and applied to programming semantics, automata and language theory, concurrency in the papers [1–6].

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II. SEMIRINGS, SEMIMODULES AND SEMIALGEBRAS

Semirings, semimodules and semialgebras have been widely used in computer science to describe the behavior of weighted automata. Many new types of these structures, such as (partial) Conway and iteration semirings and semialgebras, were used to provide an axiomatic framework to weighted automata in the papers [7–13]. For example, it has been shown that rational power series may be axiomatized by the equations of iteration semirings and a few more.

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III. AUTOMATA, TREE AUTOMATA, WEIGHTED AUTOMATA

Research on automata has been performed in several directions. In addition to classical finite automata, it included tree automata and weighted automata with respect to both the classical language behavior and the bisimulation based behavior, see [16, 21–23]. In [18–20], we used tree automata to characterize the expressive power of branching time temporal logics and first-order logic enriched with Lindström quantifiers. In [17], we gave a complete axiomatization of the algebra of regular tree languages.

In [33], we studied the nondeterministic variants of synchronizing automata.

In [25] we explore weighted extended tree transducers (wxtt) over countably complete semirings systematically. We show that the backward application of a linear wxtt preserves recognizability and that the domain of an arbitrary bottom-up wxtt is recognizable.

In [14] we characterize equational tree transformations in terms of tree transformations defined by different bimorphisms, and give an equational definition for some well-known tree transformation classes. In [15] we generalize these results for weighted tree transformations with finite support over continuous and commutative semirings, and in [26] for weighted tree transformations over the max-plus semiring.

In [31] we characterize the syntactic $K\Sigma$-algebras of recognizable tree series and show that all subdirectly irreducible $K\Sigma$-algebras are syntactic. In [27] we prove a variety theorem for tree series over a field K, which establishes a bijective correspondence between the varieties of recognizable $K\Sigma$-tree series and the varieties of certain finite-dimensional $K\Sigma$-algebras.

In [28] we show that both the forward and the backward application of synchronous tree substitution grammars (stsg) preserve recognizability of weighted

tree languages in all reasonable cases. As a consequence, both the domain and the range of an stsg without chain rules are recognizable weighted tree languages.

In [30] we prove 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 [32] we present a KLEENE theorem on the equivalence of recognizability and rationality for tree series over distributive multioperator monoids. In [24] we prove that a tree series over an absorptive multioperator monoid is recognizable by weighted tree automata iff it is definable by certain MSO-like expressions.

In [34] we introduced the concept of a tree homomorphism for unranked trees. We show that they preserve recognizability.

In [35] we compare the computing powers of a given deterministic bottom-up tree transducer and a given ground term rewrite system.

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IV. LEXICOGRAPHIC ORDERINGS

Each countable linear ordering may be represented as the lexicographic ordering of a language over some alphabet. But which linear orderings may be represented as lexicographic orderings of regular or (deterministic) context-free languages? Is it decidable whether they are well-orderings, scattered orderings or dense orderings? These questions and many others were studied in the papers [36, 38, 39, 41, 43–45]. For example, we showed that the finite condensation rank of the lexicographic ordering of a context-free language is less than ω^ω, and that a well-ordering is the lexicographic ordering of a context-free language iff it is the lexicographic ordering of a deterministic context-free language iff its order type is less than ω^{ω^ω}. We also proved that there is a context-free language whose lexicographic ordering is not isomorphic to the lexicographic ordering of any deterministic context-free language. Moreover, whereas it is decidable for a context-free grammar whether the lexicographic ordering of its language is a well-ordering or a scattered ordering, it is undecidable whether it

is dense. We also constructed a context-free language whose lexicographic ordering has an undecidable first-order theory. This is interesting since the the lexicographic ordering of any deterministic context-free language has a decidable first-order, even decidable monadic second-order theory.

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V. LANGUAGES OF INFINITE WORDS

The theory of context-free languages of finite words may be extended to infinite words if one allows a derivation tree to be infinite and requires some (e.g. Büchi– or Muller–type) acceptance condition to hold over the branches of the tree. In [46, 47, 49, 51, 53] we considered the (closure, complexity, order-theoretic etc.) properties of the languages generated by context-free grammars equipped with a Büchi–type condition, while in [48,50,52] we studied the languages generated by grammars with a Muller–type condition.

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VI. TERM REWRITE SYSTEMS

In [54] we showed that it is decidable for any extended ground term rewrite system R whether there is an equivalent ground term rewrite system S.

In [55], we show that for any equivalent reduced ground term rewrite systems R and S, the same number of terms appear as subterms in R as in S. We give an upper bound on the number of reduced ground term rewrite systems equivalent to a given reduced ground term rewrite system R.

In [56] we presented a new variant of the PPP Challenge Handshake Authentication Protocol. We based our version on the concept of rewrite complements for ground term rewrite systems.

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VII. MISCELLANEOUS

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VIII. SURVEY PAPERS, BOOK CHAPTERS

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IX. EDITED VOLUMES

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X. OTHER ACTIVITIES

Zoltán Fülöp was a member of the PC of the conferences Automata and Formal Languages 2011 (Debrecen) and Algebraic Informatics (Linz) 2011. He is a member of the Editorial Board of Acta Cybernetica.

Zoltán Ésik was a member of the PC of the conferences Algebraic Informatics (Porquerolles Island) France, 2013, Developments in Language Theory (Paris) 2013, Mathematical Foundations of Computer Science (Vienna) 2013, Descriptional Complexity of Formal Systems (Braga) 2012, Fixed Points in Computer Science (Tallinn) 2012 (co-chair), Foundations of Software Technology and Theoretical Computer Science (Mumbai) 2011, Descriptional Complexity of Formal Systems (Giessen) 2011, Developments in Language Theory (Milan) 2011, International Colloquium on Automata, Languages and Programming (Zurich) 2011, Automata and Formal Languages (Debrecen) 2011, Fixed Points in Computer Science (Brno) 2010, Foundations of Software Technology and Theoretical Computer Science (Chennai) 2010, Fixed Points in Computer Science (Coimbra) 2009, Mathematical and Engineering Methods in Computer Science (Brno) 2009, Developments in Language Theory (Stuttgart) 2009, Quantitative Logics (Rhodes) 2009 (chair), Symposium on Theoretical Aspects of Computer Science (Freiburg) 2009.

He was an invited speaker of the conferences Workshop on Lattices and Relations (Amsterdam) 2012, Weighted Automata: Theory and Applications (Dresden) 2012, Algebras, Languages, Algorithms and Computation (Kyoto) 2011, Highlights of Automata (Vienna) 2010, Weighted Automata: Theory and Applications (Leipzig) 2010, AUTOMATHA 09 (Liege) 2009. Zoltán Ésik served on the steering committees od the conference series Fundamentals of Comutation Theory, Algebraic Informatics, Fixed Points in Computer Science, Automata and Formal Languages.

He is a member of the Editorial Board of Theoretical Computer Science, Theoretical Informatics and Applications, Algebra (Hindawi Publishing Corporation), Acta Cybernetica, and Alkalmazott Matematikai Lapok (J. Applied Mathematics, János Bolyai Math. Soc.).

Zoltán Ésik has been a member of the council of the European Association of Computer Science (EATCS) and the Committee for Theoretical Computer Science of the International Federation for Information Processing (IFIP). Until 2010, he was also a member of the board of the European Association for Computer Science Logic (EACSL).

XI. AWARDS

In 2010, Szabolcs Iván was awarded Gyula Farkas Prize (János Bolyai Math. Soc.). Zoltán Ésik was elected member of the Academy of Europe in 2010.

ACKNOWLEDGEMENTS

The above research has been supported by the AUTOMATHA program of the European Science Foundation, the grants K 75249 and T46686 of the National Foundation of Hungary for Scientific Research (OTKA), the grant 36 of DAAD-MÖB, the grant DFG GK 334/3 of the German Research Foundation, the programs TÁMOP-4.2.2/08/1/2008-0008 and TÁMOP-4.2.1/B-09/1/KONV-2010-0005 of the Hungarian National Development Agency, the MTA-CNRS (Hungarian-French) project Algebraic Theory of Automata, the grants 68öu2 and 77öu9 of the Austrian-Hungarian Action Fund and TéT-10-1-2011-0548 of the Hungarian National Development Agency.

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/`.

I. RECONSTRUCTION METHODS FOR DISCRETE TOMOGRAPHY

Tomography is a non-destructive technique for reconstructing and examining the inner structure of objects from their projections. In *transmission tomography* the *projections* are taken by exposing the object of study to some penetrating radiation on one side, and measuring the energy of the transmitted beams at different points on the other side, as illustrated in Figure 3. In this way, one can calculate the attenuation of the energy, and deduce the absorption properties of the object on the paths of the beams. If the projections are gathered from enough directions (which might mean hundreds of projections), one can reconstruct the material properties at arbitrary positions of the object.

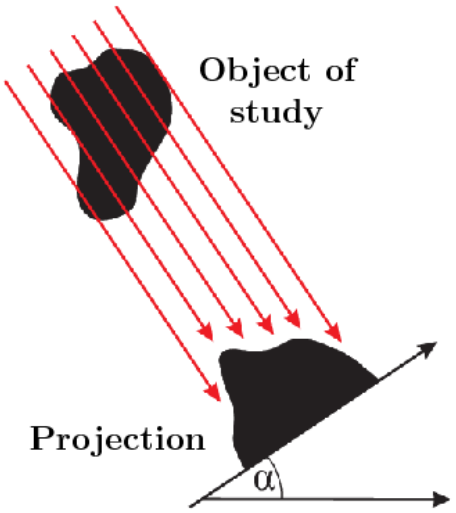

Figure 3. Illustration of a projection of an object.

In *Discrete Tomography*, we assume that the examined object consists of only a few known materials. This extra information can be used to drastically reduce the number of projections required for the reconstructions, and to minimize the cost or unwanted damaging effects of the projection acquisition process. Moreover, in *Binary Tomography* we assume that the reconstructed image contains only two intensity levels, one for the homogeneous material of the object and another one for the surrounding material (usually air).

DIRECTION-DEPENDENCY IN DISCRETE TOMOGRAPHY

With discrete tomography, one can reconstruct the inner structure of an object even from only few (say, up to 2-10) projections. In this case, the low number of projections provides a big variety for choosing their directions. The choice of projection directions can have a significant influence on the reconstructed results. Projections taken from specific directions hold more information for the reconstruction than others, thus they can lead to more accurate reconstructions. This is illustrated in Figure 4.

We designed an experimental environment for studying this phenomenon, and examined the problem from different points of view [1–6]. Such studies are motivated by practical problems. In many applications of discrete and binary tomography, there are limitations on the number of available projections, because the projection acquisition process can have a high cost, or can damage the object of study. Therefore, we could benefit from reducing the number of required projections, or increasing the accuracy of the reconstructions by only improving the projection acquisition process using proper projection selection strategies.

AN ENERGY MINIMIZATION RECONSTRUCTION ALGORITHM FOR MULTI-VALUED DISCRETE TOMOGRAPHY

Discrete reconstruction algorithms have to cope with various difficulties of tomography. The reconstruction problem commonly requires the restoration of the structure of an object from incomplete projection data, possibly affected by errors coming from the discrete formulations of the reconstruction problem and the stochastic noise affecting the projection acquisition process. Also, the general case of discrete tomography is proved to be NP-hard, and efficient algorithms providing perfect results can only be develeoped for some special cases.

We proposed an energy minimization based reconstruction algorithm for the general case of discrete tomography [7]. We constructed an energy function, that takes its minima corresponding to the solutions of the discrete reconstruction problem. We also designed an optimization process for approximating the minima of this energy function.

Based on experimental results, it became clear, that the proposed method can compete with the current cutting-edge reconstruction algorithms in the literature. Moreover it is highly robust, when the projection data is affected by random noise.

LOCAL AND GLOBAL UNCERTAINTY IN BINARY RECONSTRUCTIONS

In binary tomography, the limitations on the number of available projections often yields incomplete projection data. The lack of information can cause uncertainties in the reconstruction, i.e., some parts of the reconstructed object might not be entirely determined by the projections. In this case, many feasible reconstructions can exist, and only one among them is the correct (original) image.

We developed a method that can measure the local uncertainty of the reconstructions, i.e., it can describe how reliably a set of projections determine each part of image to reconstruct [8]. We also gave a global uncertainty measure that can give an overall evaluation of the reconstructions, and describe their expected accuracy. This measure exclusively relies on the projection sets themselves, therefore it can be used without any a-priori knowledge of the object of study. Such measures can be used in various applications of binary tomography, to evaluate, and asses the accuracy of the reconstructions. They can also be used together

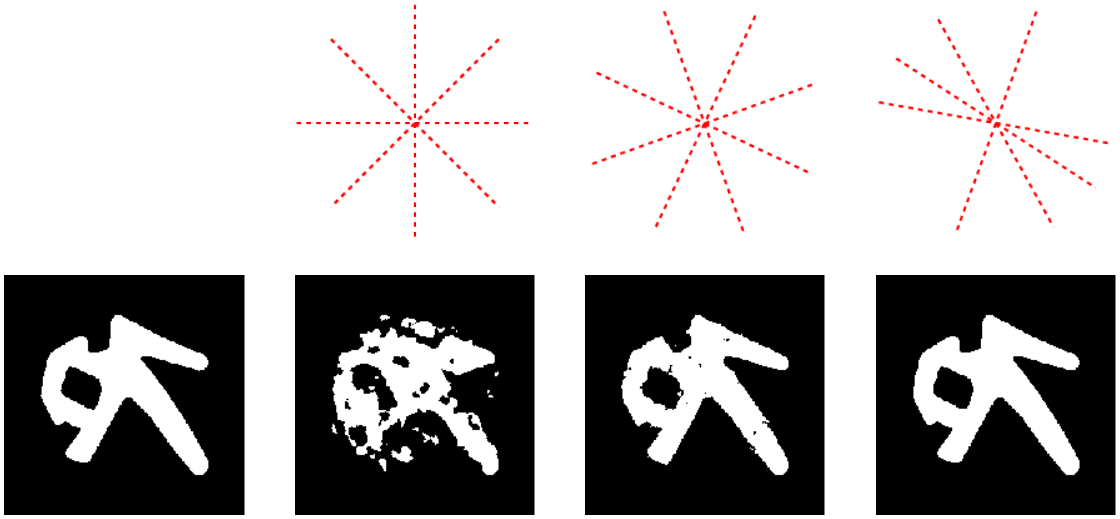

Figure 4. Reconstructions of a phantom from projection sets with different directions The first column shows the original phantoms, then in each column, dashed lines at the top indicate the directions of the projections, images below are the corresponding reconstructions.

Original Phantom Reconstruction Uncertainty map

Figure 5. Example of a highly inaccurate reconstruction and its uncertainty map. Results indicate, that further projections are needed to achieve an acceptable reconstruction.

with other reconstruction techniques to improve the results. An uncertainty map is illustrated in Figure 5.

RECONSTRUCTION WITH GEOMETRICAL AND STRUCTURAL PRIORS

One way to reduce ambiguity and to avoid intractability of the binary reconstruction is to suppose that the binary image to be reconstructed belongs to a certain class of images satisfying some geometrical or more complex structural properties (connectedness, convexity, etc.). The main challenge here is to find geometrical properties that can drastically reduce the number of possible solutions of the same reconstruction problem but still keep the reconstruction process tractable. One of the most frequently studied property is the so-called hv-convexity. Studying this class and some of its extensions, we gave important results regarding the worst case and average time-complexity of the reconstruction [9–12].

We introduced the morphological skeleton as an additional shape prior in DT, and investigated the problem of reconstructing binary images from the horizontal and vertical projections and the morphological skeleton [13, 14]. Furthermore, we also performed an experimental evaluation of the effect of median filtering in algebraic reconstructions when the image to reconstruct is supposed to be smooth [15].

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 explicitely given. We applied 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 its attributes [16–18]. We also developed advanced reconstruction methods suitable to use the learnt (uncertain) prior information [19].

FUNDATION

The research was in part suppoerted by the OTKA PD100950 project of the Hungarian Scientific Research Fund and by the János Bolyai Reasearch Scholarship of the Hungarian Academy of Sciences. The work was also supported by the TÁMOP-4.2.2/08/1/2008-0008 and TÁMOP-4.2.1/B-09/1/KONV-2010-0005 programs of the European Union and the Hungarian National Development Agency.

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II. SKELETONIZATION BY THINNING

Skeleton is a region-based shape descriptor which represents the general form of objects. Skeleton-like shape features (i.e., centerlines, medial surfaces, and topological kernels) play important role in various applications in image processing, pattern recognition, and visualization A widely used technique to obtain skeletons of binary objects is thinning, which is an iterative layer-by-layer erosion in a topology preserving way.

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.

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.

SKELETONIZATION TECHNIQUES IN DISCRETE SPACES

During the last two decades skeletonization (i.e., producing skeleton-like shape features) has been an important research field.

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. 6.

Thinning is a frequently applied skeletonization technique, since it:

- preserves topology,
- makes easy implementation possible,
- can produce different types of skeleton-like shape features (see Fig. 7),
- takes the least computational costs, and
- can be executed in parallel.

THINNING METHODOLOGIES

A 2D and a 3D binary picture is a mapping that assigns value of 0 or 1 to each point with integer coordinates in the 2D and 3D digital space denoted. 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. A reduction operation is *not* topology preserving if any object in the input picture is split (into two or more

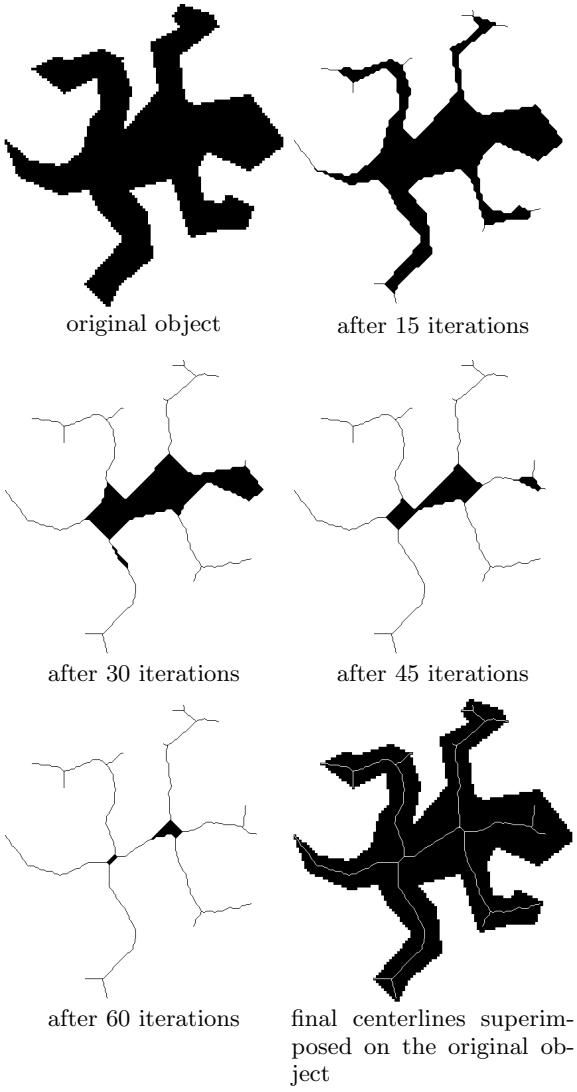

Figure 6. Example of thinning in 2D. The size of the test image is 430×460

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 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.

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), but some sequential algorithms were proposed, too. In the period of 2009–2012, we published various 2D parallel thinning algorithms [1–3], numerous 3D parallel thinning algorithms [4–9], and different order-independent sequential thinning methods [10–12].

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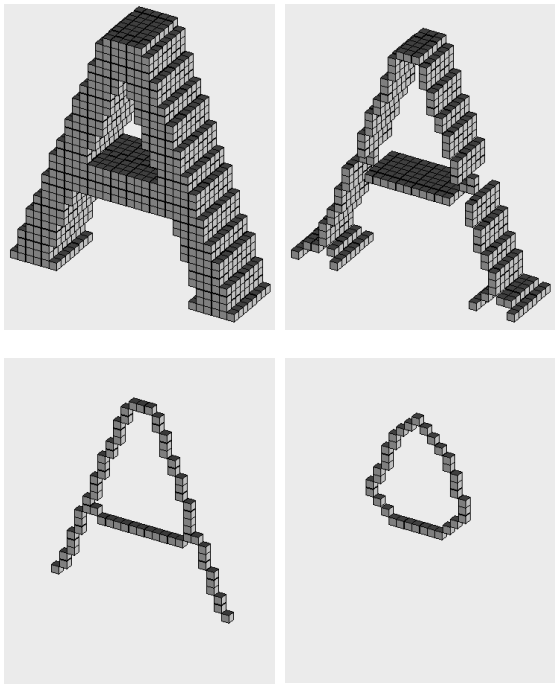

Figure 7. Different types of 3D skeleton-like shape features. The original elongated object (upper left), its medial surface produced by a surface thinning algorithm (upper right), its medial line (bottom left) extracted by a curve thinning algorithm, and its topological kernel (i.e., a minimal structure being topologically equivalent to the original object) created by a shrinking algorithm(bottom right).

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III. TOPOLOGY-PRESERVATION IN TRIANGULAR, SQUARE, AND HEXAGONAL GRIDS

There are three types of planar grids, which are formed by tiling the 2-dimensional Euclidean space with regular triangles, squares, and hexagons, see Fig. 8. The topology of the square grid is well-understood, but it cannot be said of the remaining two regular sampling schemes.

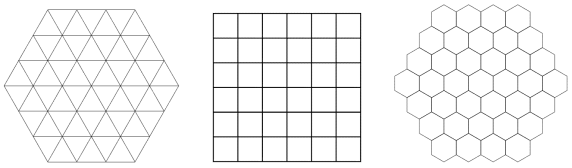

Figure 8. The three possible partitionings of the continuous plane into regular polygons.

A binary picture on a regular grid is a mapping that assigns a value of 0 or 1 to each polygon that is called a pixel. Pixels having the value of 1 are called black pixels, and those with a 0 value are called white ones. Black pixels form the objects of a picture, while the white pixels are contained in white components (i.e., the background and the cavities). A reduction operator transforms a binary picture only by changing some black pixels to white ones (which is referred to as the deletion of 1s). An operator that never turns a 1 into 0 is called a addition.

Topology preservation is a crucial property of various algorithms that are composed of reductions or additions, e.g., thinning, shrinking, or generation of skeleton by influence zones (SKIZ).

A reduction (on a 2D regular grid) is topology-preserving if each object in the original picture contains exactly one object of the produced picture, and each white component in the output picture contains exactly one white component of the input picture. Similarly, a 2D addition is topology-preserving if each object in the produced picture contains exactly one object of the original picture, and each white component in the input picture contains exactly one white component of the output picture. A black pixel is simple if its deletion is a topology-preserving reduction, while a white pixel is simple if its turning into black is a topology-preserving addition.

In the period of 2009–2012, we published a general characterization of simple pixels and some sufficient conditions for topology-preserving operators (i.e., reductions and additions) in all the three types of regular grids [1–5].

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IV. LIVE CELL SEGMENTATION IN FLUORESCENCE MICROSCOPY VIA GRAPH CUT

We propose a novel Markovian segmentation model which takes into account edge information. By construction, the model uses only pairwise interactions and its energy is submodular. Thus the exact energy minima is obtained via a max-flow/min-cut algorithm. The method has been quantitatively evaluated on synthetic images as well as on fluorescence microscopic images of live cells.

MARKOV RANDOM FIELDS

Markov Random Fields (MRF) provide a powerful tool to construct segmentation models of degraded images yielding an energy minimization problem. Unfortunately, the exact minimization of a general energy function is NP-hard, requiring iterative algorithms [4], which is a major obstacle for adopting MRF models in interactive segmentation. However, certain class of energy functions can be exactly minimized by graph cuts in *polynomial time* [6].

MRF SEGMENTATION MODEL

Segmentation can be considered as a labeling problem: Given a set of sites (or pixels) $\S \subset \mathbb{Z}^2$

and observed image features (e.g. graylevels) $\mathcal{F} = \{f_s\}_{s\in\mathcal{S}}$, we want to assign a label $\omega_s \in \{0,1\}$ to each site s. Taking a Bayesian approach, we can factorize the posterior as $P(\omega|\mathcal{F}) \propto P(\mathcal{F}|\omega)P(\omega)$, where the optimal segmentation $\widehat{\omega}$ is obtained as the *Maximum a Posteriori* (MAP) estimate. MRFs are broadly used in building probabilistic models for such labeling problems. The *Hammersley-Clifford theorem* provides a convenient way to specify MRFs through clique potentials. It states the equivalence between MRFs and Gibbs fields with probability distribution [4]

$$P(\omega|\mathcal{F}) = \frac{1}{Z}\exp\left(-\sum_{c\in\mathcal{C}} V_c(\mathcal{F},\omega)\right),$$

where Z is the normalizing constant, $\mathcal{C}$ denotes the set of cliques induced by the neighborhood system (see Fig. 9) and V_c stands for the *clique potential* functions. A *clique* is defined as the set of sites in which each site is a neighbour of all the other. The MAP estimate of the hidden *labeling field* ω is then found by minimizing the Gibbs energy. Herein, we consider 8-neighbourhood cliques on the image lattice $\mathcal{S}$, giving rise to cliques up to order 4. However, only pairwise interactions are considered in order to ensure that the Gibbs energy can be minimized via standard max-flow/min-cut [2, 6].

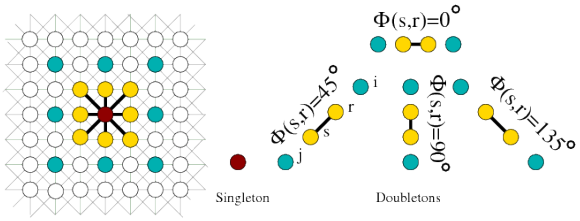

Figure 9. Neighborhood and cliques.

CLIQUE POTENTIALS

In our case (see Fig. 10), the background/foreground graylevel distributions can be easily modeled as Gaussian densities with parameters $(\mu_\lambda, \sigma_\lambda), \lambda \in \{0,1\}$. In order to ensure object coherence, $P(\omega)$ is usually chosen to be the *Ising* prior consisting of pairwise clique potentials

$$\forall (s,r) \in \mathcal{C} : \beta\delta(\omega_s,\omega_r) \qquad (1)$$

with $\delta(\omega_s,\omega_r) = -1$ for homogeneous and $+1$ for inhomogeneous arguments. Indeed, this prior will enforce homogeneity *everywhere*. A more efficient prior would be to encourage coherence only where intensity gradient is low. The idea of taking into account intensity edges has appeared as early as in [4], while recently, in the context of graph cut, a contrast-sensitive GMMRF has been proposed in [1]. However, [4] defines a separate *line process* with higher order interactions which are difficult to handle in a graph-cut framework. On the other hand, [1] uses a so called *contrast* term in the data likelihood, which is related to the squared intensity difference between interacting pixel pairs but ignores gradient direction.

In contrast to previous approaches, we propose to exploit the full gradient information (i.e. magnitude and direction) while keeping the ability to find an exact MAP solution via standard max-flow/min-cut. Obviously, the prior cannot depend on the data, hence we have to include the additional gradient terms in our data likelihood. Given the gradient vector field $\nabla\mathcal{F}$ with normalized magnitudes $|\nabla\mathcal{F}(s)| \in [0,1]$ and quantized edge directions $\theta(s) \in \{0°, 45°, 90°, 135°\}$ perpendicular to the gradient direction, we define the gradient strength $M(s,r)$ and edge direction $\Theta(s,r)$ for all doubletons $(s,r) \in \mathcal{C}$ as

$$\begin{aligned} M(s,r) &= \min\{M_{\max}, \qquad (2)\\ &\quad -\min\{\log(1-|\nabla\mathcal{F}(s)|), \log(1-|\nabla\mathcal{F}(r)|)\}\} \\ \Theta(s,r) &= \begin{cases} \theta(s) & \text{if } |\nabla\mathcal{F}(s)| > |\nabla\mathcal{F}(r)| \\ \theta(r) & \text{otherwise} \end{cases} \end{aligned}$$

where $M_{\max}$ is the maximum allowed value for $M(s,r)$ (i.e. we clip $M(s,r)$ at $M_{\max}$). Furthermore, we define an indicator function

$$F(s,r) = H((\mu_{\omega_s} - \mu_{\omega_r})(f_s + f_j - f_r - f_i)), \qquad (3)$$

where H is the Heaviside function and the location of sites j and i is shown in Fig. 9. Clearly, F will return 0 whenever the labels ω_s and ω_r are on the wrong side of the contour, because in such situations the difference in garylevel values f_s+f_j and f_r+f_i will have an opposite sign than that of the corresponding mean values. This function allows us to enforce object coherence around contours. The new doubleton potential added to the likelihood is then defined as

$$\begin{aligned} G(s,r) &= (1-F(s,r))\mathcal{M} \\ &\quad -F(s,r)H(\delta(\Theta(s,r),\Phi(s,r)))M(s,r) \qquad (4) \end{aligned}$$

where $\mathcal{M} \gg M_{\max}$ corresponds to a large constant penalty preventing wrong label assignments around object boundaries. Otherwise, the energy is decreased by $M(s,r)$ whenever the edge direction $\Theta(s,r)$ doesn't match with the clique direction $\Phi(s,r)$ (see Fig. 9), meaning that there is an intensity edge passing between s and r. The data likelihood MRF energy is then composed of singleton and doubleton potentials as follows

$$\begin{aligned} U(\mathcal{F},\omega) &= \sum_{s\in\mathcal{S}} \log(\sqrt{2\pi}\sigma_{\omega_s}) + \frac{(f_s-\mu_{\omega_s})^2}{2\sigma^2_{\omega_s}} \\ &\quad +\alpha \sum_{(s,r)\in\mathcal{C}} H(\delta(\omega_s,\omega_r))G(s,r) \qquad (5) \end{aligned}$$

Putting together Eq. (1 and Eq. (5, the Gibbs energy to be minimized can be written as

$$\widehat{\omega} = \arg\min_{\omega}\left(U(\mathcal{F},\omega) + \beta\sum_{(s,r)\in\mathcal{C}}\delta(\omega_s,\omega_r)\right) \qquad (6)$$

EXACT MAP SOLUTION VIA GRAPH CUT

Herein, we will show that the Gibbs energy of Eq. (6 can be represented by a graph $\mathcal{G}$ and hence an exact MAP solution is found in polynomial time by computing the minimum *s-t-cut* on $\mathcal{G}$ [6]. The vertices include the terminals $\mathbf{s}$ (*source*) and $\mathbf{t}$ (*sink*) as well as sites $\mathcal{S}$. Since our model uses pairwise interactions and binary labels, it can be naturally translated into a graph representation where, in addition to edges corresponding to doubletons, edges connecting vertices from $\mathcal{S}$ with the terminals $\mathbf{s}$ and $\mathbf{t}$ are also defined (see [6] for details). A cut on $\mathcal{G}$ corresponds to a binary partitioning S,T of the vertices such that $\mathbf{s} \in S$ and $\mathbf{t} \in T$, which can be described by the binary variables $\omega_s, s \in \mathcal{S}$. Each cut has also a

cost corresponding to the sum of edge weights that go from S to T, thus the energy represented by $\mathcal{G}$ can be seen as a function $E(\omega)$ equal to the cost of the cut defined by ω. In our case, $E(\omega)$ is as follows:

$$E(\omega) = \sum_{s \in \mathcal{S}} E_s(\omega_s) + \sum_{(s,r) \in \mathcal{C}} E_{s,r}(\omega_s, \omega_r), \quad (7)$$

where E_s corresponds to the Gaussian term from Eq. (5, while $E_{s,r}$ includes both the Ising prior and the gradient term of Eq. (5:

$$E_{s,r}(\omega_s, \omega_r) = \beta\delta(\omega_s, \omega_r) + \alpha H(\delta(\omega_s, \omega_r))G(s,r).$$

The main theoretical result of [6] states that a necessary and sufficient condition for graph-representability of E is the following *submodularity* condition:

$$E_{s,r}(0,0) + E_{s,r}(1,1) \leq E_{s,r}(0,1) + E_{s,r}(1,0). \quad (8)$$

It is easily seen that the left hand side is always -2β for all (s,r), as the gradient term vanishes. On the right hand side, we have a constant 2β from the Ising term, $\alpha\mathcal{M}$ from one of the inhomogeneous label configurations and either 0 or $-\alpha M(s,r)$ from the other depending on the edge direction. Thus for all $(s,r) \in \mathcal{C}$, we have

$$E_{s,r}(0,1) + E_{s,r}(1,0) \geq 2\beta + \alpha(\mathcal{M} - M_{\max})$$

since, according to Eq. (2, $M_{\max} \geq M(s,r)$ always holds. Therefore submodularity is satisfied for $\beta, \alpha > 0$ if

$$-4\frac{\beta}{\alpha} \leq \mathcal{M} - M_{\max},$$

which is always true as we have chosen $\mathcal{M} \gg M_{\max}$.

EXPERIMENTAL RESULTS

n our experiments, $\nabla\mathcal{F}$ was provided by a Sobel operator followed by non-maxima suppression and we set $M_{\max} = 10^3$ and $\mathcal{M} = 10^6$. Gaussian parameters were learned from user selected input regions (see Fig. 10), while the parameters α and β were set to their optimal value. The MAP segmentation was then obtained by the max-flow implementation of Kolmogorov (`http://www.cs.ucl.ac.uk/staff/V.Kolmogorov/software.html`) [2]. We have also compared results obtained by a classical MRF model (we simply removed the gradient term by setting $\alpha = 0$).

For quantitative evaluation, a set of synthetic images has been generated from four binary images by Gaussian smoothing with $\sigma' = \{1, 2, 3, 4\}$ and adding white noise ranging from -15dB to 10dB. The segmentation error is calculated as the percentage of misclassified pixels. Obviously, error is linearly increasing with σ' as blurred regions become bigger. On the other hand, our method is quite robust up to 0dB noise level, but becomes quickly unstable above it. We have also evaluated the separation accuracy of our method on noisy blurred images and found that even for moderate smoothing, it outperforms the classical MRF model.

APPLICATION IN TIRF MICROSCOPY

The proposed approach has also been validated on images taken in Total Internal Reflection Fluorescence (TIRF) microscopy mode, which is an elegant optical technique that provides for the excitation of fluorophores in an extremely thin axial region (optical section) [3]. Images in Fig. 10 and Fig. 11 were taken by a CytoScout fluorescent microscope system using the 488-nm argon-ion laser line for the excitation of fluorescein.

The quantitative analysis of these sub-cellular structures requires an accurate segmentation. Due to the rather low contrast, a standard background subtraction (available in Matlab) preprocessing step has been applied before segmentation. In Fig. 10, we compare results obtained by *Cellprofiler* [5] and a classical MRF model. Each method's parameters have been manually fine-tuned to get the best result. Notice that *Cellprofiler* tends to produce rather "blocky" boundaries, while the classical MRF model misses some foreground regions as well as merges nearby regions due to the lack of gradient information. Our method provides accurate segmentations. We remark that the same watershed-based postprocessing step used in *Cellprofiler* can also be applied in our method to further cut larger regions into smaller patches. Additional results can be seen in Fig. 11. These segmentation results have been validated by expert biologists who found them accurate and relevant. The runtime was consistently below 0.07 sec on TIRF images of size 100×100.

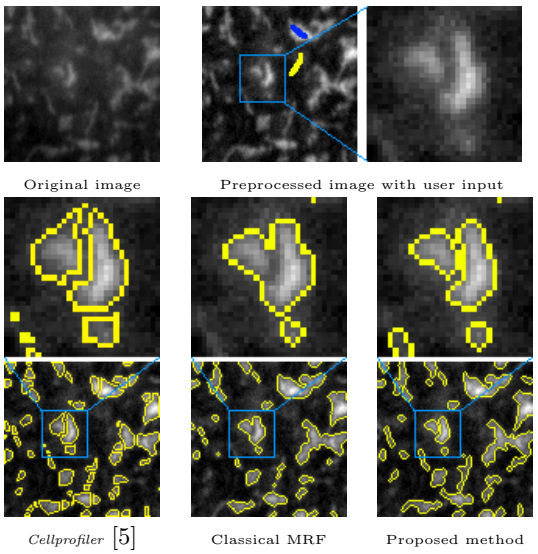

Figure 10. Comparison on a TIRF image.

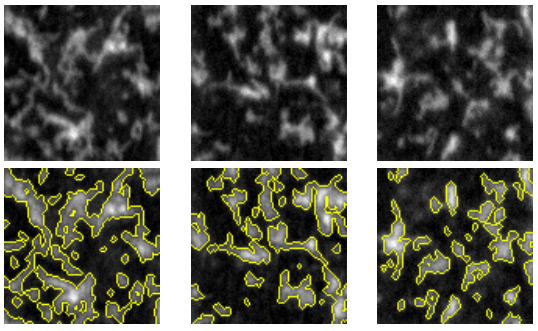

Figure 11. Results on TIRF images.

CONCLUSION

We have proposed a novel MRF model which includes edge information while also satisfying the submodularity constraint. Therefore, an exact MAP solution can be obtained via standard max-flow/min-cut within fraction of a second. Quantitative evaluation on synthetic images showed that objects in blurred noisy images can be accurately segmented. The proposed method has been successfully applied in TIRF

fluorescence microscopy and compared favorably to state of the art methods.

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V. LINEAR AND NONLINEAR SHAPE ALIGNMENT WITHOUT CORRESPONDENCES

Registration is a crucial step when images of different views or sensors of an object need to be compared or combined. Application areas include visual inspection, target tracking in video sequences, super resolution, or medical image analysis. In a general setting, one is looking for a transformation which aligns two images such that one image (called the *observation*, or moving image) becomes similar to the second one (called the *template*, or model image). Due to the large number of possible transformations, there is a huge variability of the object signature. In fact, each *observation* is an element of the orbit of the transformations applied to the *template*. Hence the problem is inherently *ill-defined* unless this variability is taken into account.

When registering an image pair, first we have to characterize the possible deformations. From this point of view, registration techniques can be classified into two main categories: physical model-based and parametric or functional representation [1]. Herein, we deal with the latter representation, which typically originate from interpolation and approximation theory.

We consider the estimation of diffeomorphic deformations aligning a known binary shape and its distorted observation. The classical solution consists in extracting landmarks, establishing correspondences and then the aligning transformation is obtained via a complex optimization procedure. Herein we present an alternative solution which works without landmark correspondences, is independent of the magnitude of transformation, easy to implement, and has a linear time complexity. The proposed universal framework is capable of recovering linear as well as nonlinear deformations.

V.1. REGISTRATION FRAMEWORK

Let us denote the point coordinates of the *template* and *observation* by $\mathbf{x} \in \mathbb{R}^n$ and $\mathbf{y} \in \mathbb{R}^n$ respectively. Corresponding point pairs $(\mathbf{x}, \mathbf{y})$ are related by an unknown diffeomorphism $\phi : \mathbb{R}^n \to \mathbb{R}^n$ such that

$$\mathbf{y} = \phi(\mathbf{x}) \quad \Leftrightarrow \quad \mathbf{x} = \phi^{-1}(\mathbf{y}), \tag{9}$$

where $\phi^{-1} : \mathbb{R}^n \to \mathbb{R}^n$ 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. The goal of registration is to recover the aligning transformation ϕ.

Classical approaches would establish a set of point correspondences $\{(\mathbf{x}_i, \mathbf{y}_i)\}_{i=1}^N$ and, making use of Eq. (9), define a *similarity metric* $S(\{(\mathbf{x}_i, \mathbf{y}_i)\}, \hat{\phi})$ which characterizes the geometric alignment of the point pairs $\{(\mathbf{x}_i, \hat{\phi}(\mathbf{y}_i))\}$ achieved by a particular transformation $\hat{\phi}$. The solution is usually obtained via an iterative optimization procedure, where S is maximized (or equivalently, the *dissimilarity* is minimized). Such procedures require a good initialization (*i.e.* the transformation must be close to identity) and are computationally expensive as the evaluation of S requires the actual execution of each intermediate transformation. Furthermore, landmark extraction and correspondence implicitly assumes, that one can observe some image features (*e.g.* gray-level of pixels [16]) f and g that are *covariant* under the transformation

$$f(\mathbf{x}) = g(\phi(\mathbf{x})) = g(\mathbf{y}). \tag{10}$$

However, lack of characteristic features (*e.g.* binary images, printed art) or changes in features (*e.g.* illumination changes, mulimodality) make landmark extraction and matching unreliable in many cases. Segmentation of such images is often straightforward and is available as an intermediate step of a complex image analysis task. Herein, we will discuss a generic correspondence-less framework which works well in such situations.

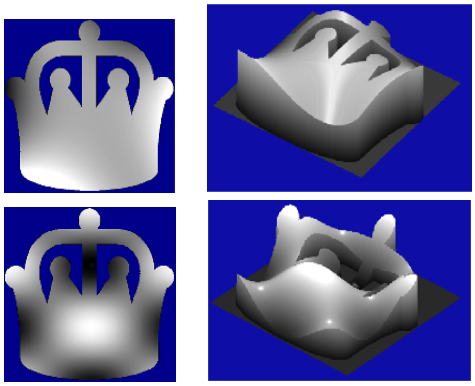

Figure 12. The effect of applying a polynomial (left) and a trigonometric (right) ω function can be interpreted as a consistent colorization or as a volume.

Since correspondences are not available, Eq. (9) cannot be used directly. However, individual point matches can be integrated out yielding the following

integral equation:

$$\int_{\mathcal{D}} \mathbf{y} d\mathbf{y} = \int_{\phi(\mathcal{F})} \mathbf{z} d\mathbf{z}, \tag{11}$$

where $\mathcal{D}$ corresponds to the *observation* shape's domain and $\phi(\mathcal{F})$ is the transformed *template* shape's domain. Note that computing the latter integral involves the actual execution of the transformation ϕ on $\mathcal{F}$, which might be computationally unfavorable. Therefore, let us rewrite the above integrals over the *template*'s domain $\mathcal{F}$ and *observation*'s domain $\mathcal{D}$ by making use of the integral transformation $\mathbf{z} \mapsto \phi(\mathbf{x})$ and $d\mathbf{z} \mapsto |J_\phi(\mathbf{x})| d\mathbf{x}$:

$$\int_{\mathcal{D}} \mathbf{y} d\mathbf{y} = \int_{\mathcal{F}} \phi(\mathbf{x}) |J_\phi(\mathbf{x})| d\mathbf{x}, \tag{12}$$

where $|J_\phi(\mathbf{x})|$ is the Jacobian determinant of the transformation ϕ. Note that the above equation corresponds to a system of n equations, where n is the dimension of the shapes. Although the space of allowed deformations is low dimensional, determined by the number of free parameters k of the deformation ϕ, n is typically 2 (planar shapes) or 3 (3D objects), which is not sufficient to solve for all parameters of a real deformation. Therefore we need a general mechanism to construct new equations. Indeed, Eq. (9) remains valid when a function $\omega : \mathbb{R}^n \to \mathbb{R}$ is acting on both sides of the equation

$$\omega(\mathbf{y}) = \omega(\phi(\mathbf{x})), \tag{13}$$

and the integral equation of Eq. (12) becomes

$$\int_{\mathcal{D}} \omega(\mathbf{y}) d\mathbf{y} = \int_{\mathcal{F}} \omega(\phi(\mathbf{x})) |J_\phi(\mathbf{x})| d\mathbf{x}. \tag{14}$$

Adopting a set of nonlinear functions $\{\omega_i\}_{i=1}^{\ell}$, each ω_i generates a new equation yielding a system of ℓ independent equations. Hence we are able to generate sufficient number of equations by choosing $\ell \geq k$. Intuitively, each ω_i generates a consistent coloring of the shapes and the equations in Eq. (14) match the volume of the applied ω_i function over the shapes (see Fig. 12). The parameters of the aligning transformation ϕ are then simply obtained as the solution of the nonlinear system of equations Eq. (14). In practice, usually an overdetermined system is constructed (*i.e.* $\ell > k$), which is then solved in the *least squares sense* by minimizing the algebraic error. Hereafter, we will omit the integration domains from the equations.

What kind of ω functions can be used to generate these independent equations? From a theoretical point of view, only trivial restrictions apply: the functions must be integrable and rich enough (*i.e.* generate a non-constant colorization). Furthermore, they have to be unbiased: each equation should have an equally balanced contribution to the algebraic error, which can be achieved by normalizing the images into the unit square (or cube in 3D) around the origin and the range of the ω functions should also be normalized [11]. Some examples can be seen in Fig. 13. From a practical point of view, we have to solve a system of integral equations meaning that intermediate deformations need to be evaluated hence complexity is highly dependent on image size. If we could get rid of the integration in the equations, then considerable speed-up could be achieved. Fortunately, the equation of Eq. (14) can be reduced to a plain polynomial system under the following conditions [5, 11]:

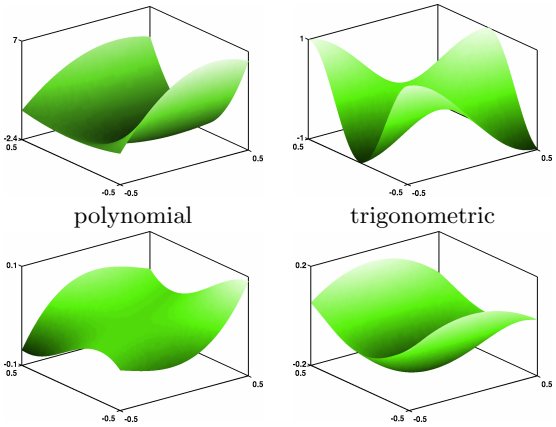

Figure 13. Various ω functions.

1. The deformation ϕ is given as a linear combination of basis functions. Note that the most common transformation groups, such as linear, polynomial and thin plate spline deformations are of such form, while other diffeomorphisms can be approximated by their Taylor expansion.
2. The adopted set of nonlinear functions $\{\omega_i\}_{i=1}^{\ell}$ are polynomial.

Let us now briefly overview how to use our framework for some typical deformation classes.

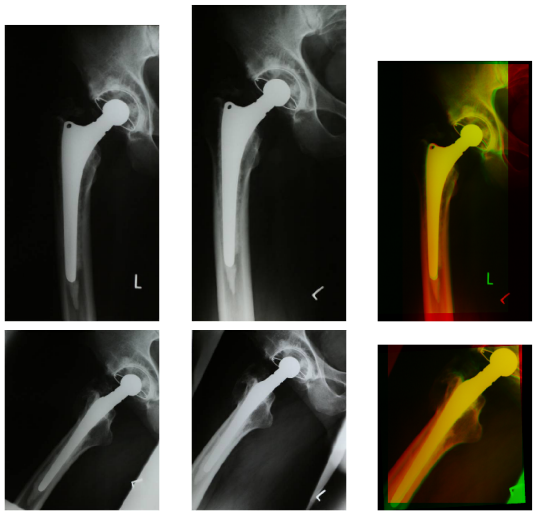

Figure 14. Fusion of hip prosthesis X-ray image pairs by registering follow up images using a 2D affine transformation (typical CPU time is around 1 sec. in Matlab).

V.2. LINEAR DEFORMATIONS

In the case of linear deformations, the diffeomorphism ϕ becomes a non-singular linear transformation matrix $\mathbf{A}$ and the identity relation takes the following simple form:

$$\mathbf{A}\mathbf{x} = \mathbf{y} \quad \Leftrightarrow \quad \mathbf{x} = \mathbf{A}^{-1}\mathbf{y}. \tag{15}$$

Since the Jacobian is simply the determinant of $\mathbf{A}$, which can be computed as the ratio of the areas of the two planar shapes to be aligned, we can easily

construct a system of polynomial equations [5, 7]:

$$\int \omega(\mathbf{x})d\mathbf{x} = \frac{1}{|\mathbf{A}|}\int \omega(\mathbf{A}^{-1}\mathbf{y})d\mathbf{y}. \qquad (16)$$

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 $\omega(x) = x^i$ (see [5]). From a geometric point of view, for $\omega(x) \equiv x$ Eq. (16) 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. (16) matches the center of mass of the shapes obtained by the nonlinear transformations ω. In the 2D affine case, we have to solve a system of polynomial equations of the following form, where q_{ki} denotes the unknown elements of the inverse transformation $\mathbf{A}^{-1}$.

$$|\mathbf{A}|\int x_k = q_{k1}\int y_1 + q_{k2}\int y_2 + q_{k3}\int 1, \qquad (17)$$

$$\begin{aligned} |\mathbf{A}|\int x_k^2 &= q_{k1}^2\int y_1^2 + q_{k2}^2\int y_2^2 \\ &+ q_{k3}^2\int 1 + 2q_{k1}q_{k2}\int y_1y_2 \\ &+ 2q_{k1}q_{k3}\int y_1 + 2q_{k2}q_{k3}\int y_2, \qquad (18) \\ |\mathbf{A}|\int x_k^3 &= q_{k1}^3\int y_1^3 + q_{k2}^3\int y_2^3 + q_{k3}^3\int 1 \\ &+ 3q_{k1}^2q_{k2}\int y_1^2y_2 + 3q_{k1}^2q_{k3}\int y_1^2 \\ &+ 3q_{k2}^2q_{k3}\int y_2^2 + 3q_{k1}q_{k2}^2\int y_1y_2^2 \\ &+ 3q_{k2}q_{k3}^2\int y_2 + 3q_{k1}q_{k3}^2\int y_1 \\ &+ 6q_{k1}q_{k2}q_{k3}\int y_1y_2. \qquad (19) \end{aligned}$$

The above system of equations can be readily solved either by a direct solver found *e.g.* in Matlab [5] or by a classical LSE solver like the *Levenberg-Marquardt* algorithm [8]. Some registration examples can be seen in Fig. 14, where hip prosthesis X-ray image pairs are aligned using a 2D affine transformation. The goal is to fuse post operative follow-up scans of the hip prosthesis to check loosening of the implant. Note that correspondence-based methods are challenged by lack of corner-like landmarks and the nonlinear radiometric distortion between follow-ups. However, segmentation of the implant is straightforward, hence binary registration is a viable option here. In spite of the inherent modeling error (the physical transformation of the implant is a 3D rigid motion followed by a projection), our method was able to find a precise alignment. This is mainly due to the fact, that images are taken in a standard position of the patient, hence affine transformation is a good approximation.

REGISTRATION OF 3D OBJECTS

The extension of the polynomial equations to 3D objects [7–9] is relatively straightforward. However, numerical implementation has to be carefully designed. Therefore, both in 2D and 3D we examined two different types of solution methods: iterative least-squares solutions and direct analytical solutions.

- In case of a direct method, limited number of equations can be used (according to the degree of freedom of the n-dimensional affine transformation), while an iterative approach allows for an overdetermined system, which may give more stability.
- Direct methods may provide many hundreds or even thousands of possible solutions, many (or even all) of them may be complex thus a solution selection scheme has to be used to produce only one real solution from these. Iterative methods provide a single real solution, but the search may fall into local minima. To avoid such local minima, usually a sophisticated search strategy is necessary.
- Direct methods can provide full affine solutions only, but in case of iterative methods restrictions to lower degree of freedom transformations are easy to impose.

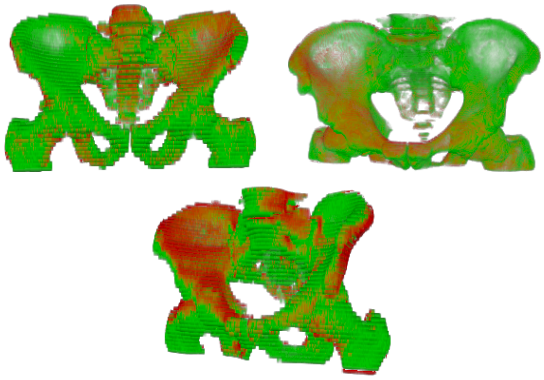

Figure 15. Registration of pelvic CT data: superimposed registered 3D bone models (typical CPU time is around 0.25 sec for 1 megavoxel objects using our Java demo program). The first two cases show good alignment. Even the third one provides a good approximation of the true alignment.

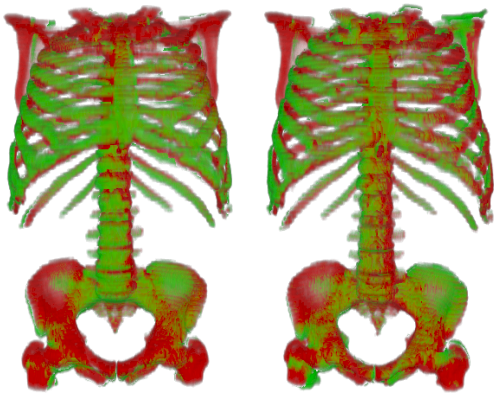

Figure 16. Registration of thoracic CT data: superimposed registered 3D bone models. Perfect alignment is not possible due to the relative movements of the bone structure. Affine alignment results are used as a good starting point for *e.g.* lymph node detection.

We found that the direct approach gives more stable results, but the iterative one is more precise. It is also possible to combine the two approaches: The direct approach provides the initialization of the iterative one.

Another issue is discretization error, which might be particularly problematic in 3D. For that purpose, we extended our method by investigating the case

when the segmentation method is capable of producing *fuzzy objects* instead of a binary result in both 2D and 3D. It has been shown that the information preserved by using fuzzy representation based on area coverage may be successfully utilized to improve precision and accuracy of our equations [7, 8]. The result of a series of synthetic tests showed that fuzzy representation yields lower registration errors in average. In Fig. 15 and Fig. 16, some registration results on 3D medical images are shown.

AFFINE PUZZLE

The affine puzzle problem can be formulated as follows: Given a binary image of an object (the *template*) and another binary image (the *observation*) containing the fragments of the *template*, we want to establish the geometric correspondence between these images which reconstructs the complete *template* object from its parts. The overall distortion is a global nonlinear transformation with the following constraint (see Fig. 17):

- the object parts are distinct (*i.e.* either disconnected or separated by segmentation),
- all fragments of the *template* are available, but
- each of them is subject to a different affine deformation, and the partitioning of the *template* object is unknown.

The proposed solution [10] consists in constructing and solving a polynomial system of equations similar to Eq. (17)–(19), which provides all the unknown parameters of the alignment. We have quantitatively evaluated the proposed algorithm on a large synthetic dataset containing 2D and 3D images. The results show that the method performs well and robust against segmentation errors. The method has been validated on 2D real images of a tangram puzzle (see Fig. 18) as well as on volumetric medical images applied to surgical planning (see Fig. 19).

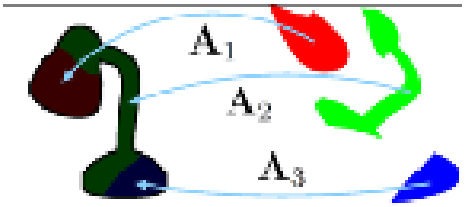

Figure 17. Affine puzzle: reconstructing the complete template object from its deformed parts.

V.3. NONLINEAR DEFORMATIONS

When ϕ is a nonlinear transformation, then the Jacobian $J_\phi(\mathbf{x})$ is not a constant anymore and thus Eq. (14) has to be used directly:

$$\int \omega_i(\mathbf{y})d\mathbf{y} = \int \omega_i(\phi(\mathbf{x}))|J_\phi(\mathbf{x})|d\mathbf{x}, \quad i = 1, \ldots, \ell \tag{20}$$

From a practical point of view, this means that our method can be applied to any diffeomorpism ϕ for which one can compute its Jacobian $J_\phi(\mathbf{x})$. Of course, in order to obtain an overdetermined system, ℓ has to be larger than the number of free parameters of ϕ.

PLANAR HOMOGRAPHY

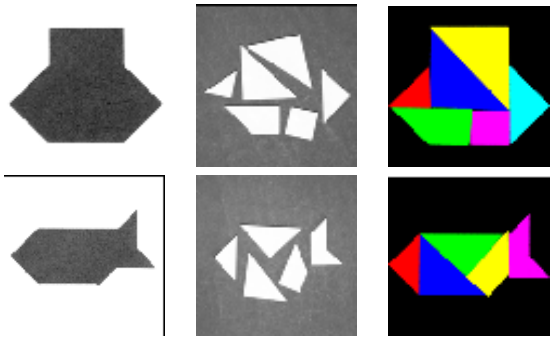

Figure 18. Two solutions of the Tangram puzzle. The average alignment runtime was about 50 sec. in Matlab.

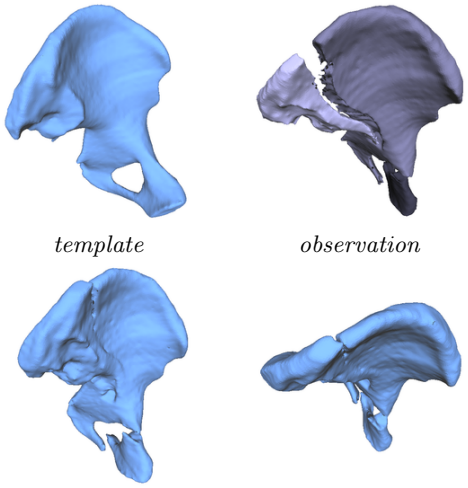

Figure 19. Bone fracture reduction (CPU time in Matlab was 15 sec. for these 1 megavoxel CT volumes). The *template* is obtained by mirroring the intact bone.

The simplest such deformation is a plane projective transformation (or planar homography), which is a linear transformation in the projective plane $\mathbb{P}^2$ [6, 11]:

$$\mathbf{y}' = \mathbf{H}\mathbf{x}' \tag{21}$$

where $\mathbf{y}', \mathbf{x}' \in \mathbb{P}^2$ are the homogeneous coordinate representations of $\mathbf{y}, \mathbf{x} \in \mathbb{R}^2$. In the Euclidean plane $\mathbb{R}^2$, however, planar homography is a nonlinear transformation due to projective division by the third (homogeneous) coordinates, and the Jacobian is of the following form:

$$|J_\phi(\mathbf{x})| = \begin{vmatrix} \frac{\partial\phi_1}{\partial x_1} & \frac{\partial\phi_1}{\partial x_2} \\ \frac{\partial\phi_2}{\partial x_1} & \frac{\partial\phi_2}{\partial x_2} \end{vmatrix} = \frac{|\mathbf{H}|}{(H_{31}x_1 + H_{32}x_2 + 1)^3}\,. \tag{22}$$

Substituting back ϕ and J_ϕ into Eq. (20), we obtain a system of equations for the unknown transformation parameters which can be solved in the least-squares sense via the *Levenberg-Marquardt* algorithm.

Since the system is solved by minimizing the algebraic error, proper normalization is critical for numerical stability. For that purpose, the *template* and *observation* coordinates are normalized into $[-0.5, 0.5]$ by applying appropriate scaling and translation. Moreover the range of the ω functions should

also be normalized into $[-1, 1]$ in order to ensure a balanced contribution of the equations to the algebraic error. This can be achieved by dividing the integrals with the maximal magnitude of the integral over the unit circle containing the objects [11]:

$$N_i = \int_{\|\mathbf{x}\| \leq \frac{\sqrt{2}}{2}} |\omega_i(\mathbf{x})| d\mathbf{x} \tag{23}$$

Some registration results on traffic sign images can be seen in Fig. 20.

Figure 20. Registration of traffic sign images using a plane projective deformation model. The first column shows the *templates*, while the second, third, and fourth columns show the registration result as an overlayed yellow contour for SIFT, Shape Context, and our method, respectively.

ELASTIC REGISTRATION OF MULTIMODAL PROSTATE IMAGES

Countries in Europe and USA have been following prostate cancer screening programs since the last 15 years [24]. A patient with abnormal findings is generally advised for a prostate biopsy to diagnose the benign or malignant lesions. During needle biopsy, the most common appearance of malignant lesions in Transrectal Ultrasound (TRUS) is hypoechoic. The accuracy of sonographic finding of hypoechoic prostate cancer lesions is typically 43% [25]. In contrast, Magnetic Resonance Imaging (MRI) has a negative predictive value of $80\% - 84\%$ for significant cancer and the accuracy of MRI to diagnose prostate cancer is approximately $72\% - 76\%$ [26]. Therefore, MRI may serve as a triage test for men deemed to be at risk of prostate cancer and may reduce the number of re-biopsies while at the same time provide more useful information for those who are sent for biopsy. Consequently, fusion of pre-biopsy MR images onto interoperative TRUS images might increase the overall biopsy accuracy [27].

In nonlinear medical registration problems, a broadly used class of parametric deformation models are splines, in particular thin plate splines (TPS) [30, 31]. TPS models are quite useful whenever a parametric free-form registration is required but the underlying physical model of the object deformation is unknown or too complex. Given a set of control points $\mathbf{c}_k \in \mathbb{R}^2$ and associated mapping coefficients $a_{ij}, w_{ki} \in \mathbb{R}$ with $i = 1, 2$, $j = 1, 2, 3$ and $k = 1, \ldots, K$,

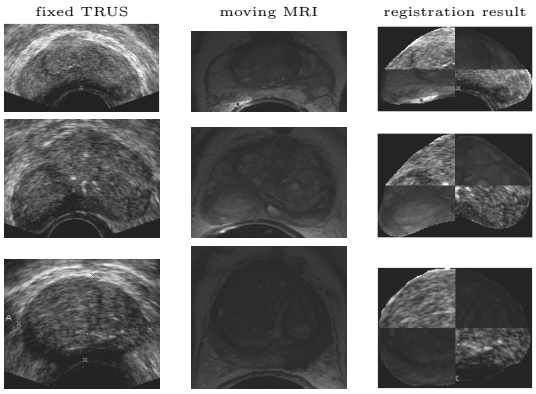

Figure 21. MRI-TRUST multimodal prostate registration results. Registration result is shown as a checkerboard of TRUS and transformed MR images to show the alignment of the inner structures.

the TPS interpolating points $\mathbf{c}_k$ is given by [31]

$$\varphi_i(\mathbf{x}) = a_{i1}x_1 + a_{i2}x_2 + a_{i3} + \sum_{k=1}^{K} w_{ki} Q(||\mathbf{c}_k - \mathbf{x}||) \ , \tag{24}$$

where $Q : \mathbb{R} \to \mathbb{R}$ is the *radial basis function*

$$Q(r) = r^2 \log r^2 \ .$$

The local parameters are also required to satisfy the following additional constraints [31], meaning basically that the TPS at infinity behaves according to its affine term:

$$\sum_{k=1}^{K} w_{ki} = 0 \quad \text{and} \quad \sum_{k=1}^{K} c_{kj} w_{ki} = 0, \quad i, j = 1, 2 \ . \tag{25}$$

Note that parameters include 6 global affine parameters a_{ij} and $2K$ local coefficients w_{ki} for the control points. In classical correspondence based approaches, control points are placed at extracted point matches, and the deformation at other positions is interpolated by the TPS. When correspondences are available, the exact mapping of the control points are also known which, using Eq. (24), provides constraints on the unknown parameters. Therefore in such cases, a TPS can be regarded as an optimal *interpolating* function whose parameters are usually recovered via a complex optimization procedure [30, 31].

However, we are interested in solving the TPS registration problem without correspondences. Therefore in our approach, a TPS can be considered as a parametric model to *approximate* the underlying deformation field [11]. Control points (*i.e.* radial basis functions) can be placed *e.g.* on a uniform grid in order to capture local deformations everywhere. Obviously, a finer grid would allow a more refined approximation of the deformation field at the price of an increased number of free parameters.

To construct our system of equations Eq. (20), we need the Jacobian $|J_\varphi(\mathbf{x})|$ of the transformation φ, which is composed of the following partial derivatives $(i, j = 1, 2)$ [11]

$$\frac{\partial \varphi_i}{\partial x_j} = a_{ij} - \sum_{k=1}^{K} 2 w_{ki} (c_{kj} - x_j) \big(1 + \log(||\mathbf{c}_k - \mathbf{x}||^2)\big) \ . \tag{26}$$

The system is then solved via *Levenberg-Marquardt* algorithm [11].

In [15], we have improved the generic non-linear registration framework of [11] by establishing prostate-specific point correspondences and regularizing the overall deformation. The point correspondences under the influence of which the thin-plate bends are established on the prostate contours by a method based on matching the shape-context ([2]) representations of contour points using Bhattacharyya distance ([28]). The approximation and regularization of the bending energy of the thin-plate splines are added to the set of non-linear TPS equations and are jointly minimized for a solution. Fig. 21 shows some registration results on multimodal prostate images.

ELASTIC REGISTRATION OF 3D LUNG CT VOLUMES

Lung alignment is a crucial task in lung cancer diagnosis [29]. During the treatment, changes in the tumor size are determined by comparing *follow-up* PET/CT scans which are taken at regular intervals depending on the treatment and the size of the tumor. Due to respiratory motion, the lung is subject to a nonlinear deformation between such *follow-ups*, hence it is hard to automatically find correspondences. A common practice is to determine corresponding regions by hand, but this makes the procedure time consuming and the obtained alignments may not be accurate enough for measuring changes.

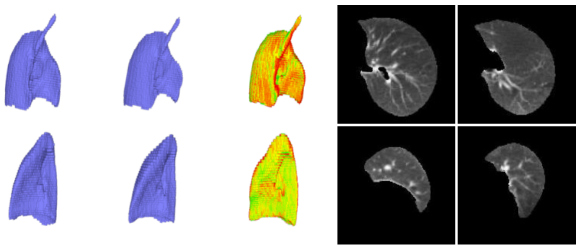

Figure 22. Alignment of lung CT volumes and the combined slices of the original and the transformed images as an 8x8 checkerboard pattern. Segmented 3D lung images were generated by the *InterView Fusion software of Mediso Ltd.*.

Our algorithm has been successfully applied [12, 13] to align 3D lung CT scans. As usual in elastic medical imaging, the adopted parametric model is a 3D Thin plate splines (TPS) [30,31] $\varsigma : \mathbb{R}^3 \to \mathbb{R}^3$ which can also be decomposed as three coordinate functions $\varsigma(\mathbf{x}) = [\varsigma_1(\mathbf{x}), \varsigma_2(\mathbf{x}), \varsigma_3(\mathbf{x})]^T$. Given a set of control points $c_k \in \mathbb{R}^3$ and associated mapping coefficients $a_{ij}, w_{ki} \in \mathbb{R}$ with $i = 1, \ldots, 3, j = 1, \ldots, 4$ and $k = 1, \ldots, K$, the TPS functions are

$$\varsigma_i(\mathbf{x}) = a_{i1}x_1 + a_{i2}x_2 + a_{i3}x_3 + a_{i4} + \sum_{k=1}^{K} w_{ki} Q(\|c_k - \mathbf{x}\|) \tag{27}$$

where $Q : \mathbb{R} \to \mathbb{R}$ is the radial basis function, which has the following form in 3D [30]:

$$Q(r) = |r|.$$

The number of the necessary parameters are $N = 3(K + 4)$ consisting of 12 affine parameters a_{ij} and 3 coefficients w_{ki} for each of the K control points c_k.

As for the prostate registration problem, we also included a bending energy regularization to ensure the proper alignment of the inner structures. Some registration results are presented in Fig. 22, where we also show the achieved alignment on grayscale slices of the original lung CT images. For these slices, the original and transformed images were combined as an 8×8 checkerboard pattern.

CONCLUSION

A unified framework for correspondence-less registration of 2D and 3D shapes has been presented. The method is applicable for various diffeomorphic deformations. In this paper, we have summarized our earlier results and peresented different medical applications. Demo implementations of our method are also available from `http://www.inf.u-szeged.hu/~kato/software/` as follows:

- *Affine Registration of Planar Shapes*: JAVA code with a direct solver (only runs under Windows).
- *Affine Registration of 3D Objects*: JAVA code with multi-threading ($\approx$ 0.2sec. CPU time for megavoxel volumes).
- *Nonlinear Shape Registration without Correspondences*: Implements planar homography, extension to other nonlinear deformations is relatively easy.

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
- Le2i-UMR CNRS 6306, Université de Bourgogne, France

ACKNOWLEDGEMENT

This research was partially supported by

- Hungarian Scientific Research Fund (OTKA – K75637)
- National Innovation Office (NIH) & the Hungarian Scientific Research Fund (OTKA) under grant CNK80370
- the European Union and co-financed by the European Regional Development Fund within the projects TÁMOP-4.2.2/08/1/2008-0008 and TÁMOP-4.2.1/B-09/1/KONV-2010-0005
- 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

The fractured bone CT images were obtained from the University of Szeged, Department of Trauma Surgery and were used with permission of Prof. Endre Varga, MD.

Pelvic CT studies and hip prosthesis Xray images were provided by Endre Szabó, Ádám Perényi, Ágnes

Séllei and András Palkó from the Radiology Department of the University of Szeged.

Lung CT images were provided by László Papp from Mediso Ltd., Hungary.

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VI. IMAGE ANALYSIS METHODS FOR VISUAL CODE DETECTION AND RECOGNITION

Visual codes are used in various places for various applications to identify or describe entities of our everyday life (e.g., merchandise, mail and postal packages, electronic parts). Codes can vary by type (e.g., 1D barcode, 2D datamatrix, OCR character strings), by size (e.g., a few hundred microns, a few centimeters, or even a meter), or by producing technology (e.g., printing, micrograving). Codes are often scanned by 2D digital cameras or line-scanners. The distortions of the surface that carries the code, uneven lighting and imprecise measuring all impose problems on the detection algorithms. In addition, the resources available for processing these data are also very limited and the requirements on the processing time and accuracy make the problem very challenging in real life applications.

The aim of this research is to study image features and processing methods for detection of regions containing visual codes, with special focus on highly accurate and efficient algorithms that can be adapted for real industrial applications.

We experiment with modifications of known localization methods in the state of the art, and work on novel approaches for efficient detection of visual codes.

MORPHOLOGICAL MIN-MAX

This method [1] treats the image as a whole, and therefore requires a fair amount of RAM and computation time. Supposed that intensity levels have been normalized, no other preprocessing operations are required since it handles noisy, blurry or distorted images well.

Knowing the maximum element size of a code pattern, we apply the morphologic gradient operator on the image with a box kernel. The next step is removing ghost elements from the feature image with a binary threshold. After that, we apply morphologic closing operation on the feature image. This is for closing gaps caused by larger blocks of elements of the same color.

Figure 23. Intermediate stages of the MIN-MAX algorithm.

LOCAL CLUSTERING

Local Clustering [1] came from examining the behaviour of textures. Most barcodes, like regular textures, can be easily identified by observing only small parts of them. These barcode parts together form the desired barcode region with known height and width. The first part of the method is partitioning the image to square tiles and look at each tile for barcode-like appearance. Each tile is assigned a value that indicates the grade of the presence of this feature. Globally, a matrix is formed from these values. Texture parts have similar local statistics in their neighbourhood, so searching this matrix for compact areas defines image ROIs representing a barcode with high possibility.

The main idea of Local clustering is that an image region that contains a barcode segment has many similar stretched pixel clusters. The minimum count of expected clusters can be derived from the widest bar of the barcode. Degree of stretch can be measured with the diameter of the cluster (defined as twice the distance of the furthest cluster point from the cluster center). With exactly horizontal or vertical lines, the largest cluster diameter is the tile size, in oblique situations, the largest cluster diameter is expected to be longer than that. Furthermore, stretched separate clusters need to be aligned approximately identically, otherwise one cluster would touch another, decreasing the number of separate clusters in a tile below our threshold. For preprocessing, we use median filter first that eliminates salt-and-pepper noise.

DISTANCE TRANSFORMATION

According to the previous idea, we follow the same method of partitioning. The assigned value showing

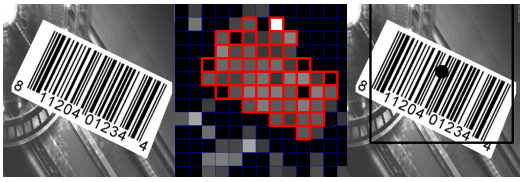

Figure 24. Intermediate stages of the Local clustering algorithm.

barcode-like appearance is based on distance transformation of the edge map. [3] Distance transformation is an operation that works with an initial set of points, like corners or edges. Value 0 is assigned to these points, and any others get the distance value to the closest point of the initial set. We apply Canny edge detector for this point set to the transformation. For each tile of the distance map, means and standard deviations are calculated. For 1D codes, distance values spread between half of the minimum and half of the maximum line width. For 2D codes, these values usually stay below half of their block size, but higher values are also possible, since blocks of the same color can be next to each other in multiple directions. Having such code parts significantly raise the mean of distance values on the image tile. However, these holes in the feature matrix are rare enough so they do not split barcode-like areas.

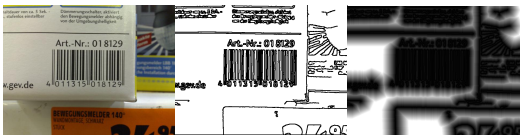

Figure 25. Intermediate stages of the algorithm using distance transform.

HOUGH TRANSFORMATION

Hough transformation can also be used as a reliable localization approach, as barcodes consist of roughly equally long, parallel lines in a small area. [2] Probabilistic Hough transformation gives a probabilistic estimation for detecting straight lines with the help of a subset of the edge points of the original image, outperforming the standard Hough transform. For preprocessing, we use a blur filter since smooth images are desired for the Canny edge detector.

After we obtain a list of lines with their center point, length, and orientation, we can group them to decide whether they constitute a barcode or not. We define the minimum number of lines, the proximity needed for the lines to be in the same group, and the tolerance for length and orientation from the means within the group.

In the final step, group centers are returned, and the image can be cropped for decoding with known barcode decoding implementations.

BOTTOM-HAT FILTERING

Our algorithm using bottom-hat filtering [6,7] consists of two main phases. In the preprocessing phase, the input image is converted to grayscale and image noise is reduced by smoothing with a Gaussian kernel. It is followed by edge enhancement using bottom-hat

Figure 26. Intermediate stages of the algorithm using Hough transform.

filtering using a linear structuring element and its rotated version by 90° and use the one that produces stronger matches. Although bottom-hat filtering is less attractive regarding operation time than other non-directional edge enhancement operations, its accuracy is higher. In the binarized images small connected components which satisfy the criteria but do not belong to barcode regions are eliminated using an area threshold that is set according to the image size.

We take advantage of the structure of the barcode, the fact that it consists of approximately regularly spaced parallel stripes. For each pixel, we calculate the Euclidean distance of the pixel from the nearest nonzero pixel, and using the distance map, objects that are far from other objects can be easily dropped, and only nearby objects (sort of a cluster of bar segments) will be kept. Since a barcode consists of a sequence of parallel bars that are located at varying distance from each other, they do not compose a single connected component. To merge these patterns, we use dilation with a square structuring element and to compensate for the merging of unwanted, non-barcode locations, we also use the dual operation, erosion, however, with a linear structuring element, consistent with the size of the 1D barcodes. Finally, a second round of filtering is done on the basis of the objects size and proportions.

Figure 27. Intermediate stages of the algorithm using bottom-hat filtering.

We concluded that these algorithms do not specialize for individual barcode types, they can efficiently detect various types of 1D and stacked 2D barcodes. Our proposed algorithm is very fast and speed is not coupled with a significant cost in accuracy. The weakness of the method appears when the images are very noisy or when there are such image areas which are similar to a barcode.

Figure 28. Localization results on real images of products with various distortions.

IMPROVING THE PERFORMANCE BY USING AN ENSEMBLE OF DETECTORS

Using the ensemble of detectors [2] increases different performance values of the single detectors based

on the aggregation method. With majority voting, we can increase the precision by losing important ROIs. Using the maximum values of all feature images gives good recall, but it decreases the precision. Weighted voting, based on the separate recall values gives good recall rate while keeping precision relatively high. Since the only difference is in how we compute the values of the final feature image, those algorithms share the same running time.

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VII. ANALYSIS OF DERMATOLOGICAL IMAGES FOR TELEDERMATOLOGY AND DIAGNOSTIC APPLICATIONS

In a recent R&D collaboration with the Department of Dermatology and Allergology and industrial partners we are researching and developing image processing algorithms for dermatological applications in diagnostic and decision making systems as well as for education. This includes the creation of a personalized surface model from a set of color and depth camera images, detection and classification of dermatological findings, such as psoriasis lesions and plaques, as well as longitudinal analysis of changes.

I. AD-HOC MOBILE AND MULTIMEDIA 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 signaling. This makes it possible to separate the data and signaling paths. We proposed that, as the signaling 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 [1], [7].

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], [6].

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 limited. 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], [7].

Reference software architecture for M2M system

M2M machine systems is a field where the embedded developments meets with centralized cloud based development. We are witnessing nowadays the widespread application of this paradigm. Finding an efficient software architecture for these kind of heterogeneous system is still a big issue for software developers. We conducted research in this field focusing on the Telemedicine as one of the prominent application area for the M2M paradigm. During our R&D projects we implemented 3 different telemedical systems and evaluated them with the help of clinical trials. During these project more than 26000 measurement was done during the lifetime of the projects. We were able to draw interesting conclusions both from software and end user perspectives. [12], [14], [15] For the mentioned telemedical systems we have elaborated and evaluated different data modells to store various data coming from a diverse set of devices. The evaluation was based on quality metrics, measurements, and empirical validation, and it identifies the key differences between a generic and a problem specific data model regarding their main advantages and drawbacks. [9], [13]

More and more health monitoring devices provide functions that can ease the life of the elderly and ill people. However, this rich set of smart devices pose challenges to system developers and health industry specialists as well. In order to find optimal healthcare system solutions, lots of tests and trials have to be done. We examined the willingness of users to use the systems with different complexity and drew interesting conclusion from those examinations. [8]

We have also elaborated a methodology and toolset for measurement of the productivity of the software developer with a given reference software architecture. We applied this methodology and toolset to our telemedicine focused M2M research projects and drew important conclusions about the applied architecture. [10], [11], [16], [17]

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.

Novel Semantic-based System Integration Framework

It is a frequent problem in system development when various different systems with similar functionality have to be integrated together. The integration can be achieved by implementing interfaces for communication and data exchange, and services for all the applications to be integrated. However, this solution requires a large amount of human resources. Here, a novel framework is proposed for data integration that makes the process much simpler by generating all the source code needed for querying data of an integrated system. The proposed framework is based on two ontology mediators; namely, a local ontology generated for the data source to be integrated, and a global or central ontology for the common query interface. This way, the integration process is reduced to finding automatically or semi-automatically the mapping between the concepts of local and global ontologies. If this semantic matching is performed, then all the predefined SPARQL queries of global ontology will be rewritten automatically to queries belonging to data sources to be integrated. Hence, the differences between the systems to be integrated will appear just in the DAO layer that is generated according to the ontology alignments. We elaborated an integration technique which does not need any program coding in practice (only visual concept matching has to be done semi-automatically), so the productivity of integration software development can be improved significantly. This framework was applied to real-world integration tasks. [18]

End User Programming

In the field of ubiquitous computing, one of the most important challenges is the proper involvement of end users in the control of the system. They should be aware of what is happening and why in the smart environment. A well known approach for end user involvement in the controlling of IT systems is end user programming. There are numerous approaches for enabling the end users to define the business logic starting with decision trees and ending with domain specific languages. In order to enable the end user to program in the smart home we have ported the Drools toolkit and runtime, a well-known open source environment, to the Android platform, and we have integrated it with the PECES middleware. With the help of a smart home simulator, we benchmarked the response time of the solution. We have found that even in the case of an intensive data source such as a 3D movement sensor, the ADL (Activity of Daily Life) detecting DSL based algorithms are performing very well. [17]

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) and later the TÁMOP-4.2.2/ 08/1/2008-0008 program of the Hungarian National Development Agency, we have been investigating the possibilities of reducing the energy consumption of embedded software 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 [3, 7]. Power dissipation graphs showing the accuracy of the resulting simulator compared to real measurement are given in Figure 29.

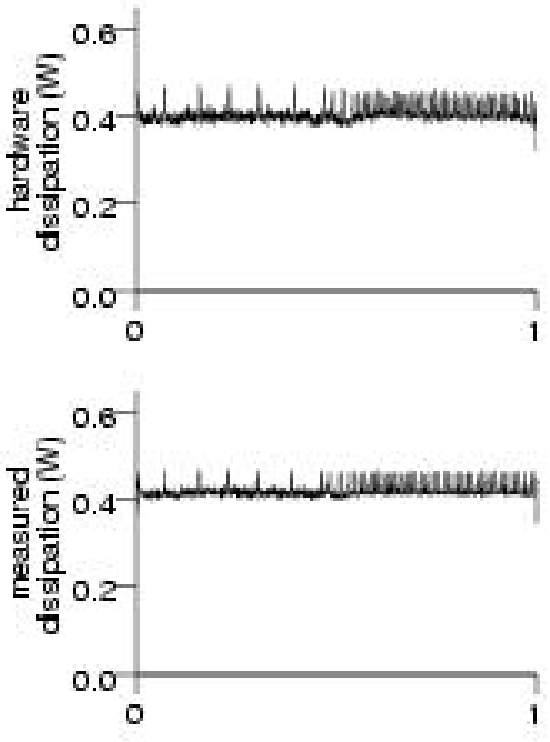

Figure 29. Measured and simulated power dissipation.

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 mostly Linux or NetBSD), need a special flash file system to store their base (root) file system. Using an ordinary file system would wear out the flash prematurely.

A few years ago one of the most popular and robust open-source flash file on Linux was JFFS2, and there was no flash file system on NetBSD. We have two important contributions on this topic:

- We developed a flash file system for NetBSD, called CHFS. Due to our work it is native flash file system is available on NetBSD, as well, it is now part of the official NetBSD kernel. [13]
- Developed a new generation flash file system on Linux, because JFFS2 has a design level limitation: practically it is not usable on flash memory bigger than 512M. We designed an improved B+ tree algorithm specially for flash file system usages [11]. The implementation was partially sponsored by Nokia, and the name of the new file system is UBIFS. It is now part of the Linux kernel, and it is used in the Nokia N900 smart phone, as well.

Browser Engine Improvements

Nowadays, web is one of the most popular application platforms. Its popularity is comparable to the desktop domain. Thus, in 2008, researchers and students of the department began investigating how several aspects of web browsing – e.g., user experience, stability, and security – could be enhanced, especially on embedded, mobile systems. The result was that we became involved in the development of the widely used WebKit browser engine [2], which formed the basis of several desktop (e.g., Safari and Chrome[1]) and mobile (e.g., in iPhone, Symbian S60, MeeGo, BlackBerry, and Android) web browsers.

The team investigated and experimented with several browsing-related topics. Since nowadays JavaScript is *the* language for developing dynamic websites, a focus area of our research were JavaScript and its execution engines. We studied memory management, the parallelization of JavaScript execution [10], and the effect of coding guidelines on the performance of JavaScript applications [5, 6]. Moreover, the developers of the department implementated a JavaScript just-in-time (JIT) compiler for the ARMv5 and ARMv7 architectures. An interesting part of JavaScript which we also investigated were regular expressions where we mined historical data and also showed how to cut down compilation time by applying caching techniques [8].

[1] Until the switch to the WebKit-fork Blink browser engine in 2013.

We have also realized that the popularity of the web comes at a cost: the Web is becoming more and more of a target for malicious attackers. Thus, its security is of major concern. In fact, since the mid-2005, more security vulnerabilities have been reported for the Web than for the desktop domain. Therefore, we examined the security evolution of WebKit, investigated its historical security data, and pointed at alarming trends [9].

As a result of the developments made for WebKit, and for being active community members [1], several members of the team have been promoted to committer or reviewer status in the project. Moreover, in 2012, the team became the 6th most active contributor of the project, being mentioned together with companies like Google, Apple, Nokia, RIM, and Igalia [4].

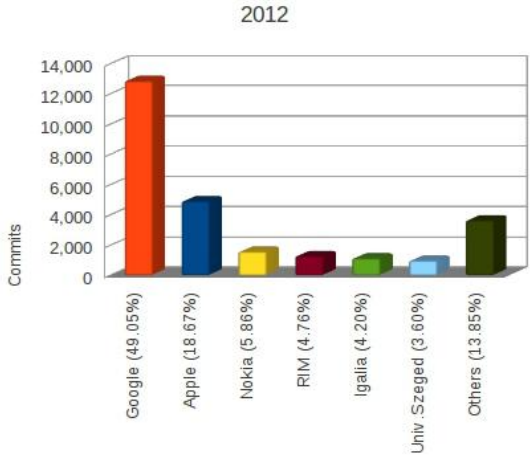

Figure 30. Activity of the six most active contributors in WebKit in 2012 [4].

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 [12] which is based on Drupal, is used by 220 active users in over 40 hospitals in East Hungary.

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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" [3]. 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 Models

In order to take the right decisions in estimating the costs and risks of a software change, it is crucial for the developers and managers to be aware of the quality attributes of their software. Maintainability is an important characteristic defined in the ISO/IEC 9126 standard, owing to its direct impact on development costs. Although the standard provides definitions for the quality characteristics, it does not define how they should be computed. We have developed a probabilistic approach for computing high-level quality characteristics, which integrate expert knowledge, and deal with ambiguity at the same time [2]. We also introduced a maintainability based model for estimating the costs of developing source code in its evolution phase [1]. Our model adopts the concept of entropy in thermodynamics, which is used to measure the disorder of a system. In our model, we use maintainability for measuring disorder (i.e. entropy) of the source code of a software system. The quality model and the cost model based on it have been implemented in a tool called *QualityGate*. We also performed many case studies involving human evaluations to gain knowledge about the perceived maintainability at source code element level [6–8]. Moreover, we revealed the connection between applying design patterns/coding best practices and software maintainability [9].

Repository Mining and Bug Prediction

Version control systems store the whole history of the source code. Since the source code of a system is organized into files and folders, the history tells us the concerned files and their changed lines only but software engineers are also interested in which source code elements (e.g. classes or methods) are affected by a change. Unfortunately, in most programming languages source code elements do not follow the file system hierarchy, which means that a file can contain more classes and methods and a class can be stored in more files, which makes it difficult to determine the changes of classes by using the changes of files. To solve this problem we developed an algorithm [18], which is able to follow the changes of the source code elements by using the changes of files and we successfully applied it on the Web Kit open source system.

Bug prediction is another very important field in software engineering. We introduced an approach and a toolset for automatic bug prediction during software development and maintenance [4]. The toolset extends the Columbus source code quality framework, which is able to integrate into the regular builds, analyze the source code, calculate different quality attributes like product metrics and bad code smells; and monitor the changes of these attributes. The new bug forecast toolset connects to the bug tracking and version control systems and assigns the reported and fixed bugs to the source code classes from the past. It then applies machine learning methods to learn which values of which quality attributes typically characterized buggy classes.

Quality Assurance of 4GL languages

Nowadays, the most popular programming languages are so-called third generation languages, such as Java, C# and C++, but higher level languages are also widely used for application development. Our work was motivated by the need for a quality assurance solution for a fourth generation language (4GL) called Magic. We realized that these very high level languages lie outside the main scope of recent static analysis techniques and researches, even though there is an increasing need for solutions in 4GL environment.

During the development of our quality assurance framework [14,15] we faced many challenges in adapting metrics from popular 3GLs and defining new ones in 4GL context. In [13] we present our results and experiments focusing on the complexity of a 4GL system. We found that popular 3GL metrics can be easily adapted based on syntactic structure of a language, however it requires more complex solutions to define complexity metrics that are closer to developers' opinion. The research was conducted in co-operation with a company where developers have been programming in Magic for more than a decade. As an outcome, the resulting metrics are used in a novel quality assurance framework based on the Columbus methodology.

In another work we proposed an approach to use the GUI information stored in the source code during automatic testing processes to create layout independent test scripts [5]. With this technique, the already recorded tests scripts will be unaffected by minor changes in the GUI. It reduces the maintenance effort of very expensive regression tests where thousands of test cases have to be maintained by testing teams. The idea was motivated by testing an application developed in a fourth generation language, Magic/uniPaaS. In this language the layout of the GUI elements (structure of the window, position and size of controls, etc.) are stored in the code an d it can be gathered via static code analysis. We implemented the presented approach for Magic/uniPaaS, and our Magic Test Automation tool is used by our industrial partner.

Static Analysis of Data-Intensive Applications

Data-intensive systems are designed to handle data at massive scale, and during the years they might evolve to very large, complex systems. In order to support maintenance tasks of these systems several techniques have been developed to analyze the source code of applications or to analyze the underlying databases for the purpose of reverse engineering, e.g. quality assurance or program comprehension. However, only a few techniques take into account the specialties of data-intensive systems (e.g. dependencies arising via database accesses). We conducted research to analyze and to improve data-intensive applications via different methods based on static analysis [11,12]: methods for recovering architecture of data-intensive systems and a quality assurance methodology for applications developed in Magic 4GL [10]. We targeted SQL as the most widespread databases are relational databases using certain dialect of SQL for their queries. With the proposed techniques we were able to analyze large scale industrial projects, such as banking systems with more than 3 million lines of code, and we successfully

recovered architecture maps and quality issues of these systems.

Complex Event Processing and Problem Prediction

Complex Event Processing deals with the detection of complex events based on rules and patterns defined by domain experts. Many complex events require real-time detection in order to have enough time for appropriate reactions. However, there are several events (e.g. credit card fraud) that should be prevented proactively before they occur, not just responded after they happened. We investigated an open research direction of Complex Event Processing: the advantages of CEP can be enhanced with the help of predictive analytics [19, 20]. We elaborated this question in greater details and presented a conceptual framework for incorporating Predictive Analytics into Complex Event Processing. The usability of the framework was demonstrated through experiments performed on real-world data using a proof-of-concept application, e.g. predicting critical problems from execution logs of a large-scale software system [21]. The achieved results were promising, the CEP solution was extended with predictive capabilities and most of the events were predicted successfully. We identified the need for real-world CEP systems, since they define more complex patterns, and require more complicated predictors than our proof-of-concept.

Architecture Reconstruction and Visualization

Having an up-to-date knowledge of the architecture of a software system is of primary importance, since it affects every aspect of software development. It aids understanding the system, helps defining high level conditions and constraints for making decisions, supports dependency analysis, logical grouping of components, evaluation of high level design, etc. During the evolution of a software, the documentation of its architecture may not be maintained because of the strict deadlines, resulting in an increasing gap between the architectural design and implementation. We developed tools for automatic architecture reconstruction and reverse engineering of software systems. It is a complex solution for automatic architecture reconstruction of software systems by offering both a flexible and highly customizable set of services and a state-of-the-art boxed product [17]. On one hand, we deal with visualization of the components and their relations. On the other hand, tracking the changes of the architectural elements during software evolution is also supported.

Nowadays software systems are typically very large, so the reconstructed architecture contains a lot of details and is really difficult to interpret. It is important therefore to have efficient methods that help in understanding and managing the architecture graph. The purpose of these methods is to try to present the information so that it is comprehensible to the users. Two important methods are selective subtree collapsion and lifting low level dependencies of the system into higher, visible levels. These enable an architect to investigate the dependencies of system components at higher levels, without the need to deal with an enormous quantity of low-level details. We defined a set of algorithms that can be used to efficiently propagate dependency edges of a graph to higher levels [16]. We also described how the results can be integrated into a software quality monitoring and visualization framework.

Conference Organization and Editorial Work

Rudolf Ferenc was a co-chair of the *4th International Workshop on Software Quality and Maintainability (SQM 2010)*, the *14th European Conference on Software Maintenance and Reengineering (CSMR 2010)*, and the *Early Research Achievements Track of the IEEE International Conference on Software Maintenance (ICSM 2010)*. Ha was the general chair of the *16th European Conference on Software Maintenance and Reengineering (CSMR 2012)* held in Szeged, Hungary.

Tibor Gyimóthy was a PC member of the *European Conference on Software Maintenance and Reengineering (CSMR)* between 2009 and 2012, the *IEEE International Conference on Software Maintenance (ICSM)* between 2010 and 2012, the *IEEE International Conference on Program Comprehension (ICPC 2009)*, and the *International Conference on the Principles and Practice of Programming in Java (2010)* Tibor Gyimóthy was the general chair of the *European Software Engineering Conference and ACM SIGSOFT Symposium on the Foundations of Software Engineering (ESEC-FSE 2011)*. He is also a member of the editorial board of *Journal of Software: Evolution and Process*.

Acknowledgements

The mentioned research tasks were supported by the Hungarian national grants GOP-1.1.2-07/1-2008-0007, GOP-1.1.1-11-2011-0038, GOP-1.1.1-11-2011-0006, GOP-1.1.1-11-2011-0049, GOP-1.1.1-07/1-2008-0077, GOP-1.2.1-08-2009-0005, OTKA K-73688, TECH 08-A2/2-2008-0089, and by the János Bolyai Research Scholarship of the Hungarian Academy of Sciences.

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IV. PROGRAM ANALYSIS

Test Case Generation

We developed a method – which is based on Category Partition Method (CPM) – for semi-automatic test case design from very high level functional software specifications, usually in the form of various business process models [1]. The CPM method is re-interpreted and specialized so that it is applicable for automatically generating high level test frames based on possible paths and determined by business rules in the business process model. The test frames can then be used, by means of filtering, weighting and specialization, to create the actual test cases. As such, it is a kind of model-based test design approach employing

automatic generation to aid the manual test case design process. The method: (1) ensures that no important path in functional description is ommitted, (2) ensures that all infeasible paths are eliminated, and (3) provides a way to assign priorities to the generated test cases. This way, the required effort of test case design is significantly reduced while providing higher reliability in the resulting test cases. We applied the method to one of the leading business process design frameworks and description languages, and validated its usefulness in an industrial case study.

Program Analysis and its Applications

Implementing automated methods to recover dependencies has many challenges, particularly in systems using databases, where dependencies may arise via database access. We proposed two techniques that can cope with these problems in most situations [4]. 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, are applicable on real-size systems, and when properly applied, can provide safe results. The first method is based on Static Execute After (SEA) relations, which uses the static call- and control flow graph and a lightweight interprocedural analysis of the system. The second method analyses the embedded SQL statements of the code and the database schemas to discover dependencies via database accesses. It computes CRUD-based dependencies between the SQL statements and propagates them to the procedure level. We quantitatively and qualitatively evaluated the methods on real-life data obtained from one of our industrial partners, and also evaluated them on some of their potential applications. The main contributions of the research are: (1) the application of a CRUD-based Usage Matrix for dependency analysis between program elements; (2) adapting SEA relations to recover dependencies in database-intensive systems; (3) applying a combination of these two methods; and (4) empirically evaluating them on real-life data.

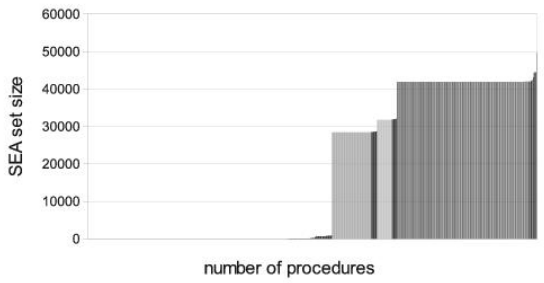

Figure 31. Monotone Size Graph of SEA impact sets of WebKit. Grey boxes represent clusters, black regions are non-cluster sets.

We performed a set of experiments using SEA for impact analysis in WebKit, a large, open source software system [5, 7]. We checked whether the impact sets of the failure introducing changes contain the modifications at the fixing revisions (we call this the prediction capability of impact analysis). We showed that a large number of real defects can be captured by impact sets computed by SEA, albeit many of them are large. We have achieved this by extending the regression test suite of WebKit with change and impact-based test selection capabilities. After investigating the large impact sets we observed that the main reason for such sets seems to be the formation of large dependence clusters in code (see Figure 31). We found that changes can often be associated to clusters, so this supports the findings of other researchers that refactoring clusters should be a concern. The contributions of this work were the following: (1) we tested the SEA algorithm on a large industrial system and found that it is suitable to be integrated into the build environment and exhibits good prediction capabilities; (2) we defined SEA-based dependence clusters and established that they are the primary causes of large impact sets; (3) we checked whether the theoretical importance of the formation of large dependence clusters, can be justified in practice; (4) we showed how SEA-based impact analysis can be used to enhance test case selection and prioritization in a regression test environment.

We investigated the application of code coverage based regression test selection and prioritization [2]. We experimentally applied selective retesting methods to the open source web browser engine project WebKit to find out the technical difficulties and the expected benefits if this method is to be introduced into the actual build process. We performed measurements about the failure detection capabilities of the selection algorithms. We also applied different test case prioritization strategies to further reduce the number of tests to execute. We investigated how successful the selection and prioritization were in reducing the test set without loosing failures and how much reduction can be achieved on average. Since we found the initial results very promising, we extended the WebKit build system with an optimized test selection component. We found that using the best selection and prioritization we can limit the size of the selection to below 10% and still detect about half of the failures.

We also investigated the applicability of impact analysis methods in practice [8, 9].

Code Coverage Measurement and Applications

In industrial testing projects compromises are often made to release a system in spite of knowing that it has outstanding defects. We performed an empirical investigation of this for one of our industrial partners [3]. Based on changes made to the system during a perfective maintenance activity, we carried out newly developed procedure level code coverage measurements with code level change impact analysis, and a similarity-based comparison of test cases in order to quantitatively check the completeness and redundancy of the tests performed. The assessment and improvement involved two phases. First, we evaluated the efficiency of testing without altering the testing procedure. We found that procedure level coverage was only 36% with at least 40% of the tests being redundant. In the second phase four months later we gave suggestions on how to design the test cases based on the uncovered components and redundant tests. In this case the coverage reached almost 100% and the number of defects reported after the release of the system were significantly reduced. These results led to a major reorganization of the company's development, testing, and operation processes.

Productivity research

During the planning, development, and maintenance of software projects one of the main challenges is to accurately predict the modification cost of a particular piece of code. We experimented with a combined use of product and process attributes (metrics) to improve cost prediction, and we applied machine learning to this end.

Micro-productivity decrease refers to the observation that the cumulative effort to implement a series of changes is larger than the effort that would be needed if we made the same modification in only one step. We investigated this phenomenon: (1) We applied our machine learning-based effort estimation method from previous work on an extended data set; (2) We introduced the notion of MPP and present the way we have calculated it for our subject projects; (3) Finally, we compared the different prediction approaches – learning models with and without the MPP – and check which one is the closest to the actual efforts [10]. The results showed that different projects have specific profiles of these micro-productivity decreases that depend on the type of the system, the development model, the composition of the team, and other factors. We found that, on average, after merely eight atomic modifications the micro-productivity halved. The calculated micro-productivity profiles for these projects could be used for effort estimation of larger tasks with more accuracy than a naive atomic change-oriented estimation.

Another new productivity metric family was defined, to be able to express the modification costs. The method depends on several important parameters which can significantly influence the success of the learning model. A search based method (genetic algorithm) was used to calibrate these parameters. For the first set of experiments four industrial projects were analyzed, and the accuracy of the predictions was compared to previous results. We found that by calibrating the parameters using search based methods we could achieve significant improvement in the overall efficiency of the prediction, from about 50% to 70% (F-measure) [11, 12]. Based on the promising result, the framework was re-factored to be able to measure larger data sets. These set of experiment was able to confirm the previous results. However these improvements and validations were not published yet, a journal article is planned to summarize all of these results.

Analysis of Preprocessed Languages

The area of program slicing is fairly diverse, and there exist lots of slicing methods and strategies. Their common attribute, however, is not to consider preprocessor macros as program points, the basic unit of slicing. We introduced the approach of dependency based macro slicing in two steps. First, we defined the Macro Dependence Graph on which forward and backward macro slices can be computed. Second, we integrated dependence graphs and defined connection points to extend traditional C/C++ slices with macro slices. The definitions of combined dependence graph and combined slices were also given. Forward and backward slicing algorithms used to calculate combined slices are listed as well. We proposed a tool architecture for the global computation of combined slices. Novel slicing notions, introduced in our work, were validated by experiments. Both macro slices and combined slices were empirically evaluated based on experiments on real-world programs. Via practical experiments, we described the benefits in terms of the completeness of the resulting slices. One of our main results is that above 75% of backward macro slices contained macro calls, where we made the slice more accurate by our analysis [6].

Practical preprocessor related results were achieved as well, to support program understanding by developers. The main problem is that the developer sees the original code, while the compiler uses the preprocessed code in the background. There is a lack of tool support in this situation because the preprocessor has its own, separate language to be analyzed. We implemented a Visual Studio plug-in (AddIn) that provides hand-on information on macros to increase the productivity of developers during debugging or program comprehension tasks. We enhanced the idea of macro folding, a technique to show/hide macro names and values within the source code editor; and defined a graphical view for macro expansions. In the background precise dynamic analysis of directives takes place, so the hint given for the developers considers all kind of preprocessor constructs, such as macros in conditionals and concatenating operators in the replacement text [13]. We also provided a detailed study on refactoring preprocessor constructs at the model level [14].

Conference Organization and Editorial Work

Árpád Beszédes was the program co-chair of the *2011 IEEE Conference on Source Code Analysis and Manipulation*, and served as the local organization chair of the *2011 ESEC/FSE conference*. Dr. Beszédes is a founding member, currently the director of accreditation, of the Hungarian Testing Board, the official national board of the International Software Testing Qualifications Board.

Tibor Gyimóthy was a PC member of the *ACM SIGSOFT Symposium on the Foundations of Software Engineering (2012)* and the *International Conference on Software Engineering Student Research Competition (ICSE-SRC 2011)*, the *International Conference on the Principles and Practice of Programming in Java (2012)*, the *IEEE International Working Conference on Source Code Analysis and Manipulation (2009)*, the *Euromicro Conference on Software Engineering and Advanced Applications (SEAA 2012)*, the *Conference on Current Trends in Theory and Practice of Informatics (SOFSEM 2011)*, and the *Symposium on Programming Languages and Software Tools (SPLST)* in 2009 and 2010.

Industrial trainings, R&D Projects

Our department performs trainings for industrial partners in the topics of requirements engineering and software testing. The department is a certified training provider of the International Software Testing Qualifications Board (ISTQB) Certified Tester Foundation Level training material, and performs trainings for local and foreign companies. The department also runs trainings for the International Requirements Engineering Board (IREB) Certified Professional for

Requirements Engineering Foundation Level exams. We have Romanian and Serbian contacts and we have given several trainings to Timisoara and Novi Sad companies.

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

Project CIRENE was funded by the EU's IPA Hungary-Serbia Cross Border Cooperation Programme. The main motivation was to strengthen the cooperation between our department and the Faculty of Technical Sciences, University of Novi Sad, and involve some industrial partners in the research. The research topic of CIRENE is a testing methodology for embedded systems.

The goal of the OTKA K-73688 project was to research on methods that tackle the problems related to practical applicability of software impact analysis in real size software systems in a short term. We built the methods upon previous results, they are of a highly experimental nature. We dealt with various topics of the research area which can provide a number of enhancement possibilities and further application fields on a national and international level.

Acknowledgements

The mentioned research activities were supported by the following grants and programmes: GOP-1.1.1-07/1-2008-0077, GOP-1.1.2-07/1-2008-0007, GOP-1.3.1-07/1-2008-0013, OTKA K-73688, TECH 08-A2/2-2008-0089, GOP-1.1.1-11-2011-0039, GOP-1.1.1-11-2011-0049.

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Department of Technical Informatics

I. ARTIFICIAL INTELLIGENCE IN TECHNICAL SOLUTIONS

In the field of eTourism, it is important to present prominent objects of tourists destinations. Nowadays demand for eTourism applications is rising and the customers need rapid software development. Google Maps API is a technology provided by Google based on AJAX, which powers many map-based services. We developed an expert system for tourists. The system utilizes a knowledge base formed by tracking user actions. The expert module suggests information of special interest to the user. In the field of computer vision we developed a fast and robust method, which is suitable for detecting human faces in real time and a real-time usable surveillance application for parking. In the field of intelligent buildings we developed a WEB based remote management and monitoring system.

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II. WIRELESS SENSOR NETWORK BASED LOCALIZATION

With the advancement of wireless technology even more wireless sensor network (WSN) applications are gaining ground. Their field of application is increasingly widening. We developed the WSN application which allows indoor localization based on the Fingerprint (FP) method. The communication between the modules was monitored during the experiment whereby the received radio signal strength indicator (RSSI) values from several modules were recorded by a mobile sensor. The received data was used for training of the feed-forward type of neural network. Through use of the trained neural network and the measured RSSI values an indoor localization was realized in a real environment.

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III. EDUCATIONAL RESEARCH

Teaching of natural sciences, engineering and informatics is rather challenging. Although there are many full-featured simulation applications available to aid understanding and practicing experimental education still have several problems due to the limited availability of expensive apparatus and dedicated experiments. We have developed software based instrument hardware including sensor-to-USB interfaces and related software applications, demonstration examples. Both the hardware and software are open source and easy to reproduce. We have also developed methods and software to use the personal computers built-in audio ports that can handle some sensor signals reliably. These achievements improve the efficiency of education significantly; all students can have an easy-to-use and transparent measurement device that can be used at several levels even from primary school to graduate programs where the students can develop their own PC or embedded application and additional hardware as well. More information can be found here: `www.inf.u-szeged.hu/edudev/`

One of the most important areas in the teaching of informatics is the laboratory realization of various pratical technical subjects. The universities are faced the burden of large numbers of students and the high costs of laboratory equipment and staff. In many cases, on top of the aforementioned problems comes the lack of space. The most appropriate solution is to develop a laboratory in a given place, this could in an industrial environment, as well, and then in real time establish access via the internet and with user interface and visualization enable two-way data exchange. This way only practice has to be organized, parameter setting, real time running can be achieved any given day or time, and from any location. The already established laboratories are capable of operating as distance laboratories if expanded with internet. At the Institute of Informatics of the University of Szeged the establishment of a distant laboratory has been started.

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IV. SCIENTIFIC INSTRUMENTATION AND SIGNAL PROCESSING

Collaboration of experts of different research fields certainly contribute to get better results faster. We regularly work together with researchers on biomedical, physical and chemical research problems. Our part of the work involves the development of algorithms to get as much information as possible from raw signals; to develop special instrumentation methods and hardware for optimal signal acquisition that can't be done with general purpose instruments. we have achieved results in time and frequency domain measurement and analysis of cardiovascular signals, fluorometry of photosynthetic bacteria, stochastic control of excimer lasers, development of gas sensor signal analysis and acquisition, inertial sensor based instrumentation to support handwriting recognition.

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V. INFORMATION PROCESSING AND APPLICATION OF NOISE AND FLUCTUATIONS

Measuring the resistance fluctuations of gas sensors provides new opportunities to enhance the selectivity and sensitivity of the sensor. Taking advantage of this possibility requires special low-noise measurement hardware and software to acquire data and perform analysis. We developed compact instruments and also provided data analysis software in order to perform the required data acquisition and signal processing. The number of components in integrated circuits is continuously increasing while to reduce power and increase speed the operating voltage is getting lower. This means that regular logic signals are operations become more sensitive to noise present in any integrated circuit. The idea of using noise as information carrier and the so-called noise-based logic can be one solution to the problems. Continuous and spiky noisy signals can be considered and logic operations can be defined. We have carried out numerical simulations in collaboration with the Department of Electronic and Computer Engineering of Texas A&M University to explore the possibilities and features of noise based logic schemes. The Kirchhoff-Law-Johnson-Noise (KLJN) secure key distribution system provides a way of exchanging secure keys by using only classical physics. The security of the system is comparable, in some aspects even better than in the case of Quantum Cryptographic Systems while the cost of the communicator units are orders of magnitude lower. Our research group has a great role in implementing and performing experimental tests on this system.

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VI. FPGA BASED DIGITAL HARDWARE DEVELOPMENT

High-speed, SAD based wavefront sensor development

The rapidly changing turbulent media distort the wavefront of the propagating light wave, thus considerably deteriorating the imaging system's performance. Wavefront sensors measure these wavefront distortions. An Adaptive Optic (AO) system using the wavefront measurement data can dynamically compensate these disturbances applying a deformable mirror (Micro-Electro-Mechanical Systems (MEMS) or other actuator devices; this provides an aberration corrected system with increased imaging performance.

An AO system correcting ability is better if the delay from sensing the wavefront to correcting is smaller than evolution time of the medium being corrected for. Thus, we have developed a single board adaptive optic system, made up of a high-speed CMOS sensor, a very fast Liquid Crystal on Silicon (LCOS) display, and a Field Programmable Gate Array (FPGA) device for control and calculation purposes, which can be seen on Fig. 32.

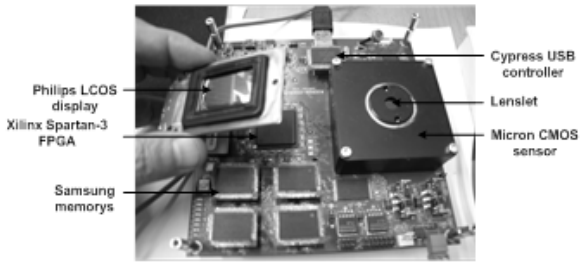

Figure 32. *The adaptive optic system*

Although several wavefront sensor architectures exist, here we applied a special version of the most popular Hartmann-Shack (HS) sensors. Considering the limitation of the FPGA devices and special parameterization of the mandatory wavefront sensors, we have chosen the Sum of Absolute Difference (SAD) method to implement the required correlation like processing.

The architecture implemented on Spartan-3 XC3S4000 FPGA has three main parts. The *Shuffle unit* is responsible for serializing the pixels required for the calculation of the SAD values. SAD values for each image are computed, and the smallest value is chosen by the *SAD unit*. This value and its 4-connected neighbors are transferred to a *Xilinx MicroBlaze soft-core processor* to determine the slope values at sub-pixel resolution motion vectors.

The *SAD unit* as the central component of the wavefront sensor was tested, and our results are compared to a correlation-based wavefront sensor system. This system is implemented on a Xilinx Virtex-4 SX35-10, in which the processing core operates on 100 MHz clock frequency. For better comparison, also the clock frequency of our *SAD unit* is decreased to 100 MHz. The results show that the Area*Time (AT) parameter of our SAD-based wavefront sensor system is smaller than the correlation-based system. In case of 8×8 sub-apertures, the AT parameter of our *SAD unit* is 22% of the correlation-based system. This ratio increases when larger sub-apertures are used. In 16×16 case, the performance difference is 29% between the two types of implementation. Thus SAD based solution provides similar accuracy but it can be computed more efficiently. The performance of our system can be further increased by using more *SAD unit*. Additionally, its operating frequency is also higher, especially in case of the Virtex-4. Even though FPGA-based SAD implementations have been published in different journals and books, systems like this were, generally, constructed on Altera FPGAs. Consequently the comparison of the Altera-based solutions with our Xilinx-based system may be not reliable, due to the architectural differences, but the overall performance of our implementation seems to out-perform them. However, our special purpose SAD architecture shows superior performance (16×16 subaperture: 10,186 slices and 496 clock cycles comparing to the published 9,478 slices and 1,600 clock cycles) with respect to the comparable motion estimation processor SAD implementations [1], [2].

Investigation of area and speed trade-offs in FPGA implementation of an image correlation algorithm

In general, determination of a correlation coefficient between two images requires high computing power, which is proportional to the size of the template image (kernel). It is desirable that the template image size should be large enough to contain relevant information. For real-time computation of the correlation coefficients, the majority of the operations can be executed on a CNN algorithm. However, analog CNN VLSI implementations have relatively low precision (7-8 bits) and very sensitive to the small changes of temperature and supply voltage. For these reasons an FPGA-based implementation is chosen.

Let us consider an input test image $\Phi(m,n)$: $R^2 \rightarrow R$ with dimension M×N. Correlation values can be computed as follows:

$$CORR(i,j) = \frac{\sum_{p=1}^{P}\sum_{q=1}^{Q}[K(p,q)-\overline{K}][\Lambda(p,q)-\overline{\Lambda}]}{\left[\sum_{p=1}^{P}\sum_{q=1}^{Q}[K(p,q)-\overline{K}]^2\right]^{\frac{1}{2}}\left[\sum_{p=1}^{P}\sum_{q=1}^{Q}[\Lambda(p,q)-\overline{\Lambda}]^2\right]^{\frac{1}{2}}} \tag{28}$$

where K(p,q): $R^2 \rightarrow R$ denotes the template image (correlation kernel) with dimension P×Q (p [1,P], q [1,Q]), Λ(p,q): $R^2 \rightarrow R$ represents the actual image region from test image $\Phi(m,n)$ compared to the kernel K(p,q), with dimension P×Q, (p [1,P], q [1,Q]), respectively. $\overline{K}$: is the mean intensity value of the template image $\overline{\Lambda}$: is the mean intensity value of the test image. Previous equation can be rewritten as follows:

$$CORR^2(i,j) = \frac{\left[\overline{[K(p,q)-\overline{K}][\Lambda(p,q)-\overline{\Lambda}]}\right]^2}{\overline{[K(p,q)-\overline{K}]^2}\cdot\overline{[\Lambda(p,q)-\overline{\Lambda}]^2}} \tag{29}$$

Investigating the implementation of the image correlation algorithm according to the previous equation three different ways are possible: a sequential, a semi-parallel and a massively/fully-parallel approaches. Our proposed semi-parallel solution provides a good trade-off between the serial and fully parallel implementations. In this case several processing MAC units with additional logic elements are linearly arranged and they can calculate the correlation coefficients parallel in a row-wise order. Using this method the area requirement of the architecture increases proportionally to the template size, so relatively large kernel images (e.g. 64×64, 128×128) could be handled in real-time, as well. The architecture of the implemented system can be seen on Fig. 33.

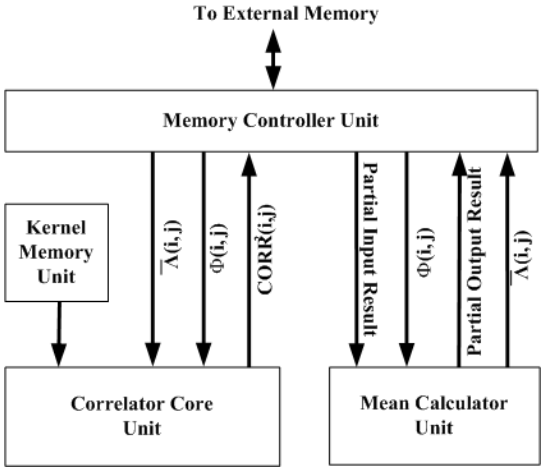

Figure 33. *The architecture of the implemented system*

The architecture was implemented on Xilinx Series-7 FPGA. The implementation results are compared to an existing fully-parallel implementation. The comparison is made with a test image having 511×511 pixel size and a 64×64 pixel-sized kernel. In our proposed semi-parallel implementation the required processing time is about 57ms, while with the fully parallel architecture the processing time is only 0.652ms. However, our solution consumes only 274 DSP MAC slices, while in case of fully-parallel implementation 14-times more dedicated MAC blocks are required [3].

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VII. MOBILE ROBOTIC RESEARCH

Obstacle avoidance, trajectory planning and tracking are common autonomous motion control problems for mobile robot navigation. In order to track a trajectory, real-time trajectory planning must be first achieved. In a dynamicaly changing environment obstacle avoidance is a common feature too.

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VIII. PNEUMATIC ARTIFICIAL MUSCLE RESEARCH

Pneumatic artificial muscle (PAM) is a relatively new type of linear actuator. There are many advantages of using PAM actuators instead of a conventional one, but mostly the extreme power-to-weight or power-to-size parameter is the deciding factor. Accurate modeling of the actuator is necessary to develop a reliable and precise control system using PAM components.

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Research Group on Artificial Intelligence

The main research direction of the group was research and development in the area of language technology, and the members of the research unit played an important role in carrying out the tasks of the research grants won by the host institution, the Department of Informatics of the University of Szeged. Hence, our research results related to language technology are presented in the chapter of the Department of Computer Algorithms and Artificial Intelligence. The research group also performed significant research in the area of self-organizing systems and fully distributed data mining, thanks to the support of Hungarian and EU projects. The unit also continued its research in the area of speech recognition, which was partly supported by a TÁMOP grant. Finally, three of our researchers achieved significant new results in the areas of theoretical and applied machine learning.

I. Speech Recognition

Our research in the area of speech recognition mainly focused on the development of new, improved acoustic models that are based on neural networks. In the area of segment-based acoustic modelling we proposed a new method to discriminate phonetic and non-phonetic speech segments [1]. We experimented with spectro-temporal feature extraction methods, and found that they can attain a performance similar to that of standard methods on clean data, while they behave much better on noisy data [3,10]. Besides very noisy data, we also experimented with unusually clean data. Though this may sound surprising, we thought that such experiments can give a good insight on what the current recognition methods are capable of in the best case. These experiments were carried out on recordings taken from audiobooks, and we found that under these nearly optimal conditions our algorithms are capable of attaining a phone recognition accuracy of almost 90% [2,6]. Most recently, we developed a new acoustic model that applies a hierarchic neural net. This model yielded the second best result ever published on the standard TIMIT database. The model was presented at ICASSP, IEEE's top speech and signal processing conference [11]. Finally, as an extension to our earlier research on cross-lingual acoustic modelling, we presented a detailed phonetic analysis of our cross-lingual acoustic model in [13].

Besides general-purpose research, we were also dealing with concrete practical applications, because our work was supported by the TÁMOP-4.2.2 grant titled "sensor network based data collection and information processing". In the framework of this project we studied low-resource signal processing and speech coding algorithms to support the speech recognition experiments on wireless sensors. For this purpose we developed a new gain control algorithm for wireless sensors, that can dynamically adjust the sound recording level of the sensor [4, 12]. Also, we experimented with speech coding methods to reduce the amount of data that has to be transferred between the sensor and the server [5]. We developed a new feature extraction algorithm that is more noise-robust than the standard methods. As our long-term goal was to extend the keyword spotting algorithms to other applications, a corpus of 28 hours of broadcast news was created, which is currently the largest public Hungarian speech technology database. The first tests of our noise-robust feature extraction keyword spotting algorithms were conducted on this broadcast news corpus [7]. To evaluate the behavior of our algorithms on noisy data, first we artificially added noise to the clean data set. After this, the algorithms were also evaluated on real signals recorded via sensors [8, 9]. The results showed that the proposed methods are usable in real environments as well.

II. Theory and Application of Machine Learning

The *statistical query model*, introduced by Kearns in 1993, became one of the best-known approaches to model learning in a noisy environment. In this model, the so called statistical query dimension characterizes the amount of information an agent needs in order to accomplish a kind of weak learning task (to perform slightly better than random guessing). The amount of information required to accomplish a strong learning performance (i.e., to achieve arbitrary accuracy) can be characterized by the so called *strong statistical query dimension*. Our contribution to this topic was a novel, uniform approach that has, additionally, significantly simplified the proofs for the characterization results, and has lead to a simplified notion of the strong statistical query dimension [14].

Another result that is related to the characterization of learnability is based on the Pollard pseudo-dimension. This is a generalization (for many-valued functions) of a central notion of learning theory, the so called Vapnik-Chervonenkis dimension, which characterizes learnability in the PAC-model. We have successfully proved that the Pollard pseudo-dimension of an arbitrary class of functions upper bounds its one-inclusion hypergrah-density [15]. As another application of our method, we have also shown that another well-known parameter, the graph-dimension also upper bounds this parameter, thereby solving an open question posed by B. I. P. Rubinsten et al.

Commonsense reasoning is a classical subfield of artificial intelligence which attracts increasing attention recently. It deals with making computers capable of human commonsense reasoning and its applications. An area within this field is belief revision, where the main question is how to modify a knowledge base if new information is received which contradicts the information previously contained in the knowledge base. Previous approaches used the full propositional calculus, for which entailment and other computational tasks are intractable (NP-hard). Our research in the field has aimed at examining the possibilities and limitations of applying Horn formulas, as a tractable class of Boolean formulas. Generalizing our previous results, we have characterized the possible candidates (called remainder sets) replacing a Knowledge Base when some new information reveals some flaw in it, and have shown that this necessarily leads to combinatorial blow-up in the size of the knowledge bases in some cases [16].

We have also investigated the question of what can one expect from a learning algorithm when the available sample is drawn from a known distribution (*distribution dependent learning*) in contrast to the case when this distribution is unknown (*distribution independent learning*). We have solved the problem in a special case of an active learning setting, called

"co-training under conditional independence". On the one hand, we have proved theoretical lower bounds for the performance of a distribution independent learner (compared to the performance of a distribution dependent one), and, on the other hand, we have also constructed distribution independent learning algorithms that achieve these bounds—which are thus basically optimal [17].

The boosting based algorithms, such as AdaBoost, undoubtedly are among the most influential supervised learning algorithms of the last decade. Our work in the domain of boosting can be grouped into four main areas: accelerating its training phases [21–23], accelerating its testing phase [18,19], improving its efficiency by designing new weak learner algorithms [27] and applying it to real-world problems beyond classification setup [24–26].

The advent of "Big Data" brought along with it new challenges in machine learning, such as devising fast training techniques which allow us to handle large data sets. For this purpose, we developed a multi-armed bandits (MAB) based framework that allows accelerating the training process of AdaBoost. We model the stepwise base classifier selection of AdaBoost as a sequential decision problem, and optimize it with MAB where each arm represents a subset of the base classifier set. The MAB gradually learns the "usefulness" of the subsets, and selects one of the subsets in each iteration. AdaBoost then searches only this subset instead of optimizing the base classifier over the whole space, and thus, the training process gets faster. We presented this idea in [22] and applied it in an open challenge that focused on large-scale learning [21]. Furthermore, by using adversarial MABs, we could prove a weak-to-strong-learning theorem, which means that the proposed technique remains a boosting algorithm in a formal sense [23].

There are numerous applications where the computational requirements of classifying a test instance are as important as the performance of the classier itself, just to mention a few, object detection in images, learning-to-rank. In our recent work [18, 19], we propose an algorithm that builds sparse decision DAGs (directed acyclic graphs) from a list of base classifiers provided by an external learning method such as AdaBoost. The basic idea is to cast the DAG design task as a Markov decision process. Each instance can decide to use or to skip each base classifier, based on the current state of the classifier being built. The result is a sparse decision DAG where the base classifiers are selected in a data-dependent way.

In practice, boosting simple learners like decision stumps has often been found to be sub-optimal. The most common solution for overcoming this problem is to use trees as base learners that call the simple base learner in a recursive fashion to partition the input space. Similarly to trees, we call the base learner as a subroutine but in an iterative rather than recursive fashion. The main advantage of the proposed method is its simplicity and computational efficiency [27].

In a comprehensive comparison of learning algorithms, it was found that AdaBoost outperforms other learning algorithms if discriminative criteria are used, but it fails badly if its output is used directly as a conditional probability estimate in a probabilistic criterion (such as cross entropy). AdaBoost orders the observations correctly according to their conditional probability, but the absolute values are off. It turns out that there is a simple fix: the output has to be rescaled using a non-linear but monotonic function using a small hold-out data set. Once this calibration is carried out, it turned out that the AdaBoost becomes an efficient learning-to-rank algorithm [24, 25].

The implementations of all the algorithms we developed are freely available in the form of C++ software packages [20].

III. Fully Distributed Data Mining

Our research inthis area mainly focused on the open problems of *fully distributed data mining*. Particularly, we investigated the question of how one can solve standard data mining tasks in a completely different computational environment. This environment consists of a huge number of networked computational devices (e.g. PCs, smart-phones or tablets) that can communicate with each other through messaging without any central control. Here the main problem is caused by the missing central control, asynchronous communication, the large number (scalability) and dynamic behavior (churn) of the users. Our task is to design *protocols* that overcome these issues and make it possible to perform efficient data mining in such environments.

As one of our early contributions, we proposed a fully distributed recommender system that builds and manages a similarity graph (overlay network) based on the user preferences applying gossiping techniques. We have empirically shown that our distributed approach converges pretty fast taking into account the load balance of the network, while the recommendation performance remains the same as in the case of its centralized variant [28]. Later on, we turned to investigate the possibilities of a more general solution for performing data mining in a fully distributed environment. So, we proposed P2Pegasos [29], an SVM solver, which can work pretty well in the above mentioned distributed environment with extreme fault tolerance. The technique applied here makes it possible to build model on data that never leave the node that contains them. Inspired by the methods developed here, we proposed our general learning framework, the Gossip Learning Framework (GoLF) [30], which improves the convergence speed by introducing a model combination component. In this framework, we successfully implemented different machine learning algorithms like perceptron, SVM, and boosting [26, 30]. These algorithms show amazing convergence properties, while they are extremely fault tolerant. We proposed a modification of the original GoLF protocol which makes it possible to tackle the problem of concept drift as well [31, 32].

The previously mentioned work was mainly supported by the FET programme FP7-COSI-ICT of the European Commission through the project QLectives (grant no.: 231200). This is a European Union project for bringing together top social modelers, peer–to–peer engineers and physicists to design and deploy next generation self–organizing socially intelligent information systems. Our achievements mentioned earlier are strongly related to the aims of the QLectives project.

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