Laboratory of Intelligent Decision Support Systems (IDSS) at the Poznan University of Technology, Poland

by

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The IDSS Laboratory has been established in 1990 within the Institute of Computing Science of the Poznan University of Technology. It groups today 26 researchers and academic teachers, including 1 professor, 3 associate professors, 11 assistant professors, as well as 11 assistants and Ph.D. candidates. There are, moreover, several external associates co-operating with us from both Poland and abroad. The research activity of the IDSS Laboratory is focused on **scientific methods of decision support**, in particular:

- multicriteria decision analysis, knowledge-based decision support, application of artificial intelligence in decision analysis,
- managing uncertainty and granularity of information in decision support systems using fuzzy set theory and rough set theory,
- rough set theory approach to knowledge and data engineering, in particular, to multicriteria decision analysis and approximate reasoning,
- preference modeling using decision rules,
- operational research problems and methodology, in particular, scheduling problems, including project and production scheduling, scheduling under fuzziness, water supply system programming,
- interactive methods for multiobjective mathematical programming,
- multiobjective metaheuristics for combinatorial problems,
- fuzzy linear programming with single or multiple objective functions,
- data mining and knowledge discovery,
- decision support in medicine, technology, economics and environmental studies,
- image processing and pattern recognition,
- feature construction and meta-learning,
- evolutionary computation and artificial life,
- text mining and Web mining,
- mobile decision support.

Within the area of intelligent decision support described by the above key topics, members of the IDSS Laboratory obtained original research results confirmed by many practical applications. Below, we present a brief characteristic of these results, together with a list of basic references.

A particular brand of this lab is an original knowledge discovery methodology for multiattribute and multicriteria decision support, which is based upon the concept of **rough sets** [A2,6], [B37]. Some important characteristics of the rough set concept make this methodology particularly useful in a variety of problems and concrete applications. For example, it is possible to deal with both quantitative and qualitative input data, and inconsistencies need not to be removed prior to the analysis. In terms of the output information, it is possible to acquire *a posteriori* information about the relevance of particular attributes and their subsets to the quality of approximation considered within the decision problem at hand. Moreover, the lower and upper (rough) approximations of decision classes, prepare the ground for inducing certain and possible knowledge patterns in the form of "*if..., then...*" decision rules.

Taking part in the development of rough set theory from the beginning, we adapted and extended its basic paradigm in many ways [A2], [B39,40]. For a long time, we also made attempts to employ rough set theory for decision support [B33]. The standard rough set approach was not able, however, to deal with preference-ordered attribute domains (criteria) and preference-ordered decision classes.

In the late 90's, adapting the classical rough set approach to knowledge discovery from preference-ordered data became a particularly challenging problem within the field of **multicriteria decision analysis**. Why might it be so important? The answer is related to the nature of the input preferential information available in multicriteria decision analysis and of the output of that analysis. As to the input, the rough set approach requires a set of decision examples. Such representation is also convenient for the acquisition of preferential information from decision makers. Very often in multicriteria decision analysis, this information has to be given in terms of preference model parameters, such as importance weights, substitution ratios and various thresholds. Producing such information requires significant effort on the part of the decision maker. It is generally acknowledged that people often prefer to make exemplary decisions and cannot always explain them in terms of specific parameters.

For this reason, the idea of inferring preference models from exemplary decisions provided by the decision maker is very attractive. Furthermore, the exemplary decisions may be inconsistent because of limited clear discrimination between values of particular criteria and because of hesitation on the part of the decision maker. These inconsistencies cannot be considered as a simple error or as noise. They can convey important information that should be taken into account in the construction of the decision makers preference model. The rough set approach is intended to deal with inconsistency and this is a major argument to support its application to multicriteria decision analysis. Note also that the output of the analysis, i.e. the model of preferences in terms of decision rules, is very convenient for decision support because it is intelligible and speaks the same language as the decision maker.

An extension of the classical rough set approach which enables the analysis of preference-ordered data was proposed in [B7,8,9,11,13,38]. This extension, called the **Dominance-based Rough Set Approach** (DRSA) is mainly based on the substitution of the indiscernibility relation by a dominance relation in the rough approximation of decision classes. An important consequence of this fact is the possibility of inferring (from exemplary decisions) a preference model in terms of decision rules which are logical statements of the type "*if..., then...*". The separation of certain and uncertain knowledge about the decision maker's preferences results from the distinction of different kinds of decision rules, induced from lower approximations of decision classes or from the difference between upper and lower approximations (composed of inconsistent examples). Such a preference model is more general than the classical functional models considered within multi-attribute utility theory, or the relational models considered, for example, in outranking methods. This conclusion has been acknowledged by a thorough study of **axiomatic foundations** [A5], [B10]. DRSA has also been used as a tool for inducing parameters of other preference models than the decision rules, like the relational outranking model used in multicriteria choice problems [B15].

Since the first proposal of DRSA, we have presented many **extensions** of the approach that make it a useful tool for many specific decision situations [B1,2,5,12].

As to the **application side of the rough set approach**, it has been used for discovering regularities in complex phenomena, like stormwater pollution [B36], bankruptcy risk of firms applying for bank a credit [B41], finding indications for a surgery treatment [B32] and classification of Siberian forests [B3]. A special attention has been paid to application of the rough set approach in clinical practice, to support some diagnostic and managerial decisions in hospital emergency rooms. This application required extension of the rough set approach to handle incomplete data. The results were implemented as a "decision making core" of a clinical decision support system developed on a mobile platform [B45]. The system, called MET (**Mobile Emergency Triage**), supports triage of patients with various acute conditions. It underwent a clinical trial in the Children's Hospital of Eastern Ontario in Ottawa [B27,28].

The last experience has grown our general interest in **mobile decision support systems** constructed according to the methodology known as A3 (anytime and anywhere). The A3 methodology extends the static model of a DSS introduced by Sprague by assuming that a DSS should be assembled on request of a decision maker from an ontological model and a repository of generic building blocks, and then deployed on the access platform specified in the request. This allows one to construct versatile and flexible DSSs running on a variety of platforms (e.g., handheld computers, mobile phones, desktop computers) and supporting wide range of problems.

Our interest in **data mining and knowledge discovery** has not been confined, however, to the rough set approach only. A leading theme within this area has been induction of various types of rules from large data bases, including mining association rules from preference-ordered data. We developed algorithms for inducing minimal sets of classification rules and algorithms for discovering satisfactory sets of rules having good descriptive and classification properties [B43]. The resulting sets of decision rules have then been used in some newly proposed **classifiers** [B1]. Moreover, we proposed specialized multiple classifiers, including generalizations of the multi-class n^2-classifier and bagging with attribute selection, and new techniques for aggregation of sub-classifiers answers [B42]. We are also investigating methods of **machine learning** and **feature construction/synthesis** to transform the space of source data to facilitate learning. This results in simplifying descriptions of induced knowledge and obtaining robust behavior of the classifiers [B22].

Induction of decision rules or construction of accurate classifiers is not all one can expect from knowledge discovery process. Recently, we focused our research on an assessment of interestingness measures for decision rules, adapting some **Bayesian confirmation** measures [B14]. We proposed, moreover, a way of measuring expected effects of **interventions** based on decision rules – it is particularly useful for marketing applications and customer satisfaction analysis [B6].

Special attention is also paid to techniques of attribute space reduction in data tables. The problem of analyzing data tables containing multidimensional representations of objects in terms of attributes is very common in statistics, knowledge discovery and machine learning. Irrespective of the techniques applied, such analysis may have descriptive or predictive character. In the descriptive analysis, the focus is on finding such representations of objects in terms of the attributes that satisfy particular requirements, e.g. representations that are minimal (subject to pre-defined objectives), easy interpretable (to the human) or quick to generate. In the prescriptive analysis, the focus is on finding good predictors, understood as procedures capable of foreseeing some unknown properties of objects. Both descriptive and predictive problems require good representations of objects in terms of attributes. Such representations expressed in terms of original attributes are often highly redundant, so a proper data reduction algorithm is required. Data reduction is either a pre-processing step in searching for a good description of considered objects, or a construction step of good predictors. It can also be used in object visualization, which requires low-dimensional object descriptions [B44].

Our research within data mining concerned also problems of obtaining human-perceivable information from systems of high complexity ranging from artificial neural networks to large collections of text documents. In particular, we developed new methods for supporting access to information gathered in electronic text resources, e.g. in the Web. Some new methods of text document clustering and labeling have been proposed [B31]. Among them, we elaborated an on-line method for **hierarchical clustering of Web documents** in order to discover an underlying topic structure of a document collection and thus support users in the process of efficient browsing for the desired information [B26]. The developed applications operate on snippets found by the Google browser.

Data mining and knowledge discovery are concerned also by image and sound processing, man-machine interaction, cognition and psychology. Modeling of **cognitive systems** is nowadays both challenging and still very difficult. The key problem is transition from low-level sensor data (e.g. image and/or sound) to high-level cognitive functions, such as recognition, planning, decision making, solving complex behavioral tasks, etc. Our research efforts include proposition of concepts representation which should be acquired and maintained automatically based on low-level features. A cognitive agent equipped with such a representation (knowledge) obtains world awareness which should help him to behave in the expected way [B22]. A parent topic for this area is man-machine interaction. There is a lot of real world problems concerning man-machine interaction which can be solved using psychological approach and computer science. For example, reading newspapers or books by blind or sight impaired persons could be supported by an electronic personal reading assistant. Such a system might consist of a tiny digital camera mounted in glasses, a digital signal processor (DSP), optical character recognition (OCR) and voice synthesis modules. A solution of the problem seems to be mainly an engineering task but there are a lot of scientific sub-problems which we are going to deal with.

In the field of **decision support based on pictorial information**, we developed a variety of approaches to feature synthesis that enable standard machine learners, like decision tree inducers, rule inducers, or neural nets, to learn directly from raster images and to use the acquired knowledge to perform various visual tasks, including object recognition and scene interpretation [A8]. For the task of feature synthesis, we proposed to use different paradigms of evolutionary computation. In such approaches, the learner performs a search in the space of image representations, i.e., features synthesized by the learning process. Given background knowledge in the form of elementary image processing and feature extraction operators, the evolutionary process synthesizes complex feature extraction procedures in a form of sequences or trees of elementary operators. The particular **evolutionary paradigms** include genetic programming, linear genetic programming, and cooperative coevolution [B24,25]. The developed methodology has been successfully applied to various real-world tasks, including recognition of 3D objects in visual spectrum, interpretation of medical imaging, and object recognition in radar imagery.

Another field of our research is **computer modeling and simulation**, applied to biological and physical phenomena. The motivation is either to use ideas present in nature to solve real-life problems or to investigate computer models of reality to increase knowledge of natural processes. In particular, we work on simulation of embodied agents (robots) situated in an artificial environment. This research concerns the fields of **artificial life**, biologically inspired systems, evolutionary robotics, complex systems, cognitive science, sensor evolution, and neuroscience. It involves evolution (directed or spontaneous and open-ended) of neural control and design using various genetic representations [A7], [B23].

We do not ignore, of course, classical topics of operational research and classical approaches to multicriteria decision analysis. We proposed **interactive methods** for **multiobjective programming** [B21], including **fuzzy multiobjective linear programming** [A1,3], [B35], as well as metaheuristic procedures for approximation of efficient frontiers in **multiobjective combinatorial optimization**, like Pareto simulated annealing [B17]. Recently, our main interest is focused on hybrid evolutionary (memetic) algorithms; we proposed a Pareto memetic algorithm that proved to perform well on several hard combinatorial problems, e.g. traveling salesperson problem or set covering problem [B19,20]. We are also interested in evaluation of multiobjective metaheuristics which should allow for quantitative comparison of various methods of this kind among them, as well as for comparison of these methods with other competitive approaches [B18,19].

Among multiobjective combinatorial optimization problems, we considered also a special assignment problem with incompatibility and capacity constraints [B34]. Within the area of multicriteria decision analysis, we proposed a method for inferring an outranking model parameters from assignment examples [B29,30] and a graded quadrivalent logic for ordinal preference modeling [B4].

We continued also our long lasting interest in multi-mode and multi-category resource constrained **project scheduling**, fuzzy project scheduling, software project management and vehicle routing problems [A4], [B16,17]. In all these problems, fuzzy sets were used to model both uncertainty of time parameters and flexibility of time constraints. A part of our lab was involved in intensive research concerning application of project management methods to **software engineering**. This resulted in participation in two European projects: OPHELIA (5^{th} FP) and CALIBRE (6^{th} FP). The first aimed at research on open platforms and methodologies for development tools integration in a distributed environment, while the latter focused on free and open source software engineering for open development platforms for software and services.

The IDSS Laboratory is responsible for two Master's specializations at the Faculty of Computer Science and Management of the Poznan University of Technology (PUT):

- Intelligent Decision Support Systems
- Software Development Technologies

Lab members give also courses at the Doctoral School of Computer Science at PUT.

The **Web page** of the IDSS Laboratory can be found at: http://idss.cs.put.poznan.pl

Some of our home-made **software** is available

at: http://idss.cs.put.poznan.pl/site/software.html

Major Publications of members of the IDSS Laboratory

A. Books, monographs and edited volumes

1. R. Slowinski, J. Teghem (eds.), *Stochastic versus Fuzzy Approaches to Multiobjective Mathematical Programming under Uncertainty*. Kluwer Academic Publishers, Dordrecht, 1990

2. R. Slowinski (ed.), *Intelligent Decision Support - Handbook of Applications and Advances of the Rough Sets Theory*. Kluwer Academic Publishers, Dordrecht, 1992.

3. R. Slowinski (ed.), *Fuzzy Sets in Decision Analysis, Operations Research and Statistics.* Handbooks of Fuzzy Sets Series, Kluwer Academic Publishers, Boston, 1998

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5. D. Bouyssou, E. Jacquet-Lagrèze, P. Perny, R. Slowinski, D. Vanderpooten, Ph. Vincke (eds.), *Aiding Decisions with Multiple Criteria – Essays in Honor of Bernard Roy*. Kluwer Academic Publishers, Boston, 2002

6. S. Tsumoto, R. Slowinski, J. Komorowski, J.W. Grzymala-Busse (eds.), *Rough Sets and Current Trends in Computing*. Lecture Notes in Artificial Intelligence, vol. 3066, Springer-Verlag, Berlin, 2004

7. A. Adamatzky, M. Komosinski (eds.), *Artificial Life Models in Software*. Springer-Verlag, Berlin, 2005

8. B. Bhanu, Y. Lin, K. Krawiec, *Evolutionary Synthesis of Pattern Recognition Systems*, Springer Verlag, New York, 2005

B. Recent articles in journals and edited volumes

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7. S. Greco, B. Matarazzo, R. Slowinski: The use of rough sets and fuzzy sets in Multiple-Criteria Decision Making. Chapter 14 [in]: T.Gal, T.Stewart, T.Hanne (eds.), *Advances in Multiple Criteria Decision Making*, Kluwer Academic Publishers, Boston, 1999, pp. 14.1-14.59
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10. S. Greco, B. Matarazzo, R. Slowinski: Axiomatic characterization of a general utility function and its particular cases in terms of conjoint measurement and rough-set decision rules. *European Journal of Operational Research*, 158 (2004) 271-292
11. S. Greco, B. Matarazzo, R. Slowinski: Dominance-Based Rough Set Approach to Knowledge Discovery (I) – General Perspective. Chapter 20 [in]: N.Zhong, J.Liu, *Intelligent Technologies for Information Analysis*. Springer-Verlag, Berlin, 2004, pp. 513-552
12. S. Greco, B. Matarazzo, R. Slowinski: Dominance-Based Rough Set Approach to Knowledge Discovery (II) – Extensions and Applications. Chapter 21 [in]: N.Zhong, J.Liu, *Intelligent Technologies for Information Analysis*. Springer-Verlag, Berlin, 2004, pp. 553-612
13. S. Greco, B. Matarazzo, R. Slowinski: Decision rule approach. Chapter 13 [in]: J.Figueira, S.Greco and M.Ehrgott (eds.), *Multiple Criteria Decision Analysis: State of the Art Surveys*, Springer-Verlag, New York, 2005, pp. 507-562
14. S. Greco, Z. Pawlak, R. Slowinski: Can Bayesian confirmation measures be useful for rough set decision rules? *Engineering Applications of Artificial Intelligence*, 17 (2004) no.4, 345-361

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16. M. Hapke, A. Jaszkiewicz, R. Slowinski: Interactive analysis of multiple-criteria project scheduling problems. *European Journal of Operational Research*, 107 (1998) 315-324
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20. A. Jaszkiewicz, P. Kominek: Genetic local search with distance preserving recombination operator for a vehicle routing problem. *European Journal of Operational Research*, 151 (2003) no.2, 352-364
21. A. Jaszkiewicz, R. Slowinski: The 'Light Beam Search' approach - an overview of methodology and applications. *European Journal of Operational Research*, 113 (1999) no.2, 300-314
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31. S. Osinski, D. Weiss: LINGO - concept-driven algorithm for clustering search results. *IEEE Transactions on Intelligent Systems*, to appear
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