COPERNICUS - AN EXPERT SYSTEM SUPPORTING DIFFERENTIAL DIAGNOSIS OF PATIENTS EXAMINED USING THE MMPI TEST

An Index-rule Approach

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Abstract: In the paper, we present the Copernicus system - a computer tool supporting differential diagnosis of patients with mental disorders. As an example, we discuss results for a sample of 479 women examined by means of the MMPI-WISKAD personality inventory. There have been used the inductive classifiers based on the C4.5 decision tree algorithm. We have accomplished an overview of indexes generated on the basis of examined sample by several systems: Eichmann's, Diamond's, Goldberg's, Taulbee-Sisson's, and Panda-APAP (mixed with respect to indexes).

1 INTRODUCTION

One of the main tasks of building expert systems is to search for efficient methods of classification of new cases. Our research concerns psychometric data coming from the Minnesota Multiphasic Personality Inventory (MMPI) test (Lachar, 1974). MMPI is used to count the personality-psychometric dimensions which help in diagnosis of mental diseases. In years 1998-1999 a team of researchers consisting of W. Duch, T. Kucharski, J. Gomuła, R. Adamczak created two independent rule systems devised for the nosological diagnosis of persons that may be screened with the MMPI-WISKAD test (Duch et al., 1999). Testing some algorithms for the rule generation from the MMPI data was described in (Gomuła et al., 2010a), (Gomuła et al., 2010c). Our research is focused on creating a new computer tool for multicriteria diagnosis of mental diseases. The first version of this tool has been presented in (Gomuła et al., 2010b).

The Minnesota Multiphasic Personality Inventory (MMPI) test (Lachar, 1974) delivers psychometric data on patients with selected mental disorders. Originally, the MMPI test was developed and published in 1943 by a psychologist S.R. McKinley and a neuropsychiatrist J.Ch. Hathaway from the University of Minnesota. Later the inventory was adapted in above fifty countries. The MMPI-WISKAD personality inventory is the Polish adaptation of the American inventory. It has been used, among other modern tools, for carrying out nosological differential diagnosis. MMPI is also commonly used in scientific research. The test is based upon the empirical approach and originally was translated by M. Chojnowski (as WIO) (Choynowski, 1964) and elaborated by Z. Płużek (as WISKAD) in 1950 (Płużek, 1971). American norms were accepted there. On the basis of the received responses (*"Yes"*, *"Cannot Say"*, *"No"*) to selected questions we may obtain the reference and clinical scales as being directly related to specific questions (items) and recalculate the outcome into T-scores results. The T-scores ([T]) scale, which is traditionally attributed to the MMPI, represents the following parameters: offset ranging from 0 to 100 T-scores, average equal to 50 T-scores, standard deviation equal to 10 T-scores. The profile that is built for such a case always has a fixed and invariable order of its constituents as distributed on the scales. The validity part

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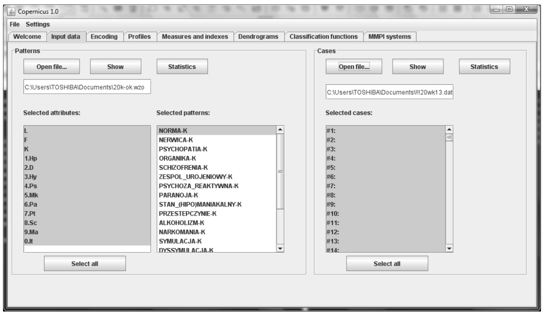

Figure 1: A graphical user interface of Copernicus.

consists of three scales: L - the scale of lying which is sensitive to all false statements aiming at representing ourselves in a better light, F - the scale which detects atypical and deviational answers to all items in the test, K - it examines self defensive mechanisms and it detects subtler attempts of the subject being screened at falsifying and aggravation. The clinical part consists of ten scales: 1. Hypochondriasis (Hp), 2. Depression (D), 3. Hysteria (Hy), 4. Psychopathic Deviate (Ps), 5. Masculinity/Femininity (Mk), 6. Paranoia (Pa), 7. Psychastenia (Pt), 8. Schizophrenia (Sc), 9. Hypomania (Ma), 0. Social introversion (It).

2 THE COPERNICUS SYSTEM - A GENERAL OVIERVIEW

The Copernicus system is a computer tool for multicriteria differential diagnosis of patients with mental disorders. The tool was designed for the Java platform. This makes the tool a modern platform-independent, object-oriented, user-friendly application. A graphical user interface is presented in Figure 1. The current version of this tool offers several main functions. We can locate patients in a profile space using a wide variety of measures and indexes (e.g., general distance measures, specialized measures, psychopathology indexes). We can match patient profiles to patterns of disorders using dendrograms generated by different clustering methods with a suitable visualization. In a tool, two approaches to generating dendrograms (Gan et al., 2007) are applied: standard hierarchical clustering techniques as well as an approach based on the so-called Wroclaw taxonomy. We can visualize patient profiles on the background of patterns of disorders as well as decision rules generated by popular data mining systems. An important thing is a unique visualization of decision rules (in the form of stripes put on profiles) supporting the nosological diagnosis. We can characterize patients by a number of indexes of the MMPI systems (Dahlstrom et al., 1986), (Kucharski and Gomuła, 1998b), (Kucharski and Gomuła, 1998a) like Diamond's, Leary's, Goldberg's, Eichmann's, Panda-APAP, and some other important and useful indexes. In the case of the Diamond's and Leary's systems, indexes are arranged in the form of appropriate diagrams (a box diagram for the Diamond's system and an radar-angular diagram for the Leary's system) which enable the user to interpret a patient profile in a graphical way. The design and implementation of the presented tool take into consideration its modularity. Therefore, the tool can easily be extended to other intelligent methods used in data mining and analysis, as well as, to other kinds of data, for example, coming from another inventories.

3 INPUT AND OUTPUT DATA

We have examined 479 clinical cases (women). A sample was selected using the competent judge method (the majority of two-thirds of votes of three clinicians-diagnosticians with several years' experience in clinical diagnosis using the MMPI-WISKAD test). Each case is classified to one of five psychiatric nosological types: neurosis (*neur*), psychopathy (*psych*), schizophrenia (*schiz*), simulation (*simu*), dissimulation (*dissimu*) as well as to norm (*norm*). Data vectors can be represented in a graphical form as the so-called MMPI profiles. The profile has always a fixed and invariable order of its constituents (scales).

In the Copernicus system, various procedures have been implemented, i.e., procedures plotting scale and index profiles, box diagrams, radar-angular diagrams as well as the basis of classification (decision) rules and their striped visualization decidedly improving differential diagnosis; the basis of nosological patterns for different genders (separately for men, separately for women) and classification (decision) rules also with respect to the examined gender; superimposing rules on patterns; visualization of classification functions. The classification functions (Cios et al., 2007) are definitely better and more precise than the rough Goldberg's indexes and they concern not four but twenty nosological classes (also with respect to gender of the examined patient). Ranges of the Goldberg's indexes, determined by us, confirm their high diagnostic relevance also for the MMPI-WISKAD data (examined women). Many clinicians feel an attachment to these indexes. Therefore, we have used an index-rule approach to the Goldberg's indexes which enables us to determine values of their ranges and classification accuracy of selected classes.

In the Copernicus system, there have been implemented numerous matching and distance measures enabling the user to inspect a degree of matching and consistency of a given profile with a nosological pattern or norm (see (Gomuła et al., 2010b)). An examined profile consists of scales. There is possibility of excluding any scales like in a clinical practice. The profile can be extended by various indexes which are calculated, added to the profile, and displayed in different ways (tabular collation, diagrams).

4 EXPERIMENTS

In our experiments, the Copernicus and WEKA systems have been used. WEKA is a collection of machine learning algorithms for data mining tasks (Witten and Frank, 2005). The main goal of experiments is generation of efficient classification (decision) rules via decision trees on the basis of profiles of patients and selected indexes calculated for profiles. Indexes added to profiles (scales) have been calculated using the Copernicus system. Next, for decision tree generation, the well-known C4.5 algorithm (Quinlan, 1993) (implemented in WEKA) has been used. To avoid excessive specificity (overfitting) of a decision tree and to improve its prediction value the standard approach, called pruning the decision tree, has been used. The complete decision tree has been generated, and next non-significant branches have been removed (the so-called post-pruning). If a decision tree is overfitted, then it captures erroneous classification information, which will tend to make it perform badly when classifying unseen cases. In the subsections, we present several experiments performed for profiles (scales) and selected indexes.

4.1 Classification Rules only from Profiles (Validity and Clinical Scales)

There is some problem with the 5.(Mf) scale. A feature selection analysis using several methods implemented in the WEKA system, for example, *SignificanceAttributeEval* together with *Ranker*, *GeneticSearch* together with *CfsSubsetEval* confirms this fact (see Table 1). The *SignificanceAttributeEval* method shows that scales: 8.(*Sc*), 6.(*Pa*), 4.(*Ps*), 3.(Hy), 0.(*It*), 7.(*Pt*), 1.(Hp), F, and 2.(D) are very important in the rank whereas scales K and L are the weakest ones and they need psychometric revision (which happened in the MMPI-2 test). Scale 9 needs refining (also in view of specificity and difficulty of test examination of maniacal states/episodes). For a decision tree generated using the C4.5 algorithm, we obtain that only ten rules are sufficient to make clinical differential diagnosis (see Table 3(a)) in the scope of five most important nosological classes and norm with accuracy 85% and greater. The average accuracy is 88%. Arrows indicate lower and upper bounds of a rule. Exemplary visualization of profiles and rules (in the form of stripes put on profiles) is shown in Figure 2. If all conditions of a given rule cut across the profile, then the rule is satisfied and diagnosis indicated by a rule can be assigned to the profile.

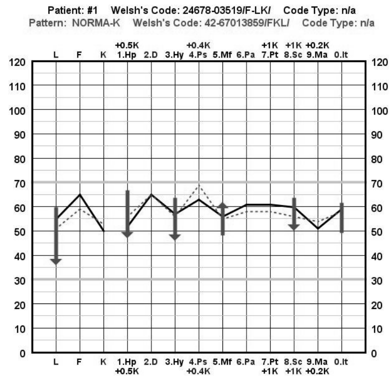

Figure 2: Visualization of profiles and rules.

Table 1: Attribute selection using (a) *SignificanceAttributeEval* together with *Ranker*, (b) *GeneticSearch* together with *CfsSubsetEval*.

a)

Avg merit	Avg rank	Attribute
0.959 ± 0.016	1 ± 0	8.(*Sc*)
0.9 ± 0.015	2.4 ± 0.92	6.(*Pa*)
0.878 ± 0.013	2.8 ± 0.4	4.(*Ps*)
0.853 ± 0.007	4.6 ± 0.92	3.(Hy)
0.854 ± 0.012	4.7 ± 1	0.(*It*)
0.841 ± 0.01	6.2 ± 0.87	7.(*Pt*)
0.84 ± 0.005	6.3 ± 0.64	1.(Hp)
0.813 ± 0.008	8 ± 0	F
0.781 ± 0.012	9 ± 0	2.(D)
0.741 ± 0.028	10 ± 0	9.(*Ma*)
0.676 ± 0.008	11 ± 0	K
0.607 ± 0.023	12.1 ± 0.3	L
0.558 ± 0.013	12.9 ± 0.3	5.(*Mk*)

b)

Number of folds (%)	Attribute
100	L
100	F
100	K
100	1.(Hp)
100	2.(D)
100	3.(Hy)
100	4.(*Ps*)
90	5.(*Mk*)
100	6.(*Pa*)
100	7.(*Pt*)
100	8.(*Sc*)
90	9.(*Ma*)
100	0.(*It*)

The 5.(*Mk*) scale was excepted. A set of rules obtained from profiles after the transformation of a decision tree is shown in Table 3(a). Rules have the form of logical implications: IF *conjunction of conditions (concerning values of scales) is satisfied*, THEN *decision (nosological class) should be taken* with a given accuracy (certainty), for example, IF $L <= 58[T]$ AND 1.(Hp) $<= 57[T]$, THEN $R1$: *norm* (with accuracy 89%). All classification (decision) rules from our set (see all tables with rules) have a separable (hence differential) character. Separability is assured by the inequality test applied in nodes of a decision

tree: $a <= v$, where a is an attribute (scale, index), v is a threshold for which the criterion of splitting is maximized. While using rule-based differential diagnosis, narrative descriptions can be restricted to scales and their ranges occurring in conditions of the satisfied rule. Such narrative based on satisfied and closed decision rules can be called a narrative diagnosis of the first level. As it is known, the appropriate clinical descriptions correspond to individual scales. Rules can be also closed by minimal or maximal value, respectively, for a given scale in a given class (or for all classes). An example is shown in Table 2. A rule is closed by minimal and maximal values of scales for the *schiz* class. There is some paradox. A process of

Table 2: An example of closing a rule.

1.(Hp)	6.(Pa)	9.(Ma)	Rule No.:class (accuracy %)
> 64	$<= 77$	> 56	R6:*schiz* (85%) - before closing
$65 - 89$	$47 - 77$	$57 - 85$	R6:*schiz* (85%) - after closing

closing conditions of rules can lead to smaller prediction values of rules, but it can increase the narrow-range accuracy of a narrative description.

4.2 Classification Rules from Profiles and Eichmann's Indexes

For each pair of different scales, the Eichmann's indexes are calculated as a sum, a difference, and an arithmetic average of two scales, for example $L-F$, $L+F$, $\frac{L-F}{2}$, ..., $L-1.(Hp)$, $L+1.(Hp)$, $\frac{L-1.(Hp)}{2}$, etc. Originally, the Eichman's system included five components (the so-called L components, K components, F components, Mf components, and NP components). A component is a scale subtracted from another scale. In our approach, we extend the Eichmann's indexes to all twelve components (subtraction of the same scales is omitted). All indexes were calculated only in [T] for the whole sample of women. Classification rules obtained from data consisting of profiles and the Eichmann's indexes are shown in Table 3(b). The average accuracy is 88.9%. We can assign clinical rational interpretation to the selected Eichmann's indexes, for example, $D-Ma$ is the activity (Diamond's) or mood disturbance index. The Eichmann's indexes indicated by a decision tree question credibility of code type systems. Not only the height of the highest scales (clinical, $>= 70[T]$ or $>= 65[T]$) in a profile constituting a given code type is important, but also sums and differences between selected scales. It concerns both validity (L, F, K) and clinical scales. All obtained rules can be treated as new code types with the determined accuracy.

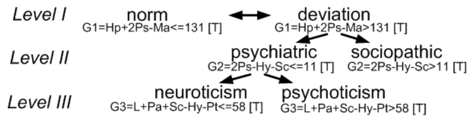

Figure 3: A hierarchy of classes for Goldberg's indexes.

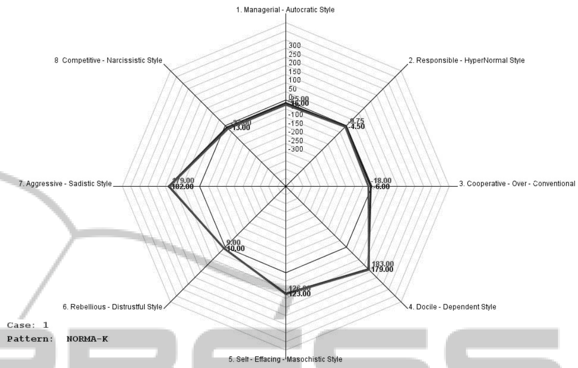

Figure 4: An exemplary Leary's diagram.

4.3 Classification Rules from Profiles and Goldberg's Indexes

The Copernicus system enables the user to calculate three Goldberg's indexes. The ranges of the Goldberg's indexes have been determined by rules for each of three levels (see Figure 3). Simulation (*simu*) and dissimulation (*dissimu*) have been excluded from the analysis. A macroclass of deviational profiles includes three classes: neurosis (*neur*), schizophrenia (*schiz*), and psychopathy (*psych*). A macroclass of psychiatric includes neurosis and schizophrenia. A class of sociopathy is formed by its counterpart, i.e., psychopathy. The Goldberg's indexes have an excellent property differentiating at each level with accuracy at least 91%. Classification rules obtained from data consisting of profiles and the Goldberg's indexes are shown in Table 4(a).

4.4 Classification Rules from Leary's Indexes

The Copernicus system enables the user to calculate the Leary's indexes (Leary, 1957). Indexes can also be visualized as it is shown in Figure 4. For decision rule generation, all of 497 profiles have been used. For each profile, eight Leary's indexes (called styles) are calculated: (1) Managerial - Autocratic style $M-A$, (2) Responsible - HyperNormal style $R-H$, (3) Cooperative-Over - Conventional style $C-C$, (4) Docile - Dependent style $D-D$, (5) Self-Effacing - Masochistic style $E-M$, (6) Rebellious

Table 3: (a) Rules obtained after transformation of a decision tree generated for all scales excluding scale 5, (b) Rules obtained for profiles and Eichmann's indexes, (c) Rules obtained for profiles and all indexes.

a)

L	1.(Hp)	3.(Hy)	6.(Pa)	8.(Sc)	9.(Ma)	0.(It)	Rule No.:class (accuracy %)
$<= 58$	$<= 57$						R1:*norm* (89%)
	$58 - 64$	$<= 59$	$<= 77$	$<= 68$			R2:*norm* (89%)
	> 64		$<= 77$		$<= 56$		R3:*neur* (85%)
	$58 - 64$	> 59	$<= 77$	$<= 68$			R4:*neur* (85%)
> 58	$<= 57$		> 58				R5:*psych* (92%)
	> 64		$<= 77$		> 56		R6:*schiz* (85%)
	$58 - 64$		$<= 77$	> 68			R7:*schiz* (85%)
> 58	$<= 57$		$<= 58$			> 59	R8:*simu* (94%)
	> 57		> 77				R9:*simu* (94%)
> 58	$<= 57$		$<= 58$			$<= 59$	R10:*dissimu*(85%)

b)

$Hy+It$	$L+Ps$	F	$D-Hy$	$Pt-Ma$	$F+Ps$	$Hy-Ma$	$Hp+D$	$L+Mk$	$D-Ma$	$K-Pt$	Rule No.:class (accuracy %)
> 119					$<= 157$	$<= 13$	$<= 123$	> 117			R1:*simu* (94.4%)
> 119					$<= 157$	$<= 13$	$<= 123$	$<= 117$			R2:*norm* (88%)
$<= 119$	$<= 125$	$<= 58$									R3:*dissimu* (70%)
$<= 119$	$<= 125$	> 58									R4:*norm* (88%)
$<= 119$	> 125		$<= 5$								R5:*dissimu* (70%)
$<= 119$	> 125		> 5	$<= 11$							R6:*psych* (94%)
$<= 119$	> 125		> 5	$<= 11$							R7:*schiz* (85.1%)
> 119	> 125		> 20		> 157						R8:*neur* (89.1%)
> 119			$<= 20$		> 157						R9:*simu* (94.4%)
> 119					$<= 157$	> 13					R10:*neur* (89.1%)
> 119					$<= 157$	$<= 13$	> 123		> 8	> -27	R11:*schiz* (85.1%)
> 119					$<= 157$	$<= 13$	> 123		> 8	$<= -27$	R12:*neur* (89.1%)

c)

$SocAgg/$	$avgDrInt$	$1.M-A$	$avgHost$	$SocInt$	0.(It)	Rule No.:class (accuracy %)
$<= 1$	$<= 67$	$<= -5$		> -12		R1:*norm* (96.0%)
> 1	> 67		$<= 73$	$<= -12$		R2:*neur* (93.1%)
$<= 1$	> 67		$<= 73$			R3:*schiz* 93.1%)
$<= 1$	$<= 67$	$<= -5$				R4:*psych* (96.8%)
$<= 1$	> 67	$<= -5$	> 73			R5:*simu* 87.9%)
$<= 1$	$<= 67$	> -5			> 55	R6:*simu* 87.9%)
$<= 1$	$<= 67$	> -5			$<= 55$	R7:*dissimu* (95.0%)

- Distrustful style $R-D$, (7) Aggressive - Sadistic style $A-S$, (8) Competitive - Narcissistic style $C-N$. After joining a profile (validity and clinical part excluding the 5.(Mk) scale) with the Leary's indexes and next generating decision rules, we came with the following conclusion: the best clinical differentiation is for styles $1.M-A$, $4.D-D$, and $7.A-S$. Two Leary's indexes determining two basic personality dimensions are not covered by a classifier and they are not used in classification. Clinical scale 4.(Ps) reinforces the accuracy of differential diagnosis of psychopathy to 60% and the average accuracy for the whole classifier to 90%. Especially, this scale differentiates well between norm and psychopathy for women. Classification rules obtained from data consisting of profiles and the Leary's indexes are shown in Table 4(b).

4.5 Classification Rules from Profiles and All Indexes

In the last experiment, rules have been induced for all system indexes (Diamond's, Leary's, Goldberg's, and PANDA-APAP (Pancheri et al., 1992)) and additional indexes important diagnostically. The PANDA system includes also the Taulbee-Sisson's system as a subsystem. The Taulbee-Sisson's system differentiates between neuroticism and psychoticism profiles.

Table 4: (a) Rules obtained for profiles and Goldberg's indexes, (b) Rules obtained for Leary's indexes (without validity and clinical scales).

a)

$G1$	$G2$	$G3$	Rule No.:class (accuracy %)
$<= 137$		$<= 63$	R1:*norm* (94.0%)
	> 120	> 63	R2:*psych* (100.0%)
> 137		$<= 63$	R3:*neur* (85.1%)
	$<= 120$	> 63	R4:*schiz* (94.1%)

b)

$1.M-A$	$4.D-D$	$7.A-S$	Rule No.:class (accuracy %)
$<= -5$	$<= 192$	$<= 184$	R1:*norm* (88%)
$<= -42$	> 192	$<= 214$	R2:*neur* (85%)
$<= -5$	$<= 192$	> 184	R3:*psych* (60%)
> -42	> 192		R4:*schiz* (87%)
	> 192	> 214	R5:*simu* (95%)
> -5	$<= 192$		R6:*dissimu* (95%)

Copernicus counts the conditional Taulbee-Sisson's indexes and next indicates neuroticism (if at least thirteen indexes are satisfied), psychoticism (if at most six indexes are satisfied), or an undefined state (otherwise). Rules have also been generated for profiles and all listed indexes. Classification rules obtained from data consisting of profiles and all listed indexes are shown in Table 3(c). The meaning of indexes is as follows: *SocAgg* - social aggression (Diamond's system), *avgDrInt* - average dreams intellectualization (Diamond's system), *avgHost* - average hostility (Diamond's system), *SocInt* - social introversion (PANDA system). In this experiment, the strongly extended Eichmann's system has been omitted. Its rule analysis was performed in Subsection 4.2.

4.6 Summarry

Rule classification trees enable the user to reduce interdependent, superfluous and strongly outlying data. Moreover, rule trees obtained by us have the "white-box" character, i.e., the knowledge representation is overt, readable and useful for diagnosticians and clinicians. Rule knowledge-based systems are small and do not exceed fifteen classification (decision) rules. The greatest number (twelve) of rules was generated for the Eichmann's system. All our analyses demonstrate that in an index-rule approach the selected indexes, Eichman's (calculated in [T]), extended Diamond's, Leary's (without two basic personality dimensions) are used not only for supporting diagnosis in the so-called interpretation quiet (mostly the range 40 - 60 [T]) or only for delivering additional interpretation (descriptive) hypotheses. Indexes selected by us and additionally transformed into the index-rule form give the high accuracy (above 80%). Therefore, they can not be overlooked. This is their new clinical and psychometric application. The systems mentioned earlier are implemented in Copernicus and they support quantitative and clinical differential diagnosis based on an index-rule approach.

5 CONCLUSIONS AND FURTHER WORK

In the paper we have shown an index-rule-based approach to differential diagnosis of patients with mental disorders. In our experiments we have used the Copernicus system and the WEKA system. The Copernicus system is a tool created by our team. Among others, it enables the user to calculate a wide variety of indexes used in diagnosis of psychopathologies. Some of them can also be visualized by means of appropriate diagrams. WEKA is a collection of machine learning algorithms for data mining tasks. Our experiments deliver important information for diagnosticians and clinicians about individual scales (their validities and utilities) used in the MMPI testing of patients. In the future work, among others, we are going to incorporate rule generation algorithms and visualization modules into the Copernicus system. Our main goal is to deliver to diagnosticians and clinicians an integrated tool supporting the comprehensive diagnosis of patients. The Copernicus system is flexible and it is dedicated for supporting differential diagnosis of profiles of patients examined using multiphasic personality inventories.

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