Evaluation of questionnaires by means of formal concept analysis*

Radim Belohlavek[1,2], Vladimír Sklenář[2], Jiří Zacpal[2], Erik Sigmund[3]

[1] Dept. Systems Science and Industrial Engineering
T. J. Watson School of Engineering and Applied Science
Binghamton University–SUNY, PO Box 6000, Binghamton, NY 13902–6000, USA
rbelohla@binghamton.edu

[2] Dept. Computer Science, Palacky University, Olomouc
Tomkova 40, CZ-779 00 Olomouc, Czech Republic
{vladimir.sklenar,jiri.zacpal}@upol.cz

[3] Centre for Kinanthropology Research, Palacky University, Olomouc
tr. Miru 115, CZ-771 11 Olomouc, Czech Republic
erik.sigmund@upol.cz

Abstract. The paper presents a method of evaluation of questionnaires. The method is supported by formal concept analysis. The role of formal concept analysis consists in providing an expert with a structured view on the data collected from the questionnaires. The method resulted from experiments with IPAQ (International Physical Activity Questionnaire). The structured view on data provided by the method suggests to the expert various hypotheses which can later be tested using statistical methods. However, the structured view on data itself proved to be sufficiently informative quite often. The paper presents experiments with evaluation of IPAQ.

1 Introduction and problem setting

Questionnaires are being used in many areas of human activities. The aim is to reveal patterns of behavior and various kinds of dependencies among variables being surveyed. Descriptive statistics and statistical hypotheses testing are among the tools traditionally used for evaluation of questionnaires. A practical disadvantage of the traditional statistical approaches is the need to formulate hypotheses to be tested. Without any prior structured view on the data contained in the questionnaires, formulation of relevant hypotheses is a difficult task. Another disadvantage of traditional statistical approaches is the limitation regarding what statistics can tell about data and how statistical summaries can be understood by experts in the field of inquiry who are not experts in statistics.

This paper presents results on evaluation of questionnaires monitoring physical activities of a population and the role of formal concept analysis in this

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evaluation. The paper is a continuation of previous studies regarding the IPAQ questionnaire, see [16, 17]. IPAQ is a standardized international questionnaire, see [20]. At the beginning of our study, there was a need for an alternative means of evaluation of questionnaires formulated by experts (domain experts) from the Faculty of Physical Culture of the Palacky University, Olomouc, who are involved in a world-wide project of monitoring physical activities in today's population. The experts struggled with classical statistical techniques and were looking for alternative methods of evaluation of the questionnaires. It turned out that basic methods of formal concept analysis (FCA) [11] are quite useful for the domain experts. Putting briefly, a concept lattice and its parts provide the experts with an easy-to-understand hierarchical view on the data. In terms of FCA, the basic idea is the following. The objects are the individuals (or their groups) being surveyed in the questionnaires, the attributes correspond to the variables being monitored by the questionnaires. The corresponding concept lattice or its parts reveals to the domain expert the groups in dependence on the attributes and the expert can see various dependencies between attributes, how large the groups are etc. Therefore, the concept lattice provides the expert with a first insight into the data. Such an insight is crucial. Very often, this insight is what the expert needs to see. Furthermore, based on this insight, the expert can pursue more detailed inquiries including those based on classical statistical techniques. In particular, the present study focuses on considering groups of individuals as objects. The groups are based on sharing common attributes specified by the expert. The groups can be seen as aggregates. Instead of having an attribute by an individual, we then naturally come to relative frequencies of attributes within the specified groups. This way, one comes from data tables with yes/no attributes (i.e. ordinary formal concepts) to data tables with numbers from the unit interval $[0, 1]$ interpreted as relative frequencies. We use particular fuzzy concept lattices for building concept lattices from such data tables. The concept lattices provide an expert with an aggregate hierarchical view on the data. The advantage of taking groups and the relative frequencies instead of individuals and original attributes is conciseness of the description provided by the resulting concept lattice which is what the experts asked for. The disadvantage, as with any other method which involves aggregation and summarization, is loss of information. We present our method, experimental results, as well as a brief description of the software tool we used.

2 The questionnaire

Each questionnaire consists of questions to be answered by respondents mostly by selection from possible answers. From the point of view of FCA, we can take the set of respondents as the set of objects and single questions as attributes. The questions need not be yes/no questions. Rather, some questions like those concerning age and education are many-valued. Correspondingly, a filled-in questionnaire can be represented by a many-valued context. Such context can be transformed to an ordinary formal context $\langle X, Y, I \rangle$ via conceptual scaling [11].

Typically, such a formal context contains many objects and a manageable number of attributes. The corresponding concept lattice is too large for an expert to comprehend. In addition, the expert might not be interested in the formal concepts from this concept lattice. Rather, the expert might want to consider aggregates of the individual respondents as objects in the formal context with the aggregates defined by having the same attributes on a set S of attributes specified by an expert, such as those regarding age, sex, etc., with S being a subset of the set Y of all attributes. Attributes from S will be called characteristic attributes.

The aggregates we consider are equivalence classes of individual respondents. For respondents $x_1, x_2 \in X$, put

$$x_1 \equiv_S x_2 \text{ if and only if } \{x_1\}^{\uparrow} \cap S = \{x_2\}^{\uparrow} \cap S.$$

Clearly, $\equiv_S$ is an equivalence relation on X and $x_1 \equiv_S x_2$ means that x_1 and x_2 have the same attributes from S, i.e. are indistinguishable by the attributes from S. We call the classes $[x]_{\equiv_S}$ of $\equiv_S$ aggregate objects and denote, furthermore,

- by X_1 the set of all classes of $\equiv_S$, i.e. $X_1 = X/\equiv_S$, by Y_1 the set of those attributes from Y not included in S, i.e. $Y_1 = Y - S$.

Now, for each class $[x]_{\equiv_S}$ from X_1 and each attribute $y \in Y_1$, we consider the relative frequency of objects in having attribute y and denote it by $I_1([x]_{\equiv_S}, y)$ or simply by $I_1(x, y)$. That is, we put

$$I_1(x, y) = \frac{|\{x_1 \in [x]_{\equiv_S} \,:\, x_1 \text{ has } y\}|}{|[x]_{\equiv_S}|}$$

We can consider I_1 a fuzzy relation which will indeed be the case in this study. Namely, we will consider a particular concept lattice associated to $\langle X_1, Y_1, I_1 \rangle$, called a lattice of crisply generated fuzzy concepts [4]. For technical reasons, we round the degrees assigned by I_1 to those from the scale $\{0, 0.01, \ldots, 0.99, 1\}$.

Remark 1. An important remark is in order. Interpreting degrees of membership of a fuzzy relation by relative frequencies is not typical. It may even seem not appropriate because degrees in fuzzy logic are typically degrees associated to graded collections and relationships. However, as we will see, the way we use the degrees with frequential interpretation is all right from the semantical point of view. In fact, the only thing which matters in our manipulation with the degrees is a comparison of the degrees, i.e. a comparison of relative frequencies.

In addition, the expert might want not to include aggregate objects $[x]_{\equiv_S}$ which contain less than m objects with m being prescribed by an expert (this requirement was suggested by our domain expert).

Example 1. Consider the following illustrative example. Let the ordinary formal context be given by Tab. 1. Consider $S = \{$SEXMale, SEXFemale, JOByes, JOBno$\}$ as the set of characteristic attributes.

Using the above-described transformation, we obtain a formal fuzzy context with 4 aggregate objects Fno (women who do not have a job), Fyes (women who have a job), Mno (men who do not have a job), Myes (men who have a job), depicted in Tab. 2.

Table 1. Original context.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	1	0	1	0	0	0	0	1	0	0	0	1	0	1	0	0
2	1	0	1	0	1	0	0	0	0	0	1	0	0	1	0	0
3	1	0	1	0	0	0	0	1	0	0	1	0	0	1	0	0
4	1	0	1	0	0	0	0	1	0	0	1	0	0	1	0	0
5	1	0	1	0	0	0	0	1	0	0	1	0	0	1	0	0
6	1	0	0	1	0	0	1	0	0	1	0	0	0	1	0	0
7	1	0	0	1	1	0	0	0	0	0	1	0	0	1	0	0
8	1	0	0	1	0	0	0	1	0	0	1	0	0	1	0	0
9	1	0	0	1	0	0	0	1	0	0	1	0	0	1	0	0
10	0	1	1	0	1	0	0	0	0	1	0	0	0	1	0	0
11	0	1	1	0	0	0	1	0	0	0	1	0	0	1	0	0
12	0	1	1	0	1	0	0	0	0	0	1	0	0	1	0	0
13	0	1	1	0	1	0	0	0	0	1	0	0	0	1	0	0
14	0	1	1	0	1	0	0	0	0	1	0	0	0	1	0	0
15	0	1	1	0	0	1	0	0	0	1	0	0	0	1	0	0
16	0	1	0	1	0	0	0	0	1	1	0	0	0	1	0	0
17	0	1	0	1	1	0	0	0	0	1	0	0	0	1	0	0
18	0	1	0	1	1	0	0	0	0	1	0	0	0	1	0	0
19	0	1	0	1	1	0	0	0	0	1	0	0	0	1	0	0

attributes:1 - SEXMale, 2 - SEXFemale, 3 - JOByes, 4 - JOBno, 5 - AGE15-24, 6 - AGE25–34, 7 - AGE35–44, 8 - AGE45–54, 9 - AGE55–65, 10 - BMIunder (Body Mass Index =body weight $[kg]$ / body height $[m]^2$), 11 - BMInormal, 12 - BMIover, 13 - BMIobesity, 14 - PAlow, 15 - PAmoderate, 16 - PAhigh

Table 2. Fuzzy context derived from the formal context from Tab. 1.

	1	2	3	4	5	6	7	8	9	10	11	12
Fno	0.75	0	0	0	0.25	1	0	0	0	1	0	0
Fyes	0.67	0.17	0.17	0	0	0.67	0.33	0	0	1	0	0
Mno	0.25	0	0.25	0.5	0	0.25	0.75	0	0	1	0	0
Myes	0.20	0	0	0.80	0	0	0.80	0.20	0	1	0	0

attributes: 1 - AGE15-24, 2 - AGE25-34, 3 - AGE35-44, 4 - AGE45-54, 5 - AGE55-65, 6 - BMIunder, 7 - BMInormal, 8 - BMIover, 9 - BMIobesity, 10 - PAlow, 11 - PAmoderate, 12 - PAhigh

3 Concept lattices from the derived contexts with relative frequencies

Given a formal fuzzy context $\langle X_1, Y_1, I_1\rangle$ consisting of a set X_1 of aggregate objects, a set Y_1 of their attributes, and a fuzzy relation I_1 with $I_1([x]_{\equiv_S}, y)$ representing relative frequency of attribute y in class $[x]_{\equiv_S}$, we use so-called crisply generated fuzzy concept lattice $\mathcal{B}(X_1, Y_1, I_1)$ for displaying the information contained in the questionnaire. Due to the limited scope, we refer the reader to [4] for a detailed information on crisply generated concept lattices.

Let us recall that a crisply generated concept lattice is a part of a fuzzy concept lattice [2, 15] generated from the arrow operators by crisp (i.e. ordinary) sets of objects (or dually, attributes). In a fuzzy setting, the deriving arrow operators are defined as follows. Let L be a scale of truth degrees such as our $L = \{0, 0.01, \ldots, 1\}$. For fuzzy sets $A \in L^{X_1}$ of objects and $B \in L^{Y_1}$ of attributes, define sets $A^{\uparrow} \in L^{Y_1}$ of attributes and $B^{\downarrow} \in L^{X_1}$ of objects by

$$A^{\uparrow}(y) = \bigwedge_{[x]_{\equiv_S} \in X_1} (A([x]_{\equiv_S}) \to I_1([x]_{\equiv_S}, y)),$$

$$B^{\downarrow}([x]_{\equiv_S}) = \bigwedge_{y \in Y_1} (B(y) \to I_1([x]_{\equiv_S}, y)).$$

Here, $\to$ is a suitable residuum (corresponds to implication connective). Note, however, that for the crisply generated formal concepts which are of interest in our approach, it does not matter, which residuum $\to$ one takes. Namely, for all the residua, the corresponding crisply generated concept lattices are isomorphic, see [4]. Now, a crisply generated fuzzy concept lattice $\mathcal{B}(X_1, Y_1, I_1)$ is the set of all fixpoints of the arrow operators which are generated by a crisp set of objects, i.e.

$$\mathcal{B}(X_1, Y_1, I_1) = \{\langle A, B\rangle \mid A^{\uparrow} = B, B^{\downarrow} = A, \text{ and } A = C^{\uparrow\downarrow} \text{ for some crisp } C \in L^{X_1}\}.$$

Note that C being crisp means that $C([x]_{\equiv_S}) = 0$ or $C([x]_{\equiv_S}) = 1$ for each $[x]_{\equiv_S} \in X_1$.

Remark 2. Formal concepts $\langle A, B\rangle$ from $\mathcal{B}(X_1, Y_1, I_1)$ can be interpreted as follows. A is a collection of aggregate objects (i.e. classes of individual respondents). B is a fuzzy set such that every aggregate object (class of individual respondents) from A has attribute y with relative frequency at least $B(y)$. Strictly speaking, A is a fuzzy set, too, and we should say that $\{[x]_{\equiv_S} \mid A([x]_{\equiv_S}) = 1\}$ is the set of aggregate objects such that for B, every $[x]_{\equiv_S} \in A$ has attribute y with relative frequency at least $B(y)$. For aggregate objects $[x]_{\equiv_S}$ with $A([x]_{\equiv_S}) < 1$, high $A([x]_{\equiv_S})$ indicate that the relative frequencies of y's are close to $B(y)$.

Note that crisply generated fuzzy concept lattices are isomorphic to Krajči's one-sided fuzzy concept lattices defined in [14] as well as to the fuzzy concept lattices defined in [7].

4 Evaluation of the questionnaire

This concept lattice $\mathcal{B}(X_1, Y_1, I_1)$ is suitable for further analysis. A frequent expert request is to find out common properties for groups of respondents (i.e. aggregate objects) which we represent by characteristic attributes. For this purpose, we find the smallest concept, which include all request aggregate objects (in degree 1). For the expert, it is important how many and which respondents are contained in such a concept. The number of respondents is sum of the numbers of objects contained in the aggregate objects which are present in the extent of the formal concept.

No less important are characteristics of respondents represented by the concept. This is given by characteristic attributes, which characterize aggregate objects included in this concept in degree 1. For example, if there is an aggregate object in the extent corresponding to attributes SEXFemale and JOBno, and and aggregate object corresponding to attributes SEXMale and JOByes, we can see, that this concept relates to women who do not have a job and simultaneously to men who do have a job.

Another type of information is contained in the intent B. A degree $B(y)$ expresses the precentage of objects which are present in the extent (in degree 1) and have attribute y. Both high and low values of $B(y)$ are interesting for the expert. For example the concept whose extent is described above and which has in its intent attribute SMOKINGno to degree 0.42 and attribute DOGyes to degree 0.65, we can see, that at least 42% of women without a job and working men do not smoke and at least 65% of women without a job and working men have a dog.

By passing down the concept lattice we can examine common attributes of different subsets of aggregate objects. A comparison of concepts created from aggregate objects is also interesting for the expert. For example, if the expert is about to examine the influence of physical activity on population, then comparing a concept which is characterized by aggregate objects SEXMale and PAlow, and SEXFemale and PAlow, with a concept, which is characterized by aggregate objects SEXMale and PAhigh, and SEXFemale and PAhigh is of interest.

5 IPAQ

International Physical Activity Questionnaire (IPAQ) is an appropriate instrument with acceptable measurement properties for monitoring of physical activity (PA) among 18 to 65 year old adults in diverse (international) populations ([1], [20]).

Every participant is filling out the time spent on performing physical activities including walking, including personal data (sex, age, body weight and height) and lifestyle characteristics (education, job time, type of housing - own house apartment, family status - living alone × in family × in family with children, smoking - yes × no, ownership of a car, a dog, a bike or weekend house, participation in an organized PA). The most important result from the IPAQ is the finding how many adults (%) meet the category "low", "moderate" or "high" level of PA in relation to the guidelines of healthy lifestyle and health support. However, complex and transparent description of groups of adults with different PA level is necessary. This description should include environmental, social, and somatic factors determining the lifestyle of the participants. Simple and multiple correlation analysis did not show ($-0.15 \leq r_S \leq +0.15$) deeper associations between PA level and personal data and lifestyle characteristics of participated adults. Therefore, it is not possible to say that smokers or obese adults are less physically active than non-smokers or non-obese adults, due to very low correlations between PA level and smoking or body weight. This is the reason why we are looking for a "suitable tool" that will allow complex and transparent characterization of groups of adults with regard to their PA level and lifestyle characteristics. Formal concept analysis proved useful for this purpose [16].

Are there any differences between groups of females with low and high level of PA in relation to the guidelines of healthy lifestyle and health support? Are there any similarities in personal data or lifestyle characteristics in these two groups of females? Are any of these characteristics more typical for group of females with high level of PA than for group of females with low PA level? These are the types of questions formal concept analysis helps the expert with in looking for answers. The whole questionnaire data was transformed into an ordinary formal context that included 4510 objects (participants) and 47 attributes. The next step was to create agregate objects. The set of characteristic attributes contains attributes SEXMale, SEXFemale, PAlow, PAmoderate and PAhigh. As explained earlier, this way we come to a fuzzy context with 6 aggregate objects and 42 attributes. The aggregate objects are MLo (men with low PA), MMo (men with moderate PA), MHi (men with high PA), FLo (women with low PA), FMo (women with moderate PA), FHi (women with high PA). The resulting fuzzy concept lattice contains 54 concepts.

Evaluation of this concept lattice helps answer the questions formulated above. If the expert is interested in data related to women, he/she will work with the part of the concept lattice depicted in Fig. 1. This part contains formal concepts with extents with aggregate objects FLo, FMo, and FHi in degree 1. For instance, there is obviously high number of females who showed at least moderate PA level. This result is strongly influenced by everyday walking (50% of female spend more than 65 minutes per day). Ownership of a car or a dog, living in house, living alone, smoking and participation in an organized PA more than 3 times per week are attributes that do not affect the level of PA (Tab. 3). Females characterized as high active are more walking and have more optimal body weight (BMI index). We can also see that more females with low level of PA have a job. Different value of attribute Age 15-24 can indicate a fact that physical activity of young people is smaller (Tab. 3).

On the other hand we can be interested in finding features that are shared by more aggregate objects. For example, what is common for women and men with high physical activity. In this case we can examine the intent of a concept whose extent contains aggregate objects MHi and FHi in degree 1 (Tab. 4).

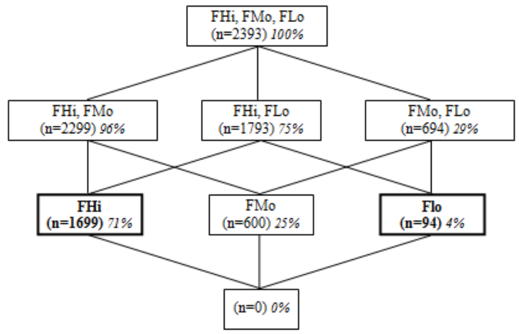

Fig. 1. The set of concepts of females differentiated according to health supported PA level, n=sum of cardinality of objects in extent in degree 1, $x\% = (n/N) * 100$ where N is sum of cardinality FLo, FMo and FHi, ie. number of woman in questionnaire

Table 3. Differences between high and low active group of females

	1	2	3	4	5	6	7	8	9	10	11	12	13
FHi (n=1699)	0.51	0.08	0.64	0.21	0.43	0.08	0.29	0.52	0.43	0.17	0.30	0.65	0.40
FLo (n=94)	0.52	0.09	0.61	0.18	0.40	0.10	0.24	0.60	0.36	0.31	0.10	0.78	0.52

attributes: 1 - Living in house, 2 - Living alone, 3 - Ownership of a car, 4 - Smoking, 5 - Ownership of a dog, 6 - Organized PA $\geq$ 3 per week, 7 - Ownership of a weekend house, 8 - BMI under, 9 - BMI normal, 10 - Walking low, 11 - Walking middle, 12 - Job yes, 13 - Age 15-24

Table 4. Attributes shared by women and men with high PA

	1	2	3	4	5	6	7	8	9	10	11	12
FHi,MHi	0.84	0.64	0.65	0.21	0.37	0.49	0.52	0.17	0.09	0.43	0.04	0.01

attributes: 1 - Ownership of a bicycle, 2 - Ownership of a car, 3 - Job yes, 4 - Smoking, 5 - Ownership of a dog, 6 - Living in house, 7 - Walking high, 8 - Walking low, 9 - BMI under, 10 - BMI normal, 11 - BMI over, 12 - BMI obesity

These are examples of how our approach via formal concept analysis assists the expert in evaluating the questionnaire data. A detailed description of the interpretation of the data is beyond the scope of this paper.

6 Software tool

We used a software tool which is developed in the Department of Computer Science at Palacky University, Olomouc, to create the fuzzy context and to browse the corresponding fuzzy concept lattice. This software tool supports the whole process of the processing and evaluation of IPAQ questionnaire. The basic overview of functions that are supported and their succession is in Fig. 2.

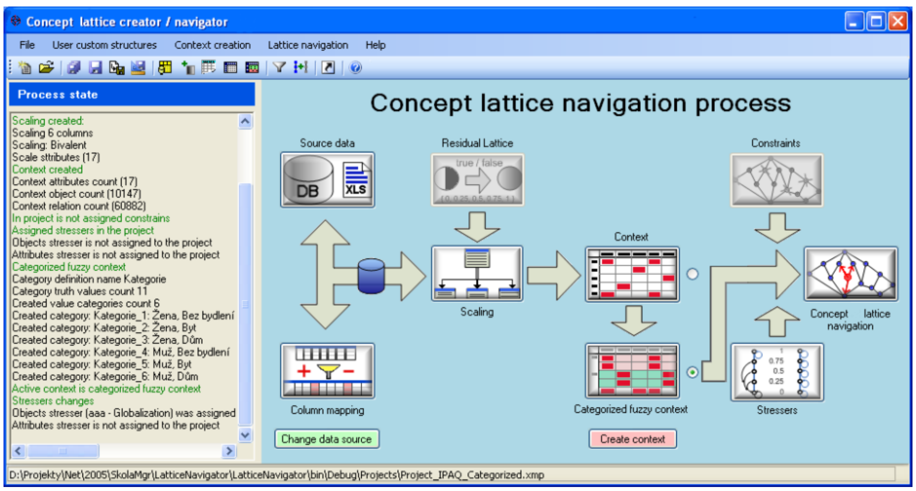

Fig. 2. Base screen of application

The processing of the questionnaire consists of the following steps.

- **Reading of data**. IPAQ questionnaire is recorded in the form of MS Excel file. The columns of this file contain respondents' answers to individual questions. The software tool allows to specify which columns are included in the processing.
- **Scaling**. The answers to some questions may be in the form of many-valued attributes. For example, the values in the column Age may be in the interval from 18 to 69. Due to this fact it is necessary to transform the original file to the form in which each column contains only 0 or 1. This process is called scaling. Our software tool allows one to specify the bivalent attributes and the scale for each column in data source file.
- **Creating aggregate objects**. It is possible to interactively specify the set of characteristic attributes. The user also chooses the residuated lattice in this step including the number of truth degrees.

The fuzzy context is created after these steps. We can examine the fuzzy concept lattice and its concepts. Our software tool does not create the concept lattice as a whole. Instead, it supports an interactive navigation in the concept lattice. It shows the information related to the current concept and its direct neighbors. A user selects next steps by choosing an ancestor or successor of the current concept. He/she can move from a more general concept to a more special concept and vice versa. He/she can also specify the content of the extent or the intent and move to the appropriate concept. We can see the user's screen in Fig. 3.

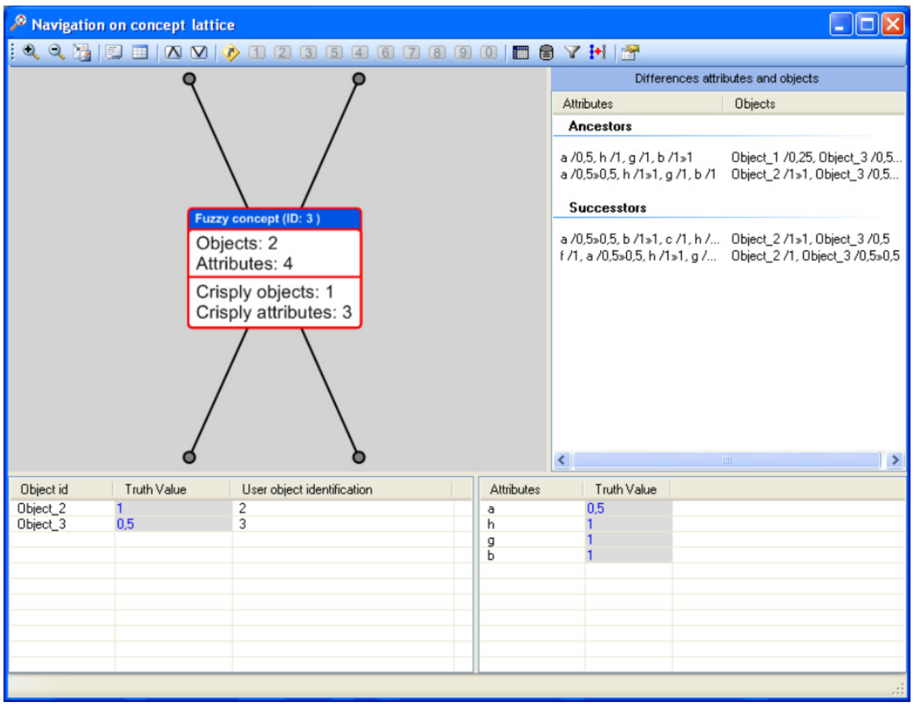

Fig. 3. Navigation in fuzzy concept lattice

The navigation in the concept lattice needs the calculation of the current concept and its neighbors only. This calculation is relatively fast and does not depend on the size of the whole concept lattice. Due to this fact the navigation proceeds on-line and the user can modify the course of navigation interactively, based on information gained. The user can also specify additional constraints to be satisfied by formal concepts which are to be presented to him/her.

7 Conclusions

We presented a way formal concept analysis can help in evaluation of questionnaires. The proposed method has been tested on evaluation of IPAQ questionnaire. The method provides an expert with a structures view on the questionnaire data with some elementary statistics and enables the expert to see important relationships in the data.

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