Detecting and Constructing Morphological Tables Using Weakly Structured Data Analysis Results

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Abstract

The principles of constructing morphological tables in morphological analysis method are being discussed. Object uncertainty sources in morphological analysis that are crucial for designing a morphological table are analyzed. Three types of morphological tables are defined and discussed: description of an object, description of an object state, description of an action (event). Classification of characteristic parameter types is introduced. Recommendations for constructing an accurate morphological table, suitable for a modified morphological analysis method, are provided along with supporting justifications.

The techniques for using weakly structured data analysis results, in the form of a knowledge base with a semantic network, to semiautomate morphological table construction are demonstrated. Baseline principles for extracting all three types of morphological table descriptions through interactive processes with a knowledge base are presented and compared. Examples for using the proposed techniques and algorithms are given, with a demonstration of some of their features and shortcomings.

Keywords

Morphological analysis method, morphological tables, scenario analysis, knowledge base, semantic network

1. Introduction

Modified morphological analysis method (MMAM) [1] is a powerful qualitative analysis tool for problems where the objects of research are characterized by imprecise, incomplete, indefinite, indistinct information, and have a vast multitude of potential variants. The term 'object' is used loosely in this context since morphological research often deals with abstract entities such as events, processes, phenomena, and strategies. The method is often applied in scenario analysis, future studies, strategic development fields to describe and study these objects, providing a convenient technique of processing their numerous undefined configurations, and making a decision in conditions of uncertainty [2–4].

The correct, adequate, productive description of an object is critical for success of the morphological study, which is why the morphological table construction is a very important step that provides the conformity of results to the real world. The construction of a morphological table is a creative process which can only be conducted by a human – a system analyst. However, large volume of data in complex multi-parametric tasks often makes this process significantly cumbersome to do manually. The situation is complicated because the MMAM specialist who facilitates the research process may have limited knowledge of the specific field of study, while the experts in the field may not have enough experience to construct a morphological table suitable for the method. The imperfect morphological tables put the reliability of the whole MMAM results into question. Therefore, there is a need to create a semi-automated technique for constructing morphological tables based on the knowledge base of the field of study.

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2. Features of Constructing Morphological Tables

2.1. Main Definitions

A morphological table is the core of both classical morphological analysis method [2–5], and its modification [1]. Let us introduce the main definitions we use when working with MMAM:

Definition 1. A *characteristic parameter* $F_i, i \in \overline{1,N}$ of the object of morphological research is a property or attribute that can be used for classification of the variety of objects of the given type.

There are virtually infinite characteristic parameters that can be attributed to any given type of object; the selection of characteristic parameters depends on the task, the field of research, and the desired level of detail. Typically, morphological analysis problems use 8-10 characteristic parameters. Larger numbers can create unwieldy tables, which may need to be broken down into separate entities and arranged as a network of morphological tables [6]. Thus, a reasonable selection of characteristic parameters for an object is an important task.

Definition 2. *Alternatives* $a_j^{(i)}, j \in \overline{1,n_i}$ of a characteristic parameter F_i of the object of morphological research are the mutually exclusive alternative states or values of the respective characteristic parameter.

Definition 3. A *morphological table* (MT) is the set of characteristic parameters $F_i, i \in \overline{1,N}$ of an object, each parameter is described by a set of possible alternatives $a_j^{(i)}, j \in \overline{1,n_i}$.

Definition 4. A *configuration s* of a morphological table is a set containing exactly one alternative for each of the MT's characteristic parameters: $s = \{a_{j_1}^{(1)}, a_{j_2}^{(2)}, ..., a_{j_N}^{(N)}\}$.

A configuration of a MT describes one possible state from a multitude of potential states of an object defined by its morphological table. A graphic representation of a sample morphological table is given in Table 1. Note that the number of alternatives is usually different for each parameter.

Table 1
A sample morphological table

Parameter 1 (F_1)	Parameter 2 (F_1)	Parameter 3 (F_1)
Alternative 1.1 ($a_1^{(1)}$)	Alternative 2.1 ($a_1^{(2)}$)	Alternative 3.1 ($a_1^{(3)}$)
Alternative 1.2 ($a_2^{(1)}$)	Alternative 2.2 ($a_2^{(2)}$)	Alternative 3.2 ($a_2^{(3)}$)
Alternative 1.3 ($a_3^{(1)}$)	Alternative 2.3 ($a_3^{(2)}$)	Alternative 3.3 ($a_3^{(3)}$)

After constructing the morphological table, the modified morphological analysis method operates with likelihoods of different states of parameters for an object of morphological research, providing a breakdown of alternative and configuration probabilities, taking into account the interdependence between parameters. The procedures of MMAM are described in [1]; however, they are mostly irrelevant to this paper. The morphological table construction process studied in this paper generally suits both the classical morphological method and MMAM, although for the MMAM the problem of adequate MT construction stands much more acutely, since it provides quantifiable results and therefore is more sensitive to input data, compared to the classical morphological analysis which is more an empirical procedure than an exact method of study.

2.2. Sources of Object Uncertainty

To develop automated techniques for extracting morphological tables from a knowledge base, a thorough understanding of the principles of morphological object description is necessary. Let us start with the potential sources of object uncertainty, as they are critical for forming the characteristic parameter pool for an object of morphological study. As mentioned earlier, the object of study must have a large number of potential configurations, and this uncertainty is caused by one of the following factors:

- *The exact information regarding the object's configuration is absent*. As specific values of the object's characteristics are unknown, we have to operate with a whole set of potential values for each of the characteristics, their exact values can only be assumed with some degree of probability. This type of uncertainty can be categorized into two main groups:
    a. *The object of study is considered in the future*. Because of this, the object's characteristics are not yet set. Examples: the state of economy in five years; a planned military operation; the aftermath of a hurricane etc.
    b. *There is no plausible way of obtaining the exact information*. In this case the object itself exists but learning its precise characteristics is either technically, financially, or in other way unreasonable, or even outright impossible. Examples: weather conditions on other planet; geological composure of soil at the pre-project stage of construction; plans of competing organization etc.
- *A totality of some type of an object is considered*. Here, each individual object has defined characteristics. However, as the multitude of these objects is considered, the state of each characteristic parameter becomes uncertain, as different objects have varying characteristics. This type of research is often conducted for some negative events (e.g. traffic accidents, fires, conflicts) to assess the efficiencies of methods that mitigate a multitude of these events, influencing them all with a greater or lesser extent depending on their configuration. Other examples include a company's customers, website visitors, and bank loan cases.
- *The object of morphological study represents a decision*. This is a common type of morphological study present at the second stage of the two-stage morphological analysis [1, 7]. Technically this type of uncertainty reminds the first type, since a decision is something that will be implemented in the future. However, a fundamental difference lies in the internal nature of uncertainty (the decision maker sets the characteristics), unlike the external nature of uncertainty in the first case (the characteristics are set due to some independent factors). It is nearly impossible to automate the building of morphological tables for this type of study, as the characteristic parameters of a decision and their alternatives are a result of a creative process. Since MMAM is a highly universal procedure that can be applied to almost any field of knowledge, it is unlikely that common automation procedures will be useful for formulating decision alternatives. Thus, we will focus on objects of morphological study where uncertainty is caused by the first two types listed above.

2.3. Types of Morphological Descriptions

While morphological studies are very different in field and purpose, the objects of morphological study usually fall into one of only as few as three fundamentally varying categories:

- *Description of an object*. The purpose of such morphological table is to describe a certain material or abstract object, or a system. The uncertainty is inherent in the object itself due to one of the factors listed in Section 2.2. Historically early morphological analysis method applications were concerned with the synthesis of new or improved physical objects or technical systems. This type of description, by itself, has little use, but it is often included as a component in the next two categories.
- *Description of a state*. The purpose of such morphological table is to describe a current or future status of some object or, more likely, a system. The object or the system is usually known, so the uncertainty lies in the states of the object's or the system's variables that describe what exactly is happening with it. An example of such research is a description of the state of the economy in a chosen future time period. The primary parameters of a morphological table that describe a state are the indexes and indicators that characterize the object or system as a whole.
- *Description of an action (event)*. The purpose of such morphological table is to describe a specific action or interaction between objects. The system that serves as the playground for the objects' interaction is usually known; the uncertainty lies in the exact state of the

system (context of the event), the interacting objects' description, and the characteristics of the event itself. The examples for this type of study include traffic accidents or variants of introducing a new product to the market.

This classification is important, as it sets which entity in the knowledge base is generative for the morphological table. While the third type (description of an action) is by far the most common in MMAM studies, we will consider all three types of description for the extraction from a knowledge base, since the first two types are often present as simplified subtasks in the third type.

2.4. Types of Characteristic Parameters

Another important step in understanding the MT construction is the classification of characteristic parameter types, as it determines what exactly should be extracted from the knowledge base. A list of typical characteristic parameters includes these:

1. Dichotomous ("yes"/"no", "present"/"absent") – the characteristic parameters that describe the presence or absence of a certain element or a feature in an object, or an answer to a binary logical question regarding the object. Parameters like these are also necessary when emulating a parameter with multiple-choice alternatives: for example, a characteristic parameter "Does the client have a pet?", with alternatives "None", "Cat", "Dog", "Hamster" is incorrect, as it includes mutually non-exclusive alternatives (see Section 2.5); this parameter should be broken into three dichotomous paramters ("Does the client have a cat?", "Does the client have a dog?", "Does the client have a hamster?").
2. Quantitative (ordinal) – the characteristic parameters that represent an object's attribute which can be described by a value or an indicator. Sub-ranges of this value comprise the alternatives of such parameter.

   This type of parameter can be divided into subtypes based on limitations:
   a. Limited – the range for the value is limited on both ends (percentage, probability etc.);
   b. Unlimited – the range for the value is unlimited at least on one edge (time, profit, quantity etc.).

   Also, this type of parameters can be divided into subtypes by representation:
   a. Numerical – the alternatives are represented as sub-ranges «... to ...». The procedure of forming rational sub-ranges is often a non-trivial task. Generally a good set of sub-ranges covers values that are sufficiently different from each other; sometimes these sub-ranges can be found in normative documents in the research field;
   b. Verbal – the value of the alternative is described verbally, which is often convenient for non-physical indicators (e.g. customer satisfaction), or in cases when the exact ranges are impossible or inappropriate to specify (alternatives are defined, for example, as "very small", "small", "average", "large", "very large");
   c. Comparative – the value is compared verbally to a certain value, which can be a reference, an average or an expected value (e.g. "less than average", "average", "more than average").
3. Qualitative (nominal) – the alternatives of parameters like these are fundamentally different from quantitative parameters, and unlike quantitative parameters, their comparative relations cannot be established.

2.5. Rules for Morphological Tables

To properly apply the MMAM procedure, some rules of MT construction should be followed:

- *relevance of parameters* – a characteristic parameter should be interdependent with at least one other parameter (within the level of detail chosen for the problem). This means that the cross-consistency matrix [1] links at least one of the alternatives of this parameter to another parameter. While this rule is not strictly necessary, ignoring it may create an independent parameter that has no influence on the result and, accordingly, provides no benefit to the research. However, its presence may increase the workload on experts and analysts and complicate the computational procedure;

- *mutually exclusive alternatives* – as the MMAM algorithms are based on the Bayesian probability apparatus, the states of a single parameter should be mutually inconsistent. If this is not the case, the set of parameters or their alternatives should be redefined to achieve mutual exclusiveness;
- *complete set of alternatives* – each parameter should have a complete set of alternatives, so that the appearance of one of the parameter's alternatives becomes a guaranteed event. If it is impossible or inconvenient to describe all the possible states of a parameter, an alternative 'Other' should be added to the set. If the selection of one of the alternatives is not a required event, an alternative "None"/"Not necessary" should be added. More details about the completeness of the set of alternatives are provided in [8], along with methods for detecting and handling cases of incomplete alternative sets.

3. Morphological Table Extraction

The first step of the foresight process [9, 10] usually includes weakly structured data (i.e. text) analysis. As a result of this analysis, often paired with expert questioning, a knowledge base is formed, containing ontologies and semantic networks [11, 12]. These structures describing the relations between entities using "is a", "part of" relations, as well as the entities' attributes, constitute the basis for semi-automated morphological table extraction. Let us describe the proposed extraction procedures step by step starting with the more straightforward ones.

3.1. Extracting Morphological Description of an Object

The easiest element to extract from a semantic network is the morphological description of an object. From the knowledge base's point of view, the morphological table structure can have the following elements:

1. Parameter – a classification of the object by some slice, its alternatives – object's sub-classes in this slice ("is a" relation);
2. Parameter – a characteristic of an object (attribute), its alternatives – values or sub-ranges of this characteristic;
3. Pp. 1–3 for constituents of an object ("part of" relation).

Therefore, the morphological table construction is performed recursively, with the recursion depth tailored to fit the research task. Let us consider an example of a semantic table fragment (Figure 1), and a corresponding morphological table (Table 2).

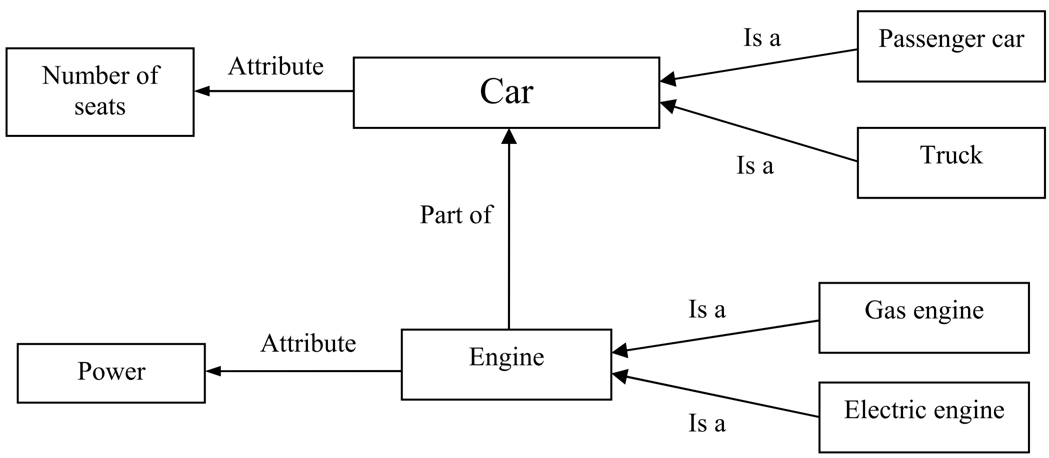

Figure 1: A semantic network fragment related to the node "Car"

Table 2
A constructed morphological table for an object “Car”

Type	Number of seats	Engine type	Engine power
Passenger car	2	Gas engine	Less than 100 hp
Truck	3	Electric engine	100–200 hp
	4		200–400 hp
	More than 4		More than 400 hp

The process of constructing a morphological table is performed in an interactive mode between the analyst and the knowledge base:

1. The analyst selects a generative node for the morphological table in the knowledge base.
2. The system searches for and suggests the object’s sub-classes. The analyst, if deems necessary, groups the sub-classes into one or more characteristic parameters.
3. The system searches for and suggests the object’s attributes. The analyst, if deems an attribute is suitable for a morphological table, forms a parameter from it, creating a pool of its values or sub-ranges as the alternatives of this parameter.
4. The system suggests the object’s constituents one by one. The analyst, if deems necessary, performs steps 2–4 for this new entity. If the presence or absence of this constituent part is important by itself, a dichotomous parameter may be added to reflect this.

The procedure continues until the suggestion pool is depleted.

3.2. Extracting Morphological Description of an Object State

The primary objective of this morphological table is to describe the most important indicators of the object itself and the related tangible objects. The primary highlighted groups of parameters here consist of the following:

1. The indicators and characteristics of the object of study. The alternatives for these indicators are defined in one of the forms described in Section 2.4.
2. The indicators and characteristics of the objects related to the object or system of study. Technically these are the description of their states, so this procedure can also be viewed as recursive. The related objects may include the subsystems of the object, the super-systems of an object (defining the external influence, i.e., context), and the related objects or systems of the same level (partners, competitors, other actors that affect the state of the object of study). For example, when describing the state of a commercial company, the selected parameters may be the performance indicators of its departments; the national economy indicators; the actions by the competing companies.
3. The descriptions of the related objects (if applicable, see below).

Therefore, the morphological table describes the situation that is inherent to both the object or system itself (internal characteristics and indicators) and its environment or context (external characteristics and indicators). Complex problems with a high level of detail may require morphological tables that are too large to manage. In such cases, it is reasonable to break them down into multiple tables and establish the dependencies between them, forming a network of morphological tables [6]. The description of external factors is particularly noteworthy since it can typically be transferred to another morphological table, forming a typical two-stage MMAM procedure [1, 7].

System description state may contain objects that are included in a morphological table using the object description extraction procedure previously described. For example, the state of a commercial company may depend on the product characteristics it decides to manufacture. Then, the product description itself becomes a part of the morphological table for the company's state.

It is essential to note that the generative node for this type of description is very similar to the previous case described in Section 3.1. However, the procedure for extracting a morphological table differs somewhat, as the classification of the object's type becomes irrelevant, and its possible composition details are only relevant in the sense of its constituent's states. This occurs because the object or system of study has no uncertainty. For instance, if we study the future state of our specific company, we do not need to include information that companies may be divided into large, medium, and small enterprises, or that they may have various departments. We know the exact classification result and the correct structure of our company, so most of the steps described in Section 3.1 are meaningless in this case.

3.3. Extracting Morphological Description of an Action

This is the most complex type of description to extract from a knowledge base, as it often combines several related objects or systems, uncertain both in type and state. The action (which will often be more accurately called an event) itself may have different classifications, and it involves at least one, and usually more interacting objects. The parameters that need to be specified for the morphological table are the following:

1. The characteristics and sub-classes of the studied action (event). From the semantic structure's point of view the action here is considered an object, constituting a generative node.
2. The descriptions of relevant (involved) objects.
3. The descriptions of the relevant (involved) objects' states.
4. The description of the state of the system which is the playground for an event (i.e. context).
5. The causes and reasons for the event (if applicable).

The extraction of the first four groups of parameters is covered in the previous sections, as they represent either a description of object (pp. 1, 2), or a description of an object state (pp. 3, 4).

The initial, generative node in the semantic table for this type of description is the node that refers to the action (or event) itself. For example, if traffic accidents are considered, a classification of them may be acquired from the analysis of texts (news, social media fragments, normative documents), and this classification becomes the base for a characteristic parameter, e.g.: a collision with a stationary object; a collision of two or more vehicles; a running-down accident; a vehicle failure.

Each action or event involves at least one object – the actor. Often, more objects are involved, although their detailed morphological description is not always necessary. Sometimes, just one classification parameter is enough. The state of the related objects may also be important. Taking again the example of traffic accidents – the car that caused the accident, and its driver are obviously involved objects which may be described more in detail for the morphological research; however, a lot of possible classification parameters may become irrelevant depending on the reasons for the study. For a social study, the driver's attributes (e.g. gender, age etc.) may be relevant; but on the other hand, if the study concerns only the road safety, then most of these parameters become irrelevant, while the driver's mental state may be important (e.g. whether the driver is drunk).

The description of the state of the system which is the playground for an event is especially valuable, as it gives the circumstances (context) of the event. Sometimes there are several super-systems which are relevant for the study: for example, a traffic accident happens in the city's traffic system (defining the place: for example, crossroads, road section, bridge, tunnel etc.), but also it is viewed in the natural system, which is described by weather, time of day.

The cause/reason parameters are not always present in morphological tables for actions/events (for example, natural phenomena do not need these parameters). But if they are necessary, they usually become the most difficult to extract, as naturally they are not present in semantic networks, at least not explicitly. The potential methods of semi-automated search for these parameters include:

- Applying specially adjusted text analysis procedures aimed at cause extraction. As the presence of knowledge base implies that some analysis of weakly structured data was already done, the search for reasons may require additional handcrafted procedures which work best if the reason list is already at least partly imagined – sometimes making the text analysis a redundant step. It does, however, provide insight into their likelihoods, which may be useful for automated initial assessment.

- If MMAM is part of a more general foresight procedure, it is possible that SWOT analysis was conducted for the super-system, or the involved objects. Detected weaknesses and threats are very likely causes of undesirable events.
- Similarly, if Bayesian network methods were utilized in the study, causes often could be extracted from those.

Let us demonstrate some principles of the following approach on the morphological classification of clients' debts on loans, using a fragment of a semantic network shown on Figure 2.

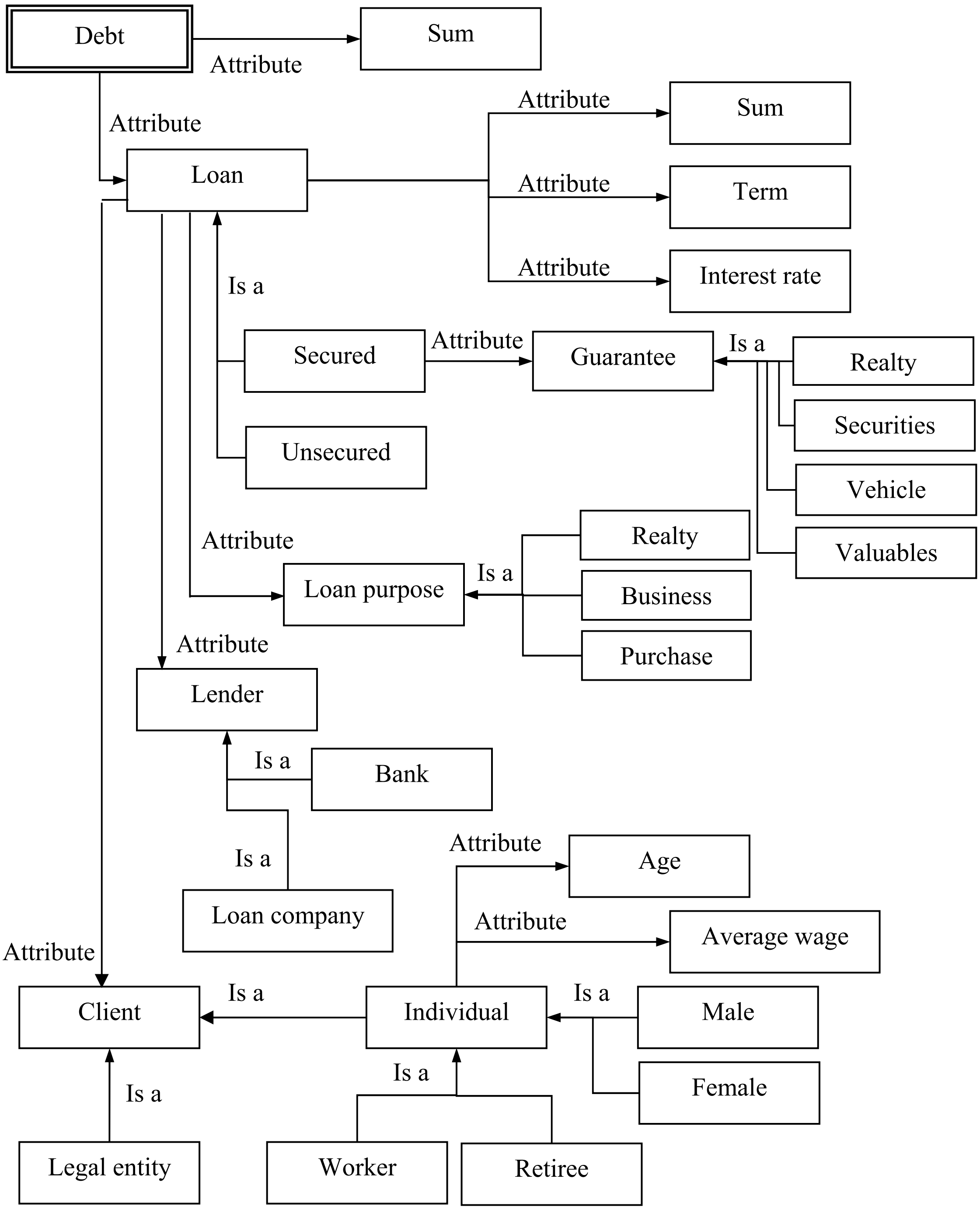

Figure 2: A limited semantic network fragment related to the node "Loan debt"

Starting with the node "Debt" we extract the parameter based on its attribute:

1. Debt sum (sub-ranges). The exact alternatives for ordinal parameters here and further will not be specified, since they are not the point of the example.

Next, we move to the node 'Loan' and extract the following parameters based on its numerical attributes:

2. Loan sum (sub-ranges).
3. Loan term (sub-ranges).
4. Loan interest rate (sub-ranges).

This node also has a number of affiliated nodes which also may become the base for morphological parameters. A parameter is based on the classification of loans:

5. Loan type (secured/unsecured).

If we further study the “secured loan” node, we can classify the loans further by guarantee type and add one more parameter:

6. Guarantee type (realty, securities, vehicle, valuables).

A discrepancy can be noticed here: If parameters 5 and 6 are separate, then the "unsecured" alternative must be paired with a guarantee type, creating a contradiction. This is fixed either by adding an alternative “None” to parameter 6, and then defining the interdependency between parameters within a cross-consistency matrix, or in this case a simpler way will be to combine both parameters into parameter 5a:

5a. Loan type (guaranteed by realty, guaranteed by securities, guaranteed by vehicle, guaranteed by valuables, unsecured).

A related node “Loan purpose” creates another classification:

7. Loan purpose (realty, business, purchase, unspecified).

An alternative “unspecified” was added to the list of alternatives. Generally, each classification that results in a qualitative characteristic parameter should be studied to determine if a variant of 'None' or 'Other' alternatives needs to be added to provide completeness of the alternative set (see Section 2.5).

One more classification can be added from the “Lender” node:

8. Lender (bank, loan company).

However, this parameter only makes sense if an uncertainty is related to the lender. If a certain bank studies the problem of the loan debts in its portfolio, then this parameter is meaningless. On the other hand, if the research is made by some financial monitoring or law-making entity that studies the whole credit system, then the parameter makes sense. Of course, the nodes “Bank” and “Loan company” are rich semantic nodes by themselves, and can be further broken down by several classifications and attribute values if needed.

Another node related to “Loan”, is “Client”, producing one more characteristic parameter:

9. Client type (individual, legal entity).

Next, the “Individual” node has quite a lot of semantic relations, some of which may have value in this morphological research (age, average wage, classification by gender, classification by working status etc.). Again, those parameters will be meaningless if the alternative “legal entity” is selected in parameter 9. This problem is harder to circumvent than the same problem with parameters 5 and 6, since individuals and legal entities have completely different non-intersecting classifications, and trying to include them in a single consistent morphological table can be quite difficult. But in this case, it is probably not needed at all, as the problems of credit debts of individuals and legal entities are separate cases that require different approaches, remedies and bear different consequences. Trying to mix these studies into a single morphological table is counterproductive. So, the MMAM specialist in this case should follow only one branch in a semantic network, taking the further classification parameters from there.

As we can see, even such a small, limited network fragment produces more than 10 characteristic parameters for a morphological table. And as was stated in the process, a lot of these nodes are also semantically rich and can be further ramified. Automated semantic network crawl can produce dozens of parameters, so the analyst’s task is to trim the search on the nodes that do not need to be further detailed. The example also showed that the automated parameter extraction requires some manual adjustments by the morphological analysis specialist.

The given network does not allow to extract the “Reason for debt” parameter, which probably ought to be included, as it is critical for the study, and moreover, is interdependent with many of the other extracted parameters. In this case we have either to refer to analyst's or experts' knowledge, or to use one of the techniques proposed above.

4. Conclusion

The presented techniques and algorithms offer a convenient method for creating a draft morphological table interactively with a knowledge base. Since the modified morphological analysis method is a highly versatile tool, its research objects differ substantially, necessitating slightly different extraction procedures that work with varying degrees of success with different description types. Although descriptions of an object or its state can be extracted almost entirely from a high-quality semantic network, a description of an action or event may require additional input from an analyst or experts in the field of research.

The results of extracting morphological tables often require additional review from a morphological specialist. However, a correctly implemented extraction procedure provides a thorough analysis, ensuring that no critical characteristics are omitted in the morphological research. Overall, the proposed technique is a valuable asset for setting up morphological research for complex multi-factor problems related to decision-making, scenario analysis, and strategic planning.

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