Attributes, scales and measures for knowledge representation and processing models

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***Abstract*—The system of measures and features for scaling and ranking knowledge processing phenomena is considered. Some types of measurement scales were generalized. Such attributes and measures as key elements of the knowledge representation language and the distance between the texts of such languages were considered together with others combining means of the set theory, ordered sets and the theory of formal languages. The proposed concepts are towards the integration of knowledge processing models, including artificial neural networks.**

***Keywords*—semantic networks, knowledge representation, knowledge processing, scales, features, measure, measurement**

I. Introduction

The purpose of the article is to get answers to the following questions:

- What are the types of scales [1], [2] are and their features (attributes)?
- How complex is the measurement scale for an arbitrary set of features?
- What features can be mined from knowledge representation [3], [4] models?
- What features can be mined from information processing [3]–[6] models and knowledge processing phenomena [3], [4], [7]?

Objects are designated by signs in the order of perception processes for the representation of knowledge. The becoming of signs in these processes allows to investigate the properties and attributes of objects.

II. Measurement scales and features

From a mathematical point of view, a feature is defined by a function that is defined on a set of objects and allows for each of them to get a particular value of the feature. Each feature with relational structures [4] or models on a set of objects and a set of values of this feature form a scale. The relational structure or model allows to structure a set of objects or a set of values of the feature. Depending on the complexity, scales vary by types. The complexity of the scale is determined by power of the model carrier set and its structure. One of the ways to set the scale structure is to order the set of values of the feature. In this case, the signature of the corresponding model contains a binary relation of a reflexive order [8], which has the properties of antisymmetry and transitivity. If the order is trivial (has the property of symmetry), then the scale is called nominal. Another important type of scale with an order relation is the (linear) ordinal scale, the order on which has the property of linearity. An important type of scales and features (attributes) and are quantitative scales and features which values are numbers. Often these are scales with a linear order. Quantitative attributes (measures) allow measurements. Within the scale, the values of one feature can be considered as objects that may have their own features. Thus, a sequence of scales can be built, reflecting one set of features and their models to the next ones. One of the quantitative scales in such sequences and the corresponding features are the scale and the feature that measures the number (power of the set) of the mapped objects for any value of the feature in another scale. The model of feature values in this scale is in one-to-one correspondence with a well -ordered set of cardinal numbers. Such a feature as modishness is associated with this scale and order on it:

$$\sup_{\gamma\in\Sigma}\left(\left|\arg_{\chi\in\Sigma}\left(\left\langle s\left(\chi\right),s\left(\gamma\right)\right\rangle\right)\right|\right) \tag{1}$$

Here arg means a function that returns a subset of objects of a set Σ, the value of one attribute α of which is equal to the value of another attribute β

$$\arg_{\gamma\in\Sigma}\left(\left\langle \alpha\left(\gamma\right),\beta\left(\gamma\right)\right\rangle\right) = \\ = \left\{\gamma\left|\left(\gamma\in\Sigma\right)\wedge\left(\alpha\left(\gamma\right)=\beta\left(\gamma\right)\right)\right.\right\} \tag{2}$$

Under the mods are understood the elements of the set of objects of the primary scale, the feature values of which are not less than modishness. If there are no such elements, the modishness is external, otherwise it is internal.

$$\arg_{\zeta\in\Sigma}\left(\left\langle\left|\arg_{\chi\in\Sigma}\left(\left\langle s\left(\chi\right),s\left(\zeta\right)\right\rangle\right)\right|,\sup_{\gamma\in\Sigma}\left(\left|\arg_{\chi\in\Sigma}\left(\left\langle s\left(\chi\right),s\left(\gamma\right)\right\rangle\right)\right|\right)\right\rangle\right) \tag{3}$$

The projection (mapping) of the original scale on a non-empty set of modes forms a new scale (subscale), all objects in which are modes.

$$\max_{\chi\in\Sigma}\left(\alpha\left(\chi\right)\right)=\max\left(\left\{\alpha\left(\chi\right)\left|\chi\in\Sigma\right.\right\}\right) \tag{4}$$

It is natural to distinguish scales and attributes by the number of values of a attribute in a scale, according to which attributes and scales can be finite, including binary attributes and scales, scales with n values, and infinite ones. In addition to modes in scales with an order relation, you can select the medians, the set of all medians in the scale forms a medianoid.

Section φ on a scale ψ:

$$\begin{gathered} O\left(\langle\varphi,\psi\rangle\right) = \\ = \left(\forall\chi\left(\forall\gamma\left(\left(\langle\chi,\gamma\rangle\in\varphi\right)\to\left(\neg\left(\psi\left(\chi\right)\geq\psi\left(\gamma\right)\right)\right)\right)\right)\right) \end{gathered} \tag{5}$$

The lower sections of the set Σ on the scale ψ:

$$\begin{gathered} LS\left(\langle\Sigma,\psi\rangle\right) = \\ = \left\{\langle\alpha,\beta\rangle \middle| \left(\begin{array}{c} \left(O\left(\langle\alpha\times\beta,\psi\rangle\right)\wedge\left(\beta\subset\Sigma\right)\right)\wedge \\ \left(\left(\alpha=\Sigma/\beta\right)\wedge\left(|\alpha|\leq|\beta|\right)\right) \end{array}\right)\right\} \end{gathered} \tag{6}$$

$$\begin{gathered} LS\left(\langle\Sigma,\psi\rangle\right) = \\ = \left\{\langle\alpha,\beta\rangle \middle| \left(\begin{array}{c} \left(O\left(\langle\alpha\times\beta,\psi\rangle\right)\wedge\left(\beta\subset\Sigma\right)\right)\wedge \\ \left(\left(\alpha=\Sigma/\beta\right)\wedge\left(|\alpha|\leq|\beta|\right)\right) \end{array}\right)\right\} \end{gathered} \tag{7}$$

The upper sections of the set Σ on the scale ψ:

$$\begin{gathered} US\left(\langle\Sigma,\psi\rangle\right) = \\ = \left\{\langle\alpha,\beta\rangle \middle| \left(\begin{array}{c} \left(O\left(\langle\alpha\times\beta,\psi\rangle\right)\wedge\left(\alpha\subset\Sigma\right)\right)\wedge \\ \left(\left(\beta=\Sigma/\alpha\right)\wedge\left(|\alpha|\geq|\beta|\right)\right) \end{array}\right)\right\} \end{gathered} \tag{8}$$

Embedding sections φ:

$$\begin{gathered} C\left(\varphi\right) = \\ = \left\{\langle\langle\alpha,\beta\rangle,\langle\gamma,\delta\rangle\rangle \middle| \left(\begin{array}{c} \left(\left(\alpha\subseteq\gamma\right)\wedge\left(\delta\subseteq\beta\right)\right)\wedge \\ \left(\langle\langle\alpha,\beta\rangle,\langle\gamma,\delta\rangle\rangle\in\varphi\right) \end{array}\right)\right\} \end{gathered} \tag{9}$$

Medianoid embedding sections φ:

$$\begin{gathered} M\left(\varphi\right) = \\ = \left\{\mu \middle| \left(\forall\beta\left(\forall\gamma \begin{array}{c} \left(\exists\alpha\left(\exists\delta\left(\langle\langle\alpha,\beta\rangle,\langle\gamma,\delta\rangle\rangle\in\varphi\right)\right)\right) \\ \to\left(\left(\mu\in\beta\right)\sim\left(\mu\in\gamma\right)\right) \end{array}\right)\right)\right\} \end{gathered} \tag{10}$$

Medianoid set Σ on the scale φ:

$$\begin{gathered} M(C((LS\left(\langle\Sigma,\varphi\rangle\right)/US\left(\langle\Sigma,\varphi\rangle\right))\times \\ (US\left(\langle\Sigma,\varphi\rangle\right)/LS\left(\langle\Sigma,\varphi\rangle\right)))) \end{gathered} \tag{11}$$

A scale [1] is called quantitative if the values of the attribute in it are numbers. If the numbers are real, then the scale will be called charged [9], [10]. A charged scale, the numbers in which are non-negative, will be called the measured scale [1], [2]. The feature values in the scale can also be elements of a module or a vector space. If a pseudometric or metric is defined on a set of values of a feature in a scale, then the corresponding scales will be called pseudometric or metric [2], [13]. For them, the concept of medoid can be defined depending on the measures α and β.

$$\arg_{\zeta\in\Sigma}\left(\left\langle\alpha\left(\langle\Sigma,\zeta\rangle\right),\inf_{\gamma\in\Sigma}\left(\beta\left(\langle\Sigma,\gamma\rangle\right)\right)\right\rangle\right) \tag{12}$$

The measure β is usually the same as α, which has the following form:

$$\alpha\left(\langle\Sigma,\gamma\rangle\right) = \sum_{\chi\in\Sigma}\mu\left(\langle\chi,\gamma\rangle\right) \tag{13}$$

a measure can taked as $\alpha\left(\langle\Sigma,\gamma\rangle\right) = \sup_{\chi\in\Sigma}\left(\mu\left(\langle\chi,\gamma\rangle\right)\right)$ or $\alpha\left(\langle\Sigma,\gamma\rangle\right) = |L\left(\langle\Sigma,\gamma\rangle\right)|$, where L is the function of the remote set of a point χ in the set Σ:

$$\begin{gathered} L\left(\langle\Sigma,\chi\rangle\right) = \\ = \left\{\gamma\left|\left(\left(\sigma\in S\left(\langle\Sigma,\chi,\gamma\rangle\right)\right)\wedge\left(\left(\sigma\geq 0\right)\wedge\left(\gamma\in\Sigma\right)\right)\right)\right.\right\} \end{gathered} \tag{14}$$

and S is the function of distancing the point χ from the point γ on the set Σ:

$$\begin{gathered} S\left(\langle\Sigma,\chi,\gamma\rangle\right) = \\ = \left\{\sigma \middle| \left(\sigma=\sum_{\zeta\in\Sigma}\left(\mu\left(\langle\chi,\zeta\rangle\right)-\mu\left(\langle\gamma,\zeta\rangle\right)\right)\right)\right\} \end{gathered} \tag{15}$$

Also, a medoid can be selected based on distancing at

$$\beta\left(\langle\Sigma,\gamma\rangle\right) = 1. \tag{16}$$

When considering an arbitrary set of features defined on a set of objects, it is possible to move from this set to a single multiple feature according to the scheme:

$$\left|\mathop{\times}_{i\in\Gamma}\left({P_i}^O\right)\right| = \left|\left(\mathop{\times}_{i\in\Gamma}P_i\right)^O\right| \tag{17}$$

There is possible reverse transition. If the source features are binary, then the multiple feature has a range of power 2. Any n-ary feature can be presented as a multiple feature with the range of the same power $2^{|\Gamma|}$. It should be noted that a countable number of binary features for a finite set of objects corresponds to an element of uncountable set of multiple features. The finite multiple features of binary features and a set of objects generate the formal context [11] for which the lattice of formal concepts [12] can be constructed. The corresponding indicator sets in rows or columns of the formal context can be interpreted as elements of a vector space [13] of finite dimension over a finite field F_2 [14]. Thus, the lattice can be extended to a vector space. The same is true for any n ary features when n is an integer power of a prime number. Thus, a finite formal context can be spliced onto a set of finite vector spaces (a pseudometric and pseudonorm can be introduced).

The graph of the lattice of formal concepts [11], [15] can be considered as the carrier of a metric space. Also, a finite formal context can be mapped into a set of finite modules that can be mapped to a non-infinite module of integers [16].

III. Knowledge representation languages, its texts and features

Languages [17], [18] will be called straight languages iff each text of which does not contain its components more than once. By analogy with symmetric (symmetrical) languages [3], languages containing as strings all lines that are the result of cyclic permutations [19] of any other text of this language will be called cyclic languages. In a similar way, inverted (palindromic), dihedral and alternating [19] (antisymmetric) language are considered.

In processes and phenomena, frequently occurring fragments (sub-phenomens and substrings) are distinguished. Frequent repetitions of adjacent identified phenomena are recorded and fixed as meta-events. The ratio of the presence or absence of a fragment in a phenomenon is an attribute. Each designation is associating with a coordinate vector in an infinite-dimensional space with a metric introduced on the set of these vectors.

On the set of texts such features as key elements are investigated. Consider the texts of some sublanguage L of the language U in the alphabet A. Let's set text τ transformation into functional form:

$$\varphi(\tau) = \{\langle i, \tau_i\rangle \,|(i \le \dim(\{\tau\})) \wedge (i \in N)\} \quad (18)$$

Least powerful sets:

$$\begin{array}{l} N(\langle\gamma,\chi\rangle) = (\forall\alpha(\forall\beta(((\{\alpha,\beta\} \subseteq \chi) \wedge (\alpha \subset \beta)) \rightarrow \\ (\exists\delta((\delta \in \gamma) \wedge (\delta \subseteq \alpha) \wedge (|\alpha/\delta| = |\beta/\alpha|)))))) \\ L(\langle\gamma,\chi\rangle) = (\chi \subseteq \gamma) \wedge N(\langle\gamma,\chi\rangle) \wedge \\ (\forall\delta((\delta \in \gamma) \rightarrow (\exists\alpha((\alpha \in \chi) \wedge (\alpha \subseteq \delta))))) \end{array} \quad (19)$$

Set of combinations of ε-covering σ-elements:

$$\begin{array}{l} D(\langle\alpha,\gamma,\varepsilon,\sigma\rangle) = (\forall\chi(\forall\lambda(((\chi \in \lambda) \wedge (\lambda \in \gamma)) \sim \\ \left(\exists\beta\left((\beta \subseteq \alpha) \wedge (|\beta| \ge \varepsilon) \wedge \left(\{\chi\} \subseteq \sigma \cap \bigcap_{\delta\in\beta}\delta\right)\right)\right)))) \end{array} \quad (20)$$

Key rank (φ-rank):

$$\begin{array}{l} X(\langle\alpha,\beta,\gamma,\sigma,\varphi\rangle) = \\ \max(\{\varepsilon\,|(D(\langle\alpha,\gamma,\varepsilon,\sigma\rangle) \wedge \varphi(\langle\alpha,\beta,\gamma\rangle))\}) \end{array} \quad (21)$$

Extra key combinations (φ-combinations):

$$\begin{array}{l} F(\langle\alpha,\beta,\sigma,\varphi\rangle) = \{\chi|\exists\gamma(L(\langle\gamma,\chi\rangle) \wedge \\ D(\langle\alpha,\gamma,X(\langle\alpha,\beta,\gamma,\sigma,\varphi\rangle),\sigma\rangle) \wedge \varphi(\langle\alpha,\beta,\gamma\rangle))\} \end{array} \quad (22)$$

Splitting combinations:

$$\begin{array}{l} E(\langle\alpha,\gamma\rangle) = (\forall\chi((\chi \in \alpha) \rightarrow (\exists\lambda((\lambda \in \gamma) \wedge (\lambda \subseteq \chi))))) \\ I(\langle\beta,\gamma\rangle) = (\forall\chi(\forall\lambda(((\chi \in \beta) \wedge (\lambda \in \gamma)) \rightarrow (\neg(\lambda \subseteq \chi))))) \\ T(\langle\alpha,\beta,\gamma\rangle) = E(\langle\alpha,\gamma\rangle) \wedge I(\langle\beta,\gamma\rangle) \end{array} \quad (23)$$

Key combinations (φ-combinations):

$$\begin{array}{l} R(\langle\alpha,\beta,\sigma,\varphi\rangle) = \\ \{\gamma\,|(\gamma \in F(\langle\alpha,\beta,\sigma,\varphi\rangle)) \wedge (\neg G(\langle\alpha,\beta,\sigma,\varphi,\gamma\rangle))\} \end{array} \quad (24)$$

where

$$\begin{array}{l} G(\langle\alpha,\beta,\sigma,\varphi,\gamma\rangle) = (\exists\chi(\exists\lambda(\chi \in \lambda) \wedge \\ (\lambda \in \gamma) \wedge (\{\lambda/\{\chi\}\} \cup (\gamma/\{\lambda\}) \in F(\langle\alpha,\beta,\sigma,\varphi\rangle))))) \end{array} \quad (25)$$

Key schemes (φ-schemes):

$$S(\langle\alpha,\beta,\sigma,\varphi\rangle) = \bigcup_{\gamma\in R(\langle\alpha,\beta,\sigma,\varphi\rangle)} \gamma \quad (26)$$

External key schemes (φ-schemes):

$$\begin{array}{l} SE(\langle\alpha,\beta,\sigma,\varphi\rangle) = \{\delta|\,(\delta \in S(\langle\alpha,\beta,\sigma,\varphi\rangle)) \wedge \\ (\forall\chi((\chi \in \beta) \rightarrow (\chi \cap \delta = \emptyset)))\} \end{array} \quad (27)$$

Internal key schemes (φ-schemes):

$$\begin{array}{l} SI(\langle\alpha,\beta,\sigma,\varphi\rangle) = \{\chi \cap \delta|\,(\delta \in S(\langle\alpha,\beta,\sigma,\varphi\rangle)) \wedge \\ ((\chi \in \beta) \wedge (\emptyset \subset \chi \cap \delta))\} \end{array} \quad (28)$$

Let define

$$\begin{array}{l} W(\Gamma) = \{\lambda|(\exists\chi((\chi \in \Gamma) \wedge (\forall\iota((\iota \in N) \rightarrow \\ \left(\lambda(\iota) = \chi\left(\iota + \min\left(\bigcup_{\gamma\in\chi}\{\gamma_1\}\right) - \min(N)\right)\right)))))\} \end{array} \quad (29)$$

and

$$\begin{array}{l} U(\Gamma) = \bigcup_{\gamma\in\Gamma}\gamma \\ V(\Gamma) = \bigcup_{\gamma\in\Gamma}\{\gamma_2\} \end{array} \quad (30)$$

Key phrases (φ-phrases):

$$P(\tau) = W(S(\tau)) \quad (31)$$

where $\tau = \langle U/L, L, A, T\rangle$ with universal language U, selected (sub)language L with alphabet A and predicate T.

External (PE) and internal (PI) key phrases are defined as follows:

$$\begin{array}{l} PE(\tau) = W(SE(\tau)) \\ PI(\tau) = W(SI(\tau)) \end{array} \quad (32)$$

Key components (C) and its external (CE) and internal (CI) ones are defined in similar way:

$$\begin{array}{l} C(\tau) = U(S(\tau)) \\ CE(\tau) = U(SE(\tau)) \\ CI(\tau) = U(SI(\tau)) \end{array} \quad (33)$$

Finally, key elements (E) as well as external (EE) and internal (EI) components are:

$$\begin{array}{l} E(\tau) = V(C(\tau)) \\ EE(\tau) = V(CE(\tau)) \\ EI(\tau) = V(CI(\tau)) \end{array} \quad (34)$$

Key schemes, phrases, components, elements and their sets, are features of languages [18] and families of phenomena [3]. Other features of texts are: length, period [20], etc. Other features can be obtained by correlating texts of languages and texts in languages obtained by canonization, symmetrization [3], [19], circulation, looping, etc. The investigation of texts and associations with key elements allows to explore the model semantics of these key elements [3].

For comparing texts of languages [17], [18] and phenomena [3], it is possible to use scales of distant vectors, whose components correspond to the number of deleted, added, rearranged, duplicated or merged components of a particular class in the texts. In turn, the norm of distant vectors corresponding to the metric on the metric scale can be calculated using the metric operator. The texts of languages and phenomena are mapped respectively on this scale. These and other attributes correspond to the functions defined on the relations of the knowledge specification model [5].

IV. Formal models and phenomena of knowledge processing

Among the formal information processing models [5], [6], it is possible to distinguish elementary formal information processing models that have only one operation. Any formal information processing model can be reduced to an elementary one, by combining all its operations into one operation of an elementary model. It is possible to investigate the operational semantics of texts of the language representing the states of the formal information processing model in addition of the investigation of model semantics of key elements of this language. In particular, the model set-theoretic semantics is associated with the (implicit) operations of choosing (marking) the notation of a set and searching (marking) of the elements of this set. The study of operational semantics is related to discovering the rules and properties of becoming elements of texts and phenomena. The basis for the study of operational semantics is both the key elements of the language themselves and the multiple features, the distant vectors of their set and averaging between the texts before and after the application of the operation. Other features can be obtained by examining the complements or inversions of the model (models with operations complementing the original operations before the full operation (relation) or inverse them). For comparing formal information processing models [5], [6], [21], projections or the reduction of initial models to elementary formal models of information processing and features defined between them can be used. First of all, it is necessary to find operations that are the smallest symmetric differences of operations isomorphic to the operations of the compared models taking into account the maximum possible one-to-one fusion of the states of these models. Then, it is necessary to choose the one among these operations having the minimal averaging of the set of distant vectors between the texts before the application of this operation and after. This averaging or monotonously (or linearly) dependent on it value can be an analogue of the distant vector between the two models. If the models are not elementary, then they should be supplemented (if it is necessary) with empty operations and divided into one-to-one elementary models with preservation of one-to-one identification of the states so that the averaging of distant vectors between them is minimal. For finite models (finite automata) this problem is solvable.

V. Conclusion

The results of this work allow to generalize the concept of the scale and some of the features defined on them. In accordance with the knowledge specification model [5], an approach is also considered to identify key elements of texts of languages, phenomena and operations, their semantics and metric properties as the basis for scaling and analyzing the attributes of texts of languages and phenomena of information processing models in intelligent systems.

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ПРИЗНАКИ, ШКАЛЫ И МЕРЫ ДЛЯ МОДЕЛЕЙ ПРЕДСТАВЛЕНИЯ И ОБРАБОТКИ ЗНАНИЙ

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Рассмотрена система признаков и мер для шкалирования и ранжирования явлений обработки знаний. Средствами методов теории множеств, упорядоченных множеств и теории формальных языков рассмотрено обобщение шкал некоторых видов, а также впервые приведено формальное описание таких признаков и мер, как ключевые элементы языков представления знаний и метрики на текстах этих языков и моделях обработки информации. Предложенные понятия ориентированы на интеграцию моделей обработки знаний, включая искусственные нейронные сети.

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