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Semantic differential for the twenty-first century: scale relevance and uncertainty entering the semantic space

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Abstract We propose an interval-valued version of the semantic differentiation method originally proposed by Osgood et al. (The measurement of meaning, University of Illinois Press, Chicago, 1957). The semantic differential is a tool for the extraction of attitudes of respondents towards given objects or of the connotative meaning of concepts. Semantic-differential-type scales are also frequently used in social-science research. The proposed generalisation of the original method is better suited for the reflection of perceived scale relevance and provides a possible solution to specific aspects of the concept–scale interaction issue and some other issues recently identified in the literature in connection with the use of semantic differential or semantic-differential-type scales. Lower appropriateness of scales as perceived by the respondents is translated into uncertainty regions and neutral answers can be distinguished from answers where the scale is perceived to be irrelevant. We suggest a modified data collection procedure and describe the calculation of the representation of the attitude towards an object as a point in the semantic space surrounded by an "uncertainty box". The new method introduces uncertainty to the semantic space and allows for a more appropriate reflection of the meaning of concepts, words, etc. in formal models. No restrictions are introduced in terms of the availability of results—standard semantic-differential outputs including the position of objects in the semantic space and

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their semantic distance are available. The new method, however, reflects the uncertainty stemming from linguistic labels of the scale endpoints and from lower perceived appropriateness of the scales in the process.

Keywords Semantic differential · Scale relevance · Concept–scale interaction · Interval-valued · Uncertainty

1 Introduction

The method of semantic differentiation (Osgood et al. 1957) was proposed to identify the connotative meaning or attitudes of individuals towards given objects and it has been frequently used in research concerning attitudes in social psychology and related fields [see e.g. Papendick and Bohner (2017) for a recent study applying the semantic differential in the investigation of stigmatization in rape context]. Shortly after its introduction, semantic differential was adopted also in the field of economics and marketing (Mindak 1961; Ross 1971), sociology (Back et al. 1972) and public opinion measurement (Carter et al. 1968). The use of (and research on) the semantic differential continues in psychology and social sciences until today, see e.g. (Kervyn et al. 2013; Marinelli et al. 2014; Beckmeyer et al. 2017). Also the affective meanings of common language expressions are still being studied using the semantic differential even in large scale—e.g. Mukherjee and Heise (2017) identify the semantic position of almost 1500 concepts in the Bengali language. Recently, semantic differentiation has been applied even in the theory building framework in psychology in the context of reward assessment (Fennell and Baddeley 2013). The use of the semantic differential has also spread outside the social sciences and humanities into the field of information systems (Verhagen et al. 2015) and machine design (Mondragón et al. 2005). The semantic differential and the concept of distance in the semantic space have found their way even to the fuzzy modelling domain (Niskanen 1993) as a basis for the definition of a formal language for fuzzy linguistic reasoning.

Semantic-differential-type scales have become the basis of many clinical methods and psychological assessment tools. These scales are a valuable addition to the psychological measurement toolbox [and complement e.g. the Likert-type scales (Likert 1932)]. Recent psychometric study by Friborg et al. (2006) has even confirmed that in particular settings semantic-differential-type scales outperform Likert-type scales (measurement of positive psychological constructs is considered in their paper).

Several possible problems have been identified in association with the semantic differential (apart from the necessity of its standardization in the given culture/language environment on a representative sample using appropriately constructed pairs of bipolar adjectives), which include the issue of concept–scale interactions and scale relevance (Heise 1969; Weinreich 1958) and the impossibility of expressing ambivalent attitudes (Kaplan 1972). Kulas and Stachowski (2009) also describe the problem of ambiguity of middle-point answers in semantic differential scales, where although middle-point answers should be interpreted as "neutral" answers, they frequently carry the "it depends" interpretation or signify low item clarity. All these problems can, however, be approached from the fuzzy modelling perspective, introducing some sort of uncertainty or ambiguity (or tolerance) in the procedure of semantic differentiation. This paper aims on combining the benefits of semantic differentiation with the mathematical tools for the representation of uncertainty.

In light of the fact that the semantic differential method and semantic-differential-type scales are still being used, despite the possible shortcomings stemming from the simplicity of the original method proposed by Osgood et al. (1957), it seems reasonable to propose a "modernisation" of the method and the scales used within. The introduction of uncertainty to the process can transform the semantic differential and its scales into a tool that will hold up to the current requirements of the research and practice in social sciences, humanities, and even in the clinical practice.

We can also provide a broader context for the investigated topic and link it more closely to formal mathematical models used in social science research. Semantic differentiation and the determination of the position in the semantic space are also closely related to the process of finding appropriate linguistic labels to mathematical objects called linguistic approximation, as pointed out by Stoklasa et al. (2016). Linguistic approximation is based on the idea of finding labels (common language expressions with known meanings usually represented by fuzzy sets) that are the most similar or the closest to the approximated mathematical object (Yager 2004; Stoklasa et al. 2014; Stoklasa 2014). Semantic differentiation can thus provide a needed addition to the family of linguistic approximation methods by its focus on semantics. So far, however, semantic differentiation has not been used in mathematics, possibly due to its crisp nature and due to the issues with scale appropriateness in the input phase.

The conversion of mathematical outputs into the expressions of natural language and the creation of meaningful linguistic summaries of large data sets are topical issues in psychological diagnostics, decision support and also in the research relying on ever-growing data sets. It can be considered an important condition for making the complex analytical methods, that are available nowadays, more convenient to social-science researchers and also accessible to laymen users while minimizing the risk of misinterpretations (Stoklasa 2014; Yager 2004). The transition towards natural language descriptions (e.g. evaluations) usually reflects the value (valency or position of the label in the universe of discourse), and also the uncertainty (generality, imprecision) of the assigned linguistic label.

On the other hand neither of the three dimensions [evaluation (E), potency (P) and activity (A)] defining the semantic space (Osgood et al. 1957) reflects uncertainty in terms of the possible imprecision and ambiguity of the provided answers. It seems that imprecision is not explicitly present in semantic differential. This is not surprising since the notion of fuzzy sets and the focus on uncertainty have been explicitly formulated in formal mathematical models (Zadeh 1965, 1975a, b, c), that is after the introduction of semantic differential and also after the first wave of its critical verification (Fry and Claxton 1971; Heise 1969; Kaplan 1972; Weinreich 1958).

In this paper we suggest a modification of the original semantic differential which can be considered more general, as it allows for the reflection of uncertainty in the process of gathering inputs for the determination of attitudes towards (or the semantic position of) a given concept. We also focus on the issue of concept–scale interaction and allow the respondent to assess the relevance of the scale for the evaluation of the given object. Note, that when a bipolar adjective scale which is assumed to saturate e.g. the evaluation dimension has denotative meaning applied to a given object/concept, its contribution to the evaluation dimension is questionable (see e.g. Osgood et al. 1957, p. 179). We therefore assume, that the scales with denotative meaning are not used unless absolutely necessary. Darnell (1966, p. 107) confirms that the relevance of the scale (or even its polarity) might vary for different objects/concepts being evaluated. Hence even in cases when the scale does not represent the denotative meaning of the object/concept, low perceived relevance of the scale can still be an issue. It might be difficult for the respondents to see the relevance of the scale for the evaluation purpose in some cases. If no (metaphorical) link between the scale and the object/concept that is being assessed can be established by the respondent, then the answer provided by him/her might be arbitrary or very vague in its nature. In these cases of low perceived relevance of the given scale (pair of bipolar adjectives) we suggest a transformation of the information provided by the respondent into an interval of possible values of the given scale. This way the representation of a given object in the semantic space becomes a point with an assigned block of "alternative semantic positions" of the object. We also suggest alternative notions of the distance of such objects in the semantic space.

First we recall the basic concepts of the original semantic differentiation method by Osgood et al. (1957) in the Sect. 2, then we suggest the interval valued form of the semantic differential as a generalization of the original method in the following section. In the same section we suggest a method for the computation of the distance of two objects in the semantic space in the new representation. Finally, we discuss the suggested interval valued semantic differential and its possible applications in the last section.

2 Semantic differential

The semantic differential was introduced by Osgood et al. (1957) as a tool for the measurement of connotative meaning. Although the semantic differential (as a concept or general method for the measurement of attitudes) can be considered a common knowledge in psychology, we will briefly summarize here its basic principles. More specifically we introduce the formal notation for the relevant concepts we are using, specify the representation of the scales and their values and summarize the necessary computational formulas. We are doing so to facilitate easier understanding of the interval-valued alternative of the standard semantic differential proposed in the following section, its idea and its added value.

The basic idea of the standard semantic differential method is the characterization of the given object by a given number of classifications (assessments) of this object on scales represented by pairs of bipolar adjectives (such as good–bad, weak–strong, sour–sweet, etc.). Factor analysis was applied to the results and three significant factors *evaluation* (E), *potency* (P) and *activity* (A) were identified and the factor loadings of the scales to each of these factors have been determined. The three factors define a three-dimensional semantic space. The position of the given object O in the semantic space can be represented by its coordinates $C_O = (E_O, P_O, A_O)$ in the semantic space E–P–A, see Fig. 1. More specifically

$$(E_O, P_O, A_O) = \left(\frac{\sum\limits_{s_i \in S} x_{s_i} f_{s_i}^E}{\sum\limits_{s_i \in S} \left| f_{s_i}^E \right|}, \frac{\sum\limits_{s_i \in S} x_{s_i} f_{s_i}^P}{\sum\limits_{s_i \in S} \left| f_{s_i}^P \right|}, \frac{\sum\limits_{s_i \in S} x_{s_i} f_{s_i}^A}{\sum\limits_{s_i \in S} \left| f_{s_i}^A \right|} \right), \tag{1}$$

where $x_{s_i} \in [-k, k] \subset \mathbb{R}, k > 0$, is the value of the scale s_i specified by the respondent [e.g. Osgood et al. (1957) used discrete numerical scales, i.e. $x_{s_i} \in \{-k, -k+1, \dots, -1, 0, 1, \dots, k-1, k\}$, and $k \in \mathbb{N}$], $f_{s_i}^E, f_{s_i}^P, f_{s_i}^A \in [-1, 1]$ are the factor loadings of the scale x_{s_i} to factors E, P and A respectively and S is the set of scales (bipolar adjectives) used to assess the position of O in the semantic space. Alternatively, intervals of only nonnegative values can be used to represent the evaluation-scale universes, i.e. intervals $[-k, k]$ can be transformed to $[0, 2k]$ simply by shifting the original interval in the positive direction by k units. Without any loss of generality we will be assuming in this

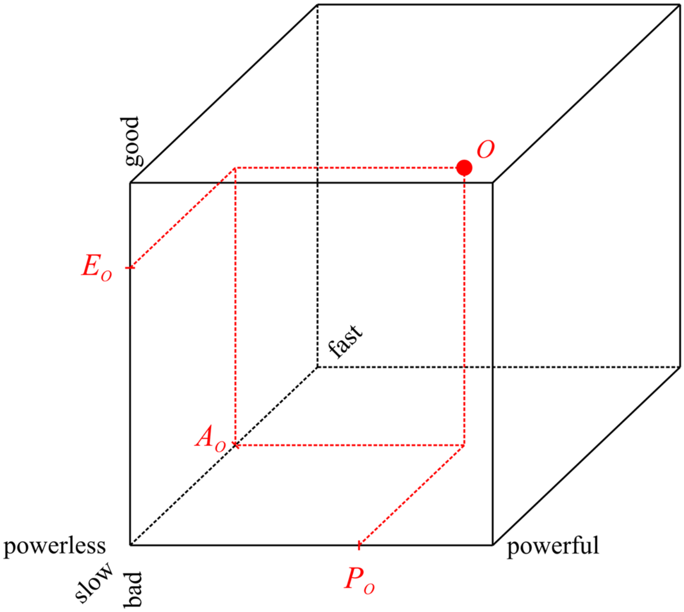

Fig. 1 A representation of the meaning of an object O in the semantic space as a point with coordinates (E_O, P_O, A_O)

paper the intervals of the type $[-k, k] \subset \mathbb{R}$, since any closed interval $[a, b]$ can be transformed into $[-\frac{b-a}{2}, \frac{b-a}{2}] = [-k, k]$. Note that the use of intervals instead of discrete (e.g. 7-point) scales is just a generalisation of the original scale used by Osgood et al. (1957). The use of a continuous scale enables the input of any value $x_i \in [-k, k]$, $i = 1, \ldots, n$, and thus graphical scales (as applied e.g. by Fennell and Baddeley 2013) can be utilized in the administration of semantic differential.

Let O and U be two objects assessed by the semantic differential and (E_O, P_O, A_O) and (E_U, P_U, A_U) their respective coordinates in the E–P–A space. The (semantic) distance of these two objects $d_1(O, U)$ can be computed using (2) as a standard Euclidean distance of two points in a three-dimensional space.

$$d_1(O, U) = \sqrt{(E_O - E_U)^2 + (P_O - P_U)^2 + (A_O - A_U)^2} \tag{2}$$

The factors E, P and A have proven to be culturally universal (Osgood 1964), but the factor loadings as well as the definition of the bipolar adjectives defining the endpoints of the scales need to be specified separately for a given culture and language environment. Let us consider the use of n scales $s_i, i = 1, \ldots, n$, represented by intervals $[-k, k] \subset \mathbb{R}, k > 0$, the endpoints of which are labelled by pairs of bipolar adjectives in accordance with the basic idea of semantic differentiation (Osgood et al. 1957)—that is the endpoints of a given scale can be labelled e.g. good (with a numerical representation $k \in \mathbb{R}$) and bad (with a numerical representation $-k \in \mathbb{R}$), the point 0 represents a state where a neutral position (neither good nor bad) is assumed. The origin (center) of the semantic space can be interpreted as complete meaninglessness, the length of the vector (E_O, P_O, A_O) [a line segment connecting (0, 0, 0) with (E_O, P_O, A_O)] represents the degree of meaningfulness and the orientation of the vector represents the semantic quality (Osgood et al. 1957).

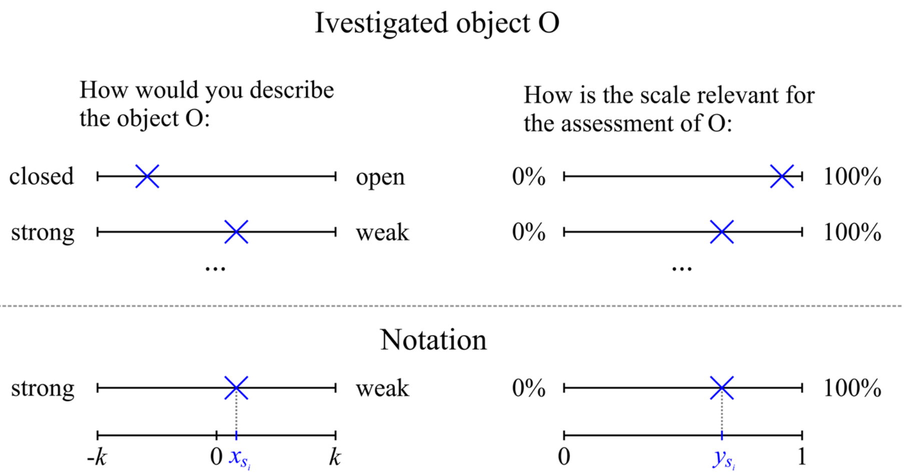

Fig. 2 An example of the scales used in the extended interval-valued version of the semantic differential proposed in this paper—as presented to the respondent (top) and the notation used for the values of the scales as provided by the respondent (bottom)

3 Interval valued semantic differential

Let us consider the use of n scales $s_i, i = 1, \dots, n$, represented by intervals $[-k, k] \subset \mathbb{R}, k > 0$. Let us also consider the three factors evaluation (E), potency (P) and activity (A) identified by Osgood et al. (1957) and let us consider that the factor loadings of each scale $s_i \in S$, where S is the set of scales (bipolar adjectives for which the factor analysis has been performed and factor loadings were found) to these factors, f_i^E, f_i^P, f_i^A, are known. In practical applications we suggest to follow the methodological framework for the creation of semantic differentials suggested by Verhagen et al. (2015, p. 116) to obtain/confirm the factors and the factor loadings of the bipolar-adjectives pairs. This methodology covers also the transformation of the semantic differentials to different languages, suggest the exploratory factor analysis to be accompanied by a confirmatory factor analysis and accounts also e.g. for anchoring effects.

Let us now consider a modified version of semantic differential administration, where we add another scale r_i to each $s_i, i = 1, \dots, n$, to assess the relevance of s_i for the description of the given object O as perceived by the respondent (see Fig. 2). The respondent is asked to assess the object O on all n scales and specify the values $x_{s_i} \in [-k, k]$ and also to evaluate the relevance of each scale s_i for the assessment of the the object O by specifying the values $y_{s_i} \in [0, 1]$. In accordance with the Fig. 2 (bottom) the respondent would mark a point on a respective line segment, which would be converted to the value x_{s_i} or y_{s_i} as suggested in Fig. 2.

First we convert the values y_{s_i} representing the relevance of the scale s_i for the assessment of O to w_{s_i} using Dombi's kappa function (Dombi and Kertész 2011):

$$w_{s_i} = \kappa(y_{s_i}) = \frac{2k}{1 + \left(\frac{\nu}{1-\nu} \frac{y_{s_i}}{1-y_{s_i}} \right)^{\lambda}} \text{ for } y_{s_i} \in [0, 1); \text{ and } w_{s_i} = 0 \text{ for } y_{s_i} = 1, \tag{3}$$

where λ and ν are parameters influencing the shape of the transformation function. The values w_{s_i} represent the widths of the intervals of "also possible alternative values" of x_{s_i}, or in other words define the intervals of possible values around x_{s_i} [see (4)], $[x^L_{s_i}, x^R_{s_i}] \subseteq [-k, k]$, as a result of the partial (or complete) irrelevance of the scale s_i for the description of O. Note, that for e.g. $\nu = 0.5$ and $\lambda \in (0, 1)$ we obtain a logit-type transformation function which corresponds well with the basic ideas of the Item Response Theory (IRT) and Rasch models.

For the sake of simplicity of notation and graphical representation we will assume $\lambda = 1$ and $\nu = 0.5$ further on, which results in a linear transformation $w_{s_i} = 2k(1 - y_{s_i})$. Values $w_{s_i}/2k$ now can be interpreted as inappropriateness measures of the scales s_i for the description of O as perceived by the respondent. We get $x_{s_i} \in [x^L_{s_i}, x^R_{s_i}]$ and $w_{s_i} = \left|[x^L_{s_i}, x^R_{s_i}]\right|$. This way we introduce an interval of uncertainty around x_{s_i} the width of which is proportional to the irrelevance of the scale for the description of O. The intervals of possible values around x_{s_i} are defined for all $i = 1, \dots, n$ in the following way:

$$[x^L_{s_i}, x^R_{s_i}] = \begin{cases} \left[x_{s_i} - \frac{w_{s_i}}{2}, x_{s_i} + \frac{w_{s_i}}{2}\right] & \text{for} \quad \left(x_{s_i} - \frac{w_{s_i}}{2}\right) \geq -k \text{ and } \left(x_{s_i} + \frac{w_{s_i}}{2}\right) \leq k, \\ [-k, -k + w_{s_i}] & \text{for} \quad \left(x_{s_i} - \frac{w_{s_i}}{2}\right) < -k, \\ [k - w_{s_i}, k] & \text{for} \quad \left(x_{s_i} + \frac{w_{s_i}}{2}\right) > k. \end{cases} \tag{4}$$

This way if it is possible to define $[x^L_{s_i}, x^R_{s_i}]$ symmetrically around x_{s_i}, so that both the endpoints of $[x^L_{s_i}, x^R_{s_i}]$ still lie within the $[-k, k]$ interval, we do so. If, however, such a symmetrical definition of $[x^L_{s_i}, x^R_{s_i}]$ would result in one of its endpoints falling out of the $[-k, k]$ interval, we shift the interval of possible values around x_{s_i} to the right (in case $(x_{s_i} - w_{s_i}/2) < -k$), or to the left (in case $(x_{s_i} + w_{s_i}/2) > k$) so that it stays within the $[-k, k]$ interval. Note, that the length of the interval $[x^L_{s_i}, x^R_{s_i}]$ is always w_{s_i}.

Note that if a scale $s_j \in S$ is considered completely irrelevant by the respondent for the description of O, we get $y_{s_j} = 0$ and thus $w_{s_j} = 2k$ and $[x^L_{s_j}, x^R_{s_j}] = [-k, k]$. In other words for a scale that is considered to be completely irrelevant for the description of O we expect that any value from $[-k, k]$ might have been chosen instead of x_{s_j} since the scale is considered to be inappropriate for the description of O. For a completely relevant scale s_h we get $y_{s_h} = 1$ and thus $w_{s_h} = 0$ and $[x^L_{s_h}, x^R_{s_h}] = [x_{s_h}, x_{s_h}]$ that is no uncertainty is associated with such an answer (since the interval $[x_{s_h}, x_{s_h}]$ represents a single number x_{s_h}). Hence each object O can now be represented in the semantic space by a 2-tuple (C_O, R_O), where $C_O = (E_O, P_O, A_O)$ is the coordinate of the object in the semantic space as suggested by the standard semantic differential (1) and $R_O = (E^{int}_O, P^{int}_O, A^{int}_O)$, where E^{int}_O, P^{int}_O and A^{int}_O computed by (5) are the intervals of "also possible coordinates" of O stemming from the less-than-complete relevance of some of the scales s_i for the assessment of O as perceived by the respondent. R_O defines an area of also possible coordinates of O in the semantic space as a cartesian product of the intervals E^{int}_O, P^{int}_O and A^{int}_O around (E_O, P_O, A_O) in the semantic space—see Fig. 3. This approach translates low scale relevance into scale-value uncertainty. The resulting "box of uncertainty" in the semantic space then represents the widest possible area containing the semantic representation of the given object stemming from the uncertainty in the scale values.

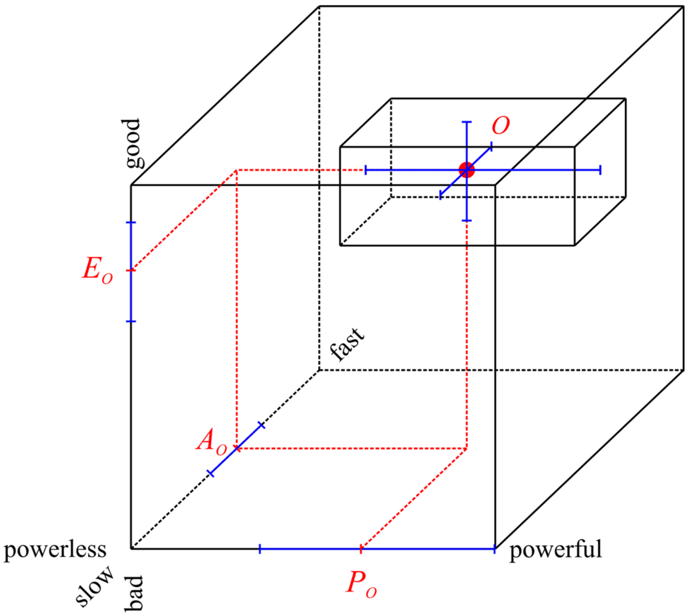

Fig. 3 The position of an object O in the semantic space represented by the red point with coordinates (E_O, P_O, A_O) along with the area of also possible locations of O in the semantic space stemming from lower relevance of some of the scales for its assessment. This area (blue block) is defined as the cartesian product of E_O^{int}, P_O^{int} and A_O^{int} represented by the blue line segments on the main axis. (Color figure online)

$$(E_O^{int}, P_O^{int}, A_O^{int}) = \left(\frac{\sum_{s_i \in S} [x_{s_i}^L, x_{s_i}^R] f_{s_i}^E}{\sum_{s_i \in S} \left| f_{s_i}^E \right|}, \frac{\sum_{s_i \in S} [x_{s_i}^L, x_{s_i}^R] f_{s_i}^P}{\sum_{s_i \in S} \left| f_{s_i}^P \right|}, \frac{\sum_{s_i \in S} [x_{s_i}^L, x_{s_i}^R] f_{s_i}^A}{\sum_{s_i \in S} \left| f_{s_i}^A \right|} \right) \tag{5}$$

Table 1 provides an example of the suggested generalization of the semantic differentiation method on an artificial data sample using an arbitrary selection of a set of bipolar adjectives and their factor loadings as used in Osgood et al. (1957). The input data provided by the respondent are presented in columns "scale score" and "scale relevance". In this example the scale scores lie in the $[-3, 3]$ interval and the relevance of the scale is assessed on the $[0\%, 100\%]$ universe. The final output is obtained in the form $(C_O, R_O) = ((0.74, 0.22, -0.43), ([0.11, 1.22], [-0.91, 0.67], [-1.23, 0.21]))$. The final output is also depicted in Fig. 4, where C_0 is represented by the red point and R_0 by the "box of uncertainty" surrounding this point. The Matlab function built to calculate the interval-valued position of the concept in the semantic space and to obtain the graphical output can be found as a supplementary material to the on-line version of this paper.[1]

[1] The function is stored in the intervaldifferential.m file. It can be called in Matlab or Octave with the following syntax: [intervals, interCoord, coord] = intervaldifferential (scores, relevances, k, factorLoadings, p). The following inputs are required for the function: *scores* is an $n \times 1$ vector of crisp values of the scales $x_i \in [-k, k]$ interval, *relevances* is an $n \times 1$ vector of crisp values of perceived scale-relevances $y_{s_i} \in [0\%, 100\%]$, k specifies the range of the numerical values of the scales defined by the bipolar adjec-

The question now is how to assess the distance of two points O and U represented in the semantic space by 2-tuples (C_O, R_O) and (C_U, R_U) respectively. We suggest to compute the distance in two components—as the distance of the point representations as proposed in the standard semantic differential (first component) accompanied by a piece of information concerning the difference of the areas of “also possible coordinates”:

$$d(O,U) = d\big((C_O,R_O),(C_U,R_U)\big) = \big(d_1(C_O,C_U), d_2(R_O,R_U)\big). \tag{6}$$

To compute the distance of the point-representations $d_1(C_O, C_U)$ we can use the standard euclidean distance formula (2). To assess the distance/difference of the areas of alternative coordinates of O and U, we suggest to calculate the distance $d_2(R_O, R_U)$ as the length of the vector the elements of which are defined as the differences of the lengths of intervals E^{int}_O, P^{int}_O and A^{int}_O and E^{int}_U, P^{int}_U and A^{int}_U respectively (see Fig. 5). That is

$$d_2(R_O,R_U) = \sqrt{\left(\left|E^{int}_O\right| - \left|E^{int}_U\right|\right)^2 + \left(\left|P^{int}_O\right| - \left|P^{int}_U\right|\right)^2 + \left(\left|A^{int}_O\right| - \left|A^{int}_U\right|\right)^2}. \tag{7}$$

Note, that the graphical representation of the region of alternative possible coordinates of an object in the semantic space in Fig. 3 might suggest to represent the uncertainty associated with position of the point O in the semantic space by the volume of the blue block. The difference in volume can, however, not be used to define d_2, since if we considered three objects O, U, and Q, out of which O was associated with a three-dimensional uncertainty represented by a block, U was associated with only two-dimensional uncertainty (represented by a rectangle in the three-dimensional semantic space with a zero volume) and Q was associated with one-dimensional uncertainty (represented by a line segment in the three-dimensional semantic space with a zero volume), we would get that the distance between O and U would be the same as the distance between O and Q regardless of the uncertainty associated with U and Q which is not desirable. An alternative definition of the d_2 distance can be based on the difference of body diagonals of the areas representing the uncertainty (denoted here by d_2'). This approach is summarized by (8). Note, that (8) disregards the orientation of the area of uncertainty but (7) takes it into account.

$$d_2'(R_O,R_U) = \left|\sqrt{\left|E^{int}_O\right|^2 + \left|P^{int}_O\right|^2 + \left|A^{int}_O\right|^2} - \sqrt{\left|E^{int}_U\right|^2 + \left|P^{int}_U\right|^2 + \left|A^{int}_U\right|^2}\right| \tag{8}$$

Using the body diagonal of the uncertainty area of the object O (stemming from the perceived irrelevance of certain scales from S for the assessment of the given object O) we can obtain a measure of uncertainty of this area $\mu_S(O) \in [0,1]$ defined by (9).

$$\mu_S(O) = \frac{\sqrt{\left|E^{int}_O\right|^2 + \left|P^{int}_O\right|^2 + \left|A^{int}_O\right|^2}}{\sqrt{12k^2}} \tag{9}$$

Footnote 1 (continued)

tive pairs, *factorloadings* is an $n \times F$ vector of factor loadings of the n bipolar adjective pairs to the F factors and p is a parameter controlling the plot option (if $p = 1$, then the graphical output presented in Fig. 4 is provided; when $p = 0$, no graphical output is provided). The function provides the following outputs: *intervals* is a vector of n interval values of the scales $[x^L_{s_i}, x^R_{s_i}]$ computed from the crisp scores s_i and scale relevances y_{s_i} applying formulas (3) and (4), *interCoord* is the vector of interval coordinates of the object in the semantic space, i.e. $interCoord = R_O = (E^{int}_o, P^{int}_o, A^{int}_o)$ and *coord* is the vector of crisp coordinates of the object in the semantic space, i.e. $coord = C_O = (E_O, P_O, A_O)$.

Table 1 An example of the use of the suggested interval-valued semantic differential and the results provided by this method, i.e. the interval coordinates in the semantic space A_O^{int}, E_O^{int} and P_O^{int} and the respective classic semantic-space coordinates A_O, E_O and P_O

Scale (bipolar adjective pair)	Factor loadings			Scale score value from [−3, 3]	Scale relevance value from [0%,100%] (%)	$2k \cdot y_{s_i}$ value from [0,6]	Uncertainty (w_{s_i}) value from [0,6]	Resulting interval score $[x_{s_i}^L, x_{s_i}^R]$
	E—evaluation	P—potency	A—activity					
Chaotic–ordered	− 0.84	0.00	0.55	− 2	80	4.8	1.2	[− 2.6, − 1.4]
Bad–good	− 0.77	− 0.27	− 0.33	1.5	100	6	0	[1.5, 1.5]
Violent–gentle	− 0.37	0.69	0.41	3	100	6	0	[3, 3]
Smooth–rough	0.83	0.00	− 0.57	2	60	3.6	2.4	[0.6, 3]
Static–dynamic	0.19	− 0.53	− 0.78	2.5	75	4.5	1.5	[1.5, 3]
Hot–cold	− 0.08	0.00	0.64	− 1	30	1.8	4.2	[− 3, 1.2]
Pleasant–unpleasant	0.59	− 0.60	− 0.02	3	100	6	0	[3, 3]
Happy–sad	0.38	− 0.71	0.34	2	100	6	0	[2, 2]
Emotional–rational	0.09	0.40	0.67	0	90	5.4	0.6	[− 0.3, 0.3]
Masculine–feminine	0.13	0.76	0.31	2	10	0.6	5.4	[− 2.4, 3]
Passive–active	0.00	0.00	− 1.00	1	100	6	0	[1, 1]
Full–empty	0.31	0.52	0.60	− 1	100	6	0	[− 1, − 1]
Soft–hard	0.09	− 0.84	− 0.39	− 3	66	3.96	2.04	[− 3, − 0.96]
Sweet–bitter	0.23	− 0.67	− 0.32	− 1	35	2.1	3.9	[− 3, 0.95]
Interval semantic space coordinates:	[0.11, 1.22]	[− 0.91, 0.67]	[− 1.23, 0.21]					
Classic semantic space coordinates:	0.74	0.22	− 0.43					

Examples of factor loadings taken from Osgood et al. (1957)

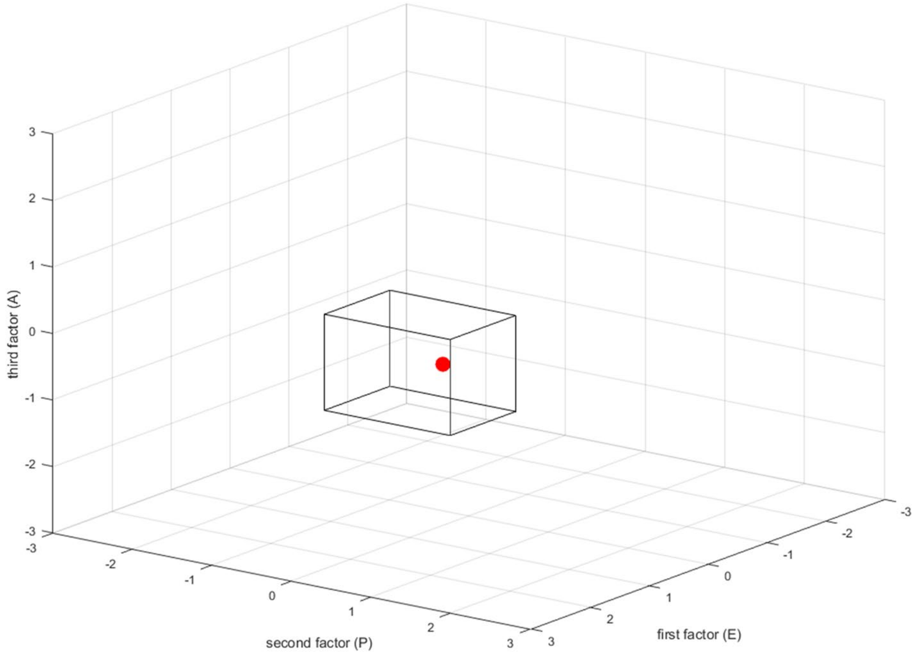

Fig. 4 The representation of the attitude towards object O (or the semantic position of this object) in the semantic space. O is now represented by the classic semantic differential output C_0—i.e. the red point and the "box of uncertainty" stemming from lower perceiver relevance of the scales (bipolar-adjective pairs). The box thus represents the R_O region computed in Table 1 by (5)

Note that $\mu_S(O) = 0$ only if all the scales in S were considered completely relevant; the maximum uncertainty, that is the situation when any coordinate in the semantic space can be considered as a possible position of O is characterized by $\mu_S(O) = 1$, that is only if all the scales in S are considered completely irrelevant for the assessment of O. Using d_1 and either d_2 or d'_2 we obtain a 2-tuple of distances characterising the difference in position and in the uncertainty of its determination for two objects in the semantic space.

4 Conclusion

In the paper we present a generalization of the semantic differential (Osgood et al. 1957) that identifies not only the position of the meaning of an object (attitude towards this object) in the E–P–A semantic space, but also the area of possible alternative coordinates of the object. We propose to register the perceived relevance of each scale used in the process of the assessment of the given object by the respondent and to convert it into intervals of "also possible values" of this scale $[x^L_{s_i}, x^R_{s_i}]$. This way the lower relevance of the scale is translated into uncertainty of the evaluation of the object using this scale. The area of also possible coordinates of the object is subsequently defined in the semantic space and represented therein as a "box of uncertainty" surrounding the crisp point C_O. We have also proposed an uncertainty measure of the resulting representation of the object in the semantic space.

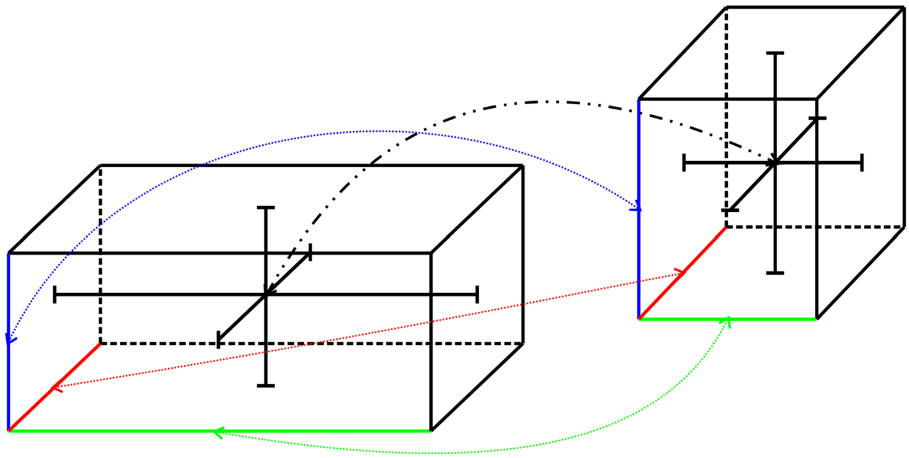

Fig. 5 The schematic representation of the distance of the representations of 2 objects O and U in the interval valued semantic differential. The distance of the point representations (black dot-and-dash line) is calculated as $d_1(C_O, C_U)$, the differences in the lengths of the E^{int}, P^{int} and A^{int} intervals represented as blue, green and red line segments respectively, are considered in $d_2(R_O, R_U)$. (Color figure online)

The proposed interval-valued semantic differential provides additional information concerning the uncertainty of the determination of position of objects in the semantic space to the standard information obtained by semantic differential (Osgood et al. 1957). It reflects the perceived scale (ir)relevance and provides means for addressing some aspects of the the concept–scale interaction issue in semantic differentiation and in the assessment of attitudes using this methodological framework, when scales with non-denotative meaning are used. The problem of ambiguity of middle answers is also solved by the introduction of uncertainty in the semantic differentiation. The "it depends" interpretation of middle answers identified by Kulas and Stachowski (2009) and linked with lower scale clarity is represented by a higher uncertainty, whereas the "neutral" interpretation is represented by a low-uncertain middle value of the scale. The information represented by the uncertainty measure μ_s can also serve as an assessment tool for the credibility of answers, and the two suggested distance measures for the areas of "also possible coordinates" d_2 and d_2' provide means for comparing the representations of different objects in the semantic space as "boxes of uncertainty". Conclusions derived from the novel interval-valued semantic differential introduced in this paper can thus enhance the strengths of the research utilizing the semantic differential by allowing for uncertainty, as well as expand the repertoire of clinical assessment tools based on semantic-differential-type scales and enhance their current capabilities. Considering that uncertainty is inherent in common language expressions, the proposed method presents a necessary prerequisite for the reflection of uncertainty in semantic differentiation and in the assessment of attitudes using this methodological framework.

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