MULTIDIMENSIONAL HETEROGENEOUS VARIABLE PREDICTION BASED ON EXPERTS' STATEMENTS*

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***Abstract**: In the works [1, 2] we proposed an approach of forming a consensus of experts' statements for the case of forecasting of qualitative and quantitative variable. In this paper, we present a method of aggregating sets of individual statements into a collective one for the general case of forecasting of multidimensional heterogeneous variable.*

***Keywords**: multidimensional variable, expert statements, coordination.*

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Introduction

Let Γ be a population of elements or objects under investigation. By assumption, L experts give predictions of values of unknown *m*-dimensional heterogeneous feature Y for objects $a \in \Gamma$, being already aware of their description $X(a)$. We assume that $X(a) = (X_1(a),...,X_j(a),...,X_n(a))$, $Y(a) = (Y_1(a),...,Y_j(a),...,Y_m(a))$, where the sets X and Y may simultaneously contain qualitative and quantitative features X_j, $j = \overline{1,n}$; or Y_j, $j = \overline{1,m}$; respectively. Let D_j^X be the domain of the feature X_j, $j = \overline{1,n}$, D_j^Y be the domain of the feature Y_j, $j = \overline{1,m}$. The feature spaces are given by the product sets: $D^X = \prod_{j=1}^n D_j^X$ and $D^Y = \prod_{j=1}^m D_j^Y$. By assumption, exactly combination of values $Y_1(a),\ldots,Y_j(a),\ldots,Y_m(a)$ is important, so we have to estimate the whole set Y simultaneously.

We shall say that a set E is a *rectangular set* in D^X if $E = \prod_{j=1}^n E_j$, $E_j \subseteq D_j^X$, $E_j = [\alpha_j, \beta_j]$ if X_j is a quantitative feature, E_j is a finite subset of feature values if X_j is a nominal feature. In the same way rectangular sets in D^Y are defined.

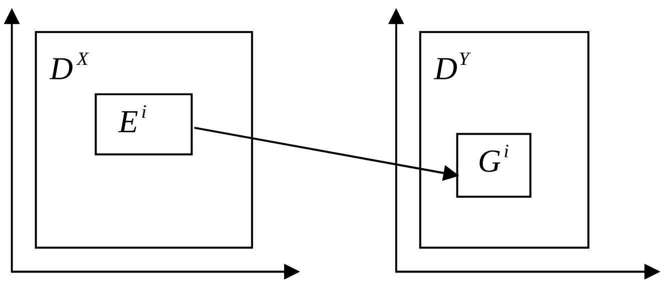

Fig. 1.

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In this paper, we consider statements S^i, $i=\overline{1,M}$; represented as sentences of type “if $X(a)\in E^i$, then $Y(a)\in G^i$”, where E^i is a rectangular set in D^X, G^i is a rectangular set in D^Y (see Fig. 1). By assumption, each statement S^i has its own weight w^i ($0<w^i\le 1$ for individual statements). Such a value is like a measure of “confidence”.

Let us remark that the statement “if $X(a)\in E$, then $Y(a)\in D^Y$” is equal to the statement “I know nothing about $Y(a)$ if $X(a)\in E$”.

Without loss of generality we may assume that experts themselves have equal “weights”.

Setting of a Problem

We begin with some definitions.

Denote by $E^{i_1 i_2} := E^{i_1}\oplus E^{i_2} = \prod_{j=1}^{n}(E_j^{i_1}\oplus E_j^{i_2})$, where $E_j^{i_1}\oplus E_j^{i_2}$ is the *Cartesian join* of feature values $E_j^{i_1}$ and $E_j^{i_2}$ for feature X_j and is defined as follows. When X_j is a nominal feature, $E_j^{i_1}\oplus E_j^{i_2}$ is the union: $E_j^{i_1}\oplus E_j^{i_2} = E_j^{i_1}\bigcup E_j^{i_2}$. When X_j is a quantitative feature, $E_j^{i_1}\oplus E_j^{i_2}$ is a minimal closed interval such that $E_j^{i_1}\bigcup E_j^{i_2}\subseteq E_j^{i_1}\oplus E_j^{i_2}$ (see Fig. 2).

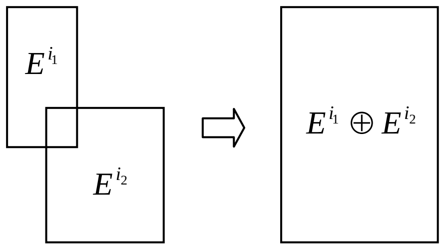

Fig. 2.

In the work [3] we proposed a method to measure the distances between sets (e.g., E^1 and E^2) in heterogeneous feature space. Consider some modification of this method. By definition, put

$\rho(E^1,E^2)=\sum_{j=1}^{n}k_j\rho_j(E_j^1,E_j^2)$ or $\rho(E^1,E^2)=\sqrt{\sum_{j=1}^{n}k_j(\rho_j(E_j^1,E_j^2))^2}$, where $0\le k_j\le 1$, $\sum_{j=1}^{n}k_j=1$.

Values $\rho_j(E_j^1,E_j^2)$ are given by: $\rho_j(E_j^1,E_j^2)=\dfrac{|E_j^1\Delta E_j^2|}{|D_j^X|}$ if X_j is a nominal feature, $\rho_j(E_j^1,E_j^2)=\dfrac{r_j^{12}+\theta|E_j^1\Delta E_j^2|}{|D_j^X|}$ if X_j is a quantitative feature, where $r_j^{12}=\left|\dfrac{\alpha_j^1+\beta_j^1}{2}-\dfrac{\alpha_j^2+\beta_j^2}{2}\right|$. It can be proved that the triangle inequality is fulfilled if and only if $0\le\theta\le 1/2$.

The proposed measure ρ satisfies the requirements of distance there may be. Note that we can use another measure of differences (for example, see [4]).

In this paper we assume that distance between rectangular sets in D^Y is known.

Consider some “natural” algorithm of forming a consensus of experts’ statements (denote it by A).

Let for some point $x \in D^X$ we have two statements S^1 and S^2 with the weights w^1 and w^2. Suppose G^1 and G^2 are the images prescribed by these statements to the point x.

If $\rho(G^1, G^2) < \varepsilon$, where ε is a threshold, then it may be assumed that the set $G^1 \oplus G^2$ is "naturally" prescribed to the point x. Note that if these statements are given by different experts, then we more confidence in resulted statement, so the weight of this statement is higher than w^1 and w^2 (it may be even more than 1).

Otherwise, if $\rho(G^1, G^2) \geq \varepsilon$, then it may be assumed that only one statement with higher weight is remained and our confidence in it (and the weight of it) is decreased.

If for some point $x \in D^X$ we have more than two statements, the algorithm A coordinates them in the same way.

Since there are M statements, we have up to 2^M sets in D^X with different prescribed images. These sets are in the form of E_1 or $E_1 \setminus (E_2 \bigcup E_3 \ldots)$, where E_i are rectangular sets in D^X.

Consider algorithms B of forming a consensus of experts' statements under restrictions on amount of resulted statements. The value $F(B) = \int_{D^X} (\rho(G_A(x), G_B(x))^2 dx$ estimates a quality of the algorithm B. Here $G_A(x)$, $G_B(x)$ are the images prescribed to the point $x \in D^X$ by algorithms A and B, respectively. In the general case, the best algorithm $B^* = \arg\min_B F(B)$ is unknown. Further on, the heuristic algorithm of forming a consensus of experts' statements is considered.

Preliminary Analysis

We first treat each expert's statements separately for rough analysis. Let us consider some special cases.

Case 1 ("coincidence"): $\max_j \max(\rho_j(E^{i_1}, E^{i_1} \oplus E^{i_2}), \rho_j(E^{i_2}, E^{i_1} \oplus E^{i_2})) < \delta$ and $\rho(G^{i_1}, G^{i_2}) < \varepsilon_1$, where δ, ε_1 are thresholds decided by the user, $i_1, i_2 \in \{1,...,M\}$. In this case we unite statements S^{i_1} and S^{i_2} into resulting one: "if $X(a) \in E^{i_1} \oplus E^{i_2}$, then $Y(a) \in G^{i_1} \oplus G^{i_2}$".

Case 2 ("inclusion"): $\min(\max_j(\rho_j(E^{i_1}, E^{i_1} \oplus E^{i_2})), \max_j(\rho_j(E^{i_2}, E^{i_1} \oplus E^{i_2}))) < \delta$ and $\rho(G^{i_1}, G^{i_2}) < \varepsilon_1$, where $i_1, i_2 \in \{1,...,M\}$. In this case we unite statements S^{i_1} and S^{i_2} too: "if $X(a) \in E^{i_1} \oplus E^{i_2}$, then $Y(a) \in G^{i_1} \oplus G^{i_2}$".

Case 3 ("contradiction"): $\max_j \max(\rho_j(E^{i_1}, E^{i_1} \oplus E^{i_2}), \rho_j(E^{i_2}, E^{i_1} \oplus E^{i_2})) < \delta$ and $\rho(G^{i_1}, G^{i_2}) > \varepsilon_2$, where ε_2 is a threshold decided by the user, $i_1, i_2 \in \{1,...,M\}$. In this case we exclude both statements S^{i_1} and S^{i_2} from the list of statements.

Coordination of Similar Statements

Consider the list of l-th expert's statements after preliminary analysis $\Omega_1(l) = \{S^1(l),..., S^{m_l}(l)\}$. Denote by $\Omega_1 = \bigcup_{l=1}^{L} \Omega_1(l)$, $M_1 = |\Omega_1|$.

Determine now distance between rectangular sets in D^X. Determine values k_j from this reason: if far sets G^{i_1} and G^{i_2} corresponds to far sets $E_j^{i_1}$ and $E_j^{i_2}$, then the feature X_j is more "valuable" than another features, hence, value k_j is higher. We can use, for example, these values: $k_j = \frac{\tau_j}{\sum_{i=1}^{n} \tau_i}$, where $\tau_j = \sum_{u=1}^{M_1} \sum_{v=1}^{M_1} \rho(G^u, G^v) \rho_j(E_j^u, E_j^v)$, $j = \overline{1,n}$.

Denote by $r^{i_1 i_2} := d(E^{i_1 i_2}, E^{i_1} \bigcup E^{i_2})$.

The value $d(E,F)$ is defined as follows: $d(E,F) = \max\limits_{E' \subseteq E \setminus F} \min\limits_{j} \frac{k_j \,|\, E'_j \,|}{diam(E)}$, where E' is any rectangular set (see Fig. 3), $diam(E) = \max\limits_{x,y \in E} \rho(x,y)$.

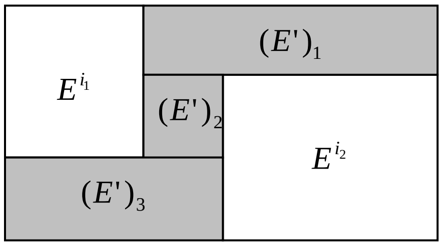

Fig. 3.

By definition, put $I_1 = \{\{1\},...,\{M_1\}\},...,$ $I_q = \{\{i_1,...,i_q\} \,|\, r^{i_u i_v} \le \delta$ and $\rho(G^{i_u}, G^{i_v}) < \varepsilon_1 \quad \forall u,v = \overline{1,q}\}$, where δ, ε_1 are thresholds decided by the user, $q = \overline{2,Q}$; $Q \le M_1$. Let us remark that the requirement $r^{i_u i_v} \le \delta$ is like a criterion of "insignificance" of the set $E^{uv} \setminus (E^{i_u} \bigcup E^{i_v})$. Notice that someone can use another value d to determine value r, for example:

$$d(E,F,G) = \max_{E' \subseteq E \setminus (F \bigcup G)} \frac{\min(diam(F \oplus E') - diam(F), diam(G \oplus E') - diam(G))}{diam(E)}.$$

Further, take any set $J_q = \{i_1,...,i_q\}$ of indices such that $J_q \in I_q$ and $\forall \Delta = \overline{1, Q-q}$ $\forall J_{q+\Delta} \in I_{q+\Delta}$ $J_q \not\subset J_{q+\Delta}$. Now, we can aggregate the statements S^{i_1}, ..., S^{i_q} into the statement S^{J_q}:

S^{J_q} = "if $X(a) \in E^{J_q}$, then $Y(a) \in G^{J_q}$", where $E^{J_q} = E^{i_1} \oplus ... \oplus E^{i_q}$, $G^{J_q} = G^{i_1} \oplus ... \oplus G^{i_q}$.

By definition, put to the statement S^{J_q} the weight $w^{J_q} = \frac{\sum_{i \in J_q} c^{iJ_q} w^i}{\sum_{i \in J_q} c^{iJ_q}}$, where $c^{iJ_q} = 1 - \rho(E^i, E^{J_q})$.

The procedure of forming a consensus of single expert's statements consists in aggregating into statements S^{J_q} for all J_q under previous conditions, $q = \overline{1,Q}$.

Let us remark that if, for example, $k_1 < k_2$, then the sets E_1 and E_2 (see Fig. 4) are more suitable to be united (to be precise, the relative statements), than the sets F_1 and F_2 under the same another conditions.

Note that we can consider another criterion of unification (instead of $r^{i_u i_v} \le \delta$): aggregate statements S^{i_1}, ..., S^{i_q} into the statement S^{J_q} only if $w^{J_q} > \varepsilon'$, where ε' is a threshold decided by the user.

After coordinating each expert's statements separately, we can construct an agreement of several independent experts. The procedure is as above, except the weights: $w^{J_q} = \sum_{i \in J_q} c^{iJ_q} w^i$ (the more experts give similar statements, the more we trust in resulted statement).

Denote the list of statements after coordination by Ω_2, $M_2 := |\Omega_2|$.

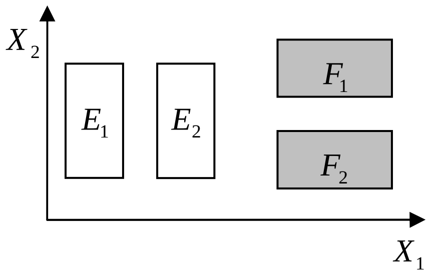

Fig. 4.

Coordination of Non-similar Statements

After constructing of a consensus of similar statements, we must form decision rule in the case of intersected non-similar statements. The procedure in such cases is as follows.

To each $h = \overline{2, M_2}$ consider statements $S^{(1)},...,S^{(h)} \in \Omega_2$ such that $\tilde{E}^h := E^{(1)} \bigcap ... \bigcap E^{(h)} \neq \varnothing$, where $E^{(i)}$ are related sets to statements $S^{(i)}$.

Denote $I(l) = \left\{ i \middle| S^i(l) \in \Omega_1(l), \quad E^i(l) \bigcap \tilde{E}^h \neq \varnothing \right\}$, where $E^i(l)$ are related sets to statements $S^i(l)$. Consider related sets $G^i(l)$, where $l = \overline{1, L}$; $i \in I(l)$. Denote by $w^i(l)$ the weights of statements $S^i(l)$.

As above, unite sets $G^{(i_1)}(l_1)$,..., $G^{(i_q)}(l_q)$ if $\rho(G^{i_u}, G^{i_v}) < \varepsilon_1 \ \forall u, v = \overline{1, q}$. Denote by $\tilde{G}^1$,..., $\tilde{G}^\lambda$,..., $\tilde{G}^\Lambda$ the sets after procedure of unification of the sets $G^i(l)$. Consider the statements $\tilde{S}^\lambda$: "if $X(a) \in \tilde{E}^h$, then $Y(a) \in \tilde{G}^\lambda$".

In order to choose the best statement, we take into consideration these reasons:

1) similarities between sets $\tilde{E}^h$ and $E^i(l)$;
2) similarities between sets $\tilde{G}^\lambda$ and $G^i(l)$;
3) weights of statements $S^i(l)$;
4) we must distinguish cases when similar / contradictory statements produced by one or several experts.

We can use, for example, such values: $w^\lambda = \sum_{l=1}^{L} \frac{\sum_{i \in I(l)} (1 - \rho(G^{(i)}(l), \tilde{G}^{(\lambda)}))(1 - \rho(E^{(i)}(l), \tilde{E}^h)^2 w^i(l)}{\sum_{i \in I(l)} (1 - \rho(E^{(i)}(l), \tilde{E}^h)}$.

Denote by $\lambda^* := \arg\max_{\lambda} w^\lambda$.

Thus, we can make decision statement: $\tilde{S}^h =$"if $X(a) \in \tilde{E}^h$, then $Y(a) \in \tilde{G}^{\lambda^*}$" with the weight $\tilde{w}^h := w^{\lambda^*} - \max_{\lambda \neq \lambda^*} w^\lambda$.

Denote the list of such statements by Ω_3.

Final decision rule is formed from statements in Ω_2 and Ω_3.

Conclusion

Suggested method of forming of united decision rule can be used for coordination of several experts statements, and different decision rules obtained from learning samples and/or time series. Notice that we can range resulted statements by their weights, and then exclude "ignorable" statements from decision rule or inquire for more information for corresponding sets from experts.

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