Applications of Fuzzy-Based Linguistic Patterns for the Assessment of Computer Screen Design Quality

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The main objective of this study was to develop a modeling framework which would unify different aspects of computer screen design and result in a quantitative criterion for an optimized computer screen format. The fuzzy set-based linguistic design patterns were utilized as a tool to build this model. The linguistic patterns are based on categories of expressions related closely to natural language and truth values, which are close to a human designer's intuition. The proposed framework is capable of assessing the quality of computer screen design based on existing knowledge in human–computer interface domain using the fuzzy-based linguistic pattern approach. Exemplary patterns for an optimal screen density, information grouping, and some aspects of screen layout are presented, along with a sequence of calculations based on the exemplary screen format. This study showed that it is possible to achieve a rational and relatively easy to interpret assessment of different screen designs in the form of the degrees of truth. Such an evaluation criterion reflects the compatibility of a given screen design with the optimal one based on the current knowledge in the field. It is believed that the proposed methodological framework for computer screen design should significantly augment the efforts of human designers.

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1. INTRODUCTION

Visual display terminals (VDTs) are the basic media for human interaction with computers. The VDT screen design plays an important role in determining the effectiveness of a computer system. Empirical studies performed by Tullis (1981, 1983) showed that a redesign of faulty screen formats reduced the mean time required by the human operator for data interpretation by 40%. Tullis (1988) also reviewed a variety of approaches devoted to screen design and stated that among well-defined quantitative (empirical) relationships between the screen formats and their effectiveness, there are many rules of thumb which are based on subjective views and anecdotal knowledge. This is due to limited empirical data, as well as the nonmeasurable character of many parameters and relationships which determine screen design quality. Also, the lack of consistent measures and quantitative criteria for assessment of screen quality makes the evaluation of system efficiency and comparison of different screen designs difficult.

The main objective of this study was to develop a model which would unify different aspects of computer screen design and result in a quantitative and robust criterion for an optimized screen format. The linguistic design patterns were used as a tool to build this model. The proposed patterns are based on categories of expressions related closely to natural language and truth values, which are close to human intuition. These soft tools accord very well with the imprecise, expert-type character of the remarkable part of human–computer interaction knowledge (Karwowski, Kosiba, Benabdallah, & Salvendy, 1990).

The proposed modeling framework encompasses relatively well-documented aspects of computer screen design. This modeling framework was designed to be generic and universal, as well as independent of the specific technology used by computer manufacturers in the design of the given human–computer interface. Therefore, the current model concentrates on such structural design issues as density of the computer screen, grouping of information, or importance and frequency of use of logically connected sequences of elements on the screen, as opposed to the design aspects which are related to, for example, the mode of information presentation such as use of windows, icons, types of font, or, in general, the type of graphical displays used.

2. OVERVIEW OF LINGUISTIC PATTERNS

Originally proposed by Grobelny (1987a, 1987b), the linguistic patterns constitute the system of concepts, relations, and definitions which include (a) the implication and definition of linguistic variables, (b) a degree of truth of an implication, (c) intensity levels of implication variables, (d) degree of truth of the consistency of two expressions, (e) definitions of linguistic relationships, and (f) definitions of modifiers for linguistic expressions and connectors.

(a) In an implication, IF X is A THEN Y is B, X and Y are interpreted as linguistic variables. A and B are the realizations of the variables X and Y and constitute expressions similar to natural language.

(b) Using Lukasiewicz's formula, one can determine the degree of truth of the implication.

$$\textit{truth} \text{ of } (X \text{ is } A \rightarrow Y \text{ is } B) = \min(1, 1 - \textit{truth} \text{ of } (X \text{ is } A) + \textit{truth} \text{ of } (Y \text{ is } B)) \quad (1)$$

where *truth* of (X is A) denotes the degree of truth defined in the continuous interval [0,1].

(c) One can also determine the intensity levels of implication variables A and B using fuzzy sets that represent natural expressions. Namely, proposition "X is F" means that the realization of variable X is represented by fuzzy set F, and

$$F : X \rightarrow [0,1], \quad (2)$$

whereas

$$F = \{F(x), x\} \quad \text{for all } x \in X \quad (3)$$

so fuzzy set F is a set of ordered pairs conforming to Equation 3. Function F(x) determines the truth value of the fact that x belongs to F. Some examples of fuzzy sets representing expressions BIG, MEDIUM, and so forth are shown in Figure 1.

(d) In addition, one can determine the degree of truth of the consistency of two expressions through the following formula:

$$\begin{aligned} \textit{truth} \text{ of } (X \text{ is } F / X \text{ is } G) &= \text{POSS}(X \text{ is } F / X \text{ is } G) \\ &= \sup_{x \in X} \min \{F(x), G(x)\} \end{aligned} \quad (4)$$

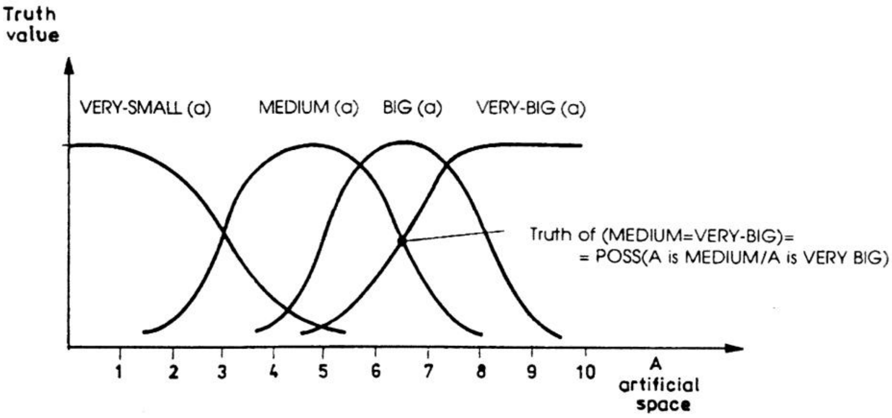

Figure 1. Membership (truth value) functions defining exemplary expressions in the arbitrary space.

where min denotes a minimum operator and POSS is a possibility measure introduced by Zadeh (1978). The possibility measure is a numerical value category which is calculated from the last element of Equation 4. Its intuitive interpretation is based on the "grade of closeness" of sets F and G. In other words, the possibility measure determines if the F realization satisfies the G criterion (or vice versa). Figure 1 illustrates the interpretation of the possibility measure.

(e) Some definitions of the linguistic relationships in categories of fuzzy sets are presented below:

Let $F: X \rightarrow [0,1]$ and $G: Y \rightarrow [0,1]$
whereas $F = \{F(x),x\}$ for all $x \in X$,
$G = \{G(y),y\}$ for all $y \in Y$,

$$F \text{ AND } G = \{\min(F(x),G(y)),(x,y)\} \text{ for all pairs } (x,y) \quad (5)$$

$$F \text{ OR } G = \{\max(F(x),G(y)),(x,y)\} \text{ for all pairs } (x,y) \quad (6)$$

As the fuzzy set is a generalization of a traditional set, the Relations 5 and 6 are generalizations of the union and sum operations for two sets. Assuming that F(x) and G(y) can only admit values 0 or 1, it can be seen that Relations 5 and 6 will behave as classical operations of the union and sum of two sets, respectively.

(f) Definitions of modifiers for linguistic expressions and connectors are as follows:

IF X is F is represented by membership function

$$F = \{F(x),x\} \quad \text{for all } x \in X$$

then NOT X is F can be represented by

$$F' = \{1 - F(x),x\} \quad \text{for all } x \in X.$$

Statements IF X THEN Y and IF Z THEN N can be connected by logical expressions ELSE, AND, and OR. The truth value of the connection is calculated as minimum of the individual truth values for the ELSE and AND connectors and maximum for the OR connector. Having formulated the above definitions, one can consider the statement

$$\text{IF "X is F" THEN "Y is G"} \quad (7)$$

as the criterion in which X and Y represent linguistic variables, and F and G are fuzzy sets representing appropriate levels or intensity definitions. Implication (7) defines the desired state, that is, a given pattern. Having measured the actual realizations of variables X and Y, one can determine the degree (or truth value) to which these realizations fulfill Pattern 7. The procedure that allows to calculate the truth value follows.

Let H and I be fuzzy sets representing measured values of X and Y, respectively.

1. Using Equation 4, and denoting the value of *truth* for the left-hand side of Pattern 7 as p, and that for the right-hand side of this pattern as q, one can determine the following:

$$p = \textit{truth} \text{ of } (X \text{ is } H/X \text{ is } F), \text{ and}$$
$$q = \textit{truth} \text{ of } (Y \text{ is } I/Y \text{ is } G).$$

2. Having computed p and q, which are the left-and right-side assessments of the fulfillment, respectively, the truth value of Pattern 7 can be calculated using Equation 1 as follows:

$$\textit{truth} \text{ of } (7) = \min(1, 1 - p + q).$$

The form of Pattern 7 could also be more complicated due to Relationships 5 and 6. It must be pointed out that Formula 4 should be treated only as one of the possible approaches in measuring similarity of a fuzzy criteria fulfillment.

3. SCREEN DENSITY AND INFORMATION GROUPING PATTERNS

Guidelines and handbooks devoted to the human–computer interaction (HCI) pay a great deal of attention to the amount of information that can be presented on the screen in parallel (Schneiderman, 1986; Shornock, 1988). In general, these guidelines recommend that only the necessary information should be displayed on a screen. More scientific approaches suggest that the percentage density of information on a screen should be used to indicate the amount and limits of display loading. Tullis (1988) discussed the limits proposed by different authors and showed that they fell within the interval 25–60%. Based on the above information, one can formulate a simple statement to describe the desired computer screen format:

(A) General screen density (GSD) should be much smaller than 60%, or in the shorter form: GSD = MUCH-LESS-THAN-60%.

A simple model for the above limits of the screen utilization can be defined as membership Functions 2 and 3 for which X is defined as a space of density percentages, and F(x) assigns degrees satisfying the expression MUCH-LESS-THAN-60 by a given x. The definition of this function, presented in Figure 2, intuitively takes into account the fact that there is not enough evidence to define the shape of the function MUCH-LESS-THAN-60(x). The linear function simply reflects a decreasing acceptability of increasing screen densities. This function is

Table 1. Discrete Numerical Definitions of Screen Density and Angular Dimension Limits of Information.

Artificial Space t	1	2	3	4	5	6	7	8	9	10
Overall density percentage (X)	0–10	10–20	20–30	30–40	40–50	50–60	60–70	70–80	80–90	90–100
Much-less-than-60 (X)	1.0	1.0	0.8	0.6	0.4	0.2	0.0	0.0	0.0	0.0
Rather-less-than-60 (X)	1.0	1.0	1.0	1.0	0.8	0.6	0.4	0.2	0.0	0.0
Visual angles (V) (degrees)	0–1	1–2	2–3	3–4	4–5	5–6	6–7	7–8	8–9	9–10
Small (v)	1.0	1.0	1.0	1.0	1.0	0.8	0.6	0.4	0.2	0.0
Large (v)	0.0	0.0	0.0	0.0	0.0	0.2	0.4	0.6	0.8	1.0

presented in Table 1 in a simplified version, which is more convenient for calculation purposes.

The above interpretation makes the A expression a measurable criterion. The measurement of GSD allows to determine the degree to which Pattern A fulfills a given screen format (see Figure 2 or Table 1). However, Tullis (1988) documented that the validity of Pattern A is limited. When information on the screen is organized in groups of closely related items, the searching times for the desired information radically improves. Such arrangement of information changes the limits proposed so far and, consequently, changes Pattern A. Furthermore, the amount of information presented in the optimally sized items, which do not exceed 5° visual angles, greatly influences the searching times (Tullis, 1988). If groups are significantly larger than optimal, the mean group size becomes the

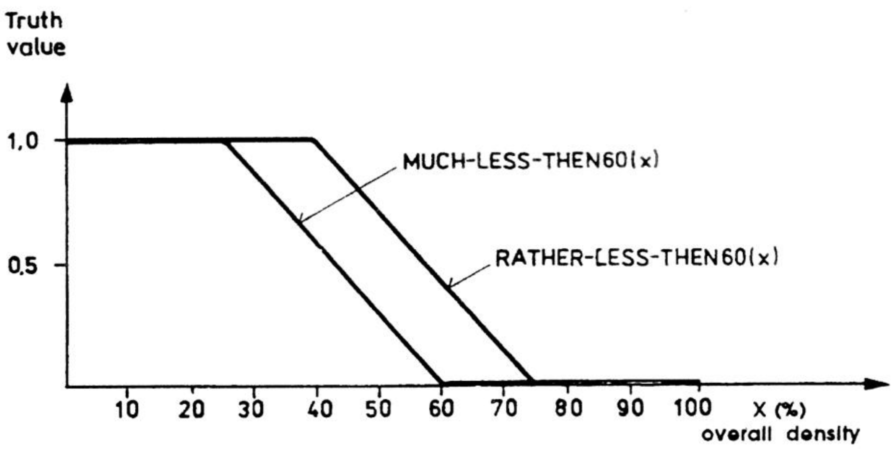

Figure 2. Propositions of membership function shapes defining two limits of a screen density for Pattern B.

main factor that can be used to predict searching times. In view of these findings, the following patterns of the desired computer screen format can be proposed:

(B) *IF* (information items are properly grouped) *AND* (the mean visual angle is SMALL), *THEN* (GSD = RATHER-LESS-THAN-60)
ELSE
IF (information is *NOT* properly grouped) *OR* (the mean visual angle is LARGE), *THEN* (GSD = MUCH-LESS-THAN-60).

The following limiting definition for GSD is proposed to keep the number of variables at the minimal level. If information items are grouped in small "chunks," the screen density limit is less restrictive (i.e., GSD = RATHER-LESS-THAN-60) than when there are large-sized groups of information or lack of such groups (i.e., MUCH-LESS-THAN-60). The proposed limits are represented in Table 1 and Figure 2. In Pattern B, the variables that represent visual angles are related to the results of Danchak's (1976) study of human visual field. The group of data which does not exceed the visual angle of about 5;18 can be taken in at one eye fixation. The exemplary definitions of SMALL and LARGE angle limits based on fuzzy approach are presented in Table 1.

One must first find all limits of the fulfillment to determine the degree to which a given screen format fulfills Pattern B. Table 1 shows the required visual angles and GSD values. Additionally, another fuzzy term of "proper grouping" should be defined and made operational in some way. In actual screen analysis, one can easily determine a "degree of proper grouping" of items. Therefore, it is reasonable to propose a "lower level pattern" to determine the degree of proper grouping as the following:

(B′) *IF* (two information items are (functionally) SIMILAR), *THEN* (they are placed in the same group (location) on the screen).

The degree of proper grouping, which can be calculated by including each pair of information items in any real screen format, is in the following formula:

$$\textit{truth} \text{ of (information items are properly grouped)} = \frac{\sum_{\text{all pairs}} \text{truth of (B}')}{\text{number of pairs}} \tag{8}$$

Equation 8 expresses the mean truth value for proper grouping of all pairs of information items. Pattern B;19 needs to be made operational for two items representing functional similarity measures. In most practical cases, the user-expert can generate directly the assessment values of similarity. The natural language expressions such as SIMILAR, VERY SIMILAR, RATHER SIMILAR constitute a convenient form of this assessment. If these expressions are represented in the fuzzy convention, one can use the possibility (POSS) measure (4) to indicate the consistency between the pattern limit (SIMILAR) and a given assessment of an expert, as illustrated in Figure 1. The final assessment data can have a form similar to the example shown in Table 2.

The procedure used to determine the truth value of B′ is as follows:

1. Using Equation 8, determine p_0 = *truth* of (information items are properly grouped), and using Formula 1, determine the B′ fulfillment for each pair of information items.
2. Determine p_1 = *truth* of (mean visual angle is SMALL), and
   p_2 = *truth* of (mean visual angle is LARGE) by substitutin the given actual mean angle, in SMALL and LARGE limit definitions, respectively (see Table 2).
3. Calculate q_1 = *truth* of (GSD = RATHER-LESS-THAN-60), and
   q_2 = *truth* of (GSD = MUCH-LESS-THAN-60) by substituting a measured level of GSD in RATHER-LESS-THAN-60 and MUCH-LESS-THAN-60 limit definitions, respectively.
4. At this time, the truth values for all elements of the complex Pattern B have already been defined. The truth value of the statement "information items are properly grouped (see Pattern B) is denoted as p_0. Similarly, the truth value for the statement "Mean visual angle is SMALL" is denoted as p_1. Furthermore, q_0 denotes the degree to which a given screen density is compatible to "RATHER-LESS-THAN-60." The truth value of the first (left) part of Pattern B can be determined using the formulas (1, 5, and 6), as well as the rules described in Section 2 (f). One can use the MIN operator (i.e., min (p_0, p_1)) which corresponds to conjunction of expressions by AND. The truth of the first part of Pattern B will then be defined according to Formula 1 as: min $(1, 1 - \min(p_0, p_1) + q_1)$. In a similar fashion, the truth of the second part of Pattern B will be defined as: min $(1, 1 - \max((1 - p_0), p_2) + q_2)$. The operator MAX represents the junction OR.

Finally, in view of this discussion, the overall truth of Pattern B can be expressed as follows:

Table 2. An Exemplary Form of Similarity Assessment Data Given by Experts to the Screen Information Placed on the Screen From Figure 3.

Item Number	2	3	4	5	6	7	8	9	10
1	0.0	**0.8**	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2		0.0	0.0	0.0	**0.9**	0.0	**0.9**	0.0	0.0
3			0.0	0.0	0.0	0.0	0.0	0.0	0.0
4				**1.0**	0.0	**0.9**	0.0	0.0	**0.8**
5					0.0	0.9	0.0	0.0	**0.8**
6						0.0	**1.0**	0.0	0.0
7							0.0	0.0	0.0
8								0.0	0.0
9									0.0

$$truth\ of\ B = \min \begin{cases} \min(1, 1 - \min(p_0, p_1) + q_1) \\ \min(1, 1 - \max(1 - p_0, p_2) + q_2) \end{cases} \quad (9)$$

The following example illustrates the above evaluation process. The screen format which is evaluated appears schematically in Figure 3. Degrees of similarity were defined by an expert and are given in Table 2. Empty places define the "lack of similarity." It is assumed that human expert opinions are rational. Because the similarity level of 1.0 means "full similarity," information items 4 and 5 have the same levels of similarity as Items 6 and 8.

According to the previously outlined procedure 1 through 4, one can analyze Pattern B;19 fulfillment through Table 2 and Figure 3 for each pair of information items. Calculations in this stage can be limited to pairs having similarity assessments greater than 0. The lack of similarity means fulfillment of patterns in the degree of 1.0 [min (1, 1 − 0 + q) = 1].

Using Figure 3, one can determine whether a given pair can be placed in the same group of information items or not and can assign an appropriate truth value (0 or 1) for the given pair. Exemplary analysis for pair 4–10 leads to the following result: *truth* of B′ = min(1, 1 − 0.8 + 0.0) = 0.2. Similarly, pair 1–3 yields the *truth* value of B′ = min(1, 1 − 0.8 + 1) = 1. Consequent calculations lead to the conclusion that the *truth* of (information items are properly grouped) = p_0 = 40.6/45 = 0.9. Furthermore, according to Figure 2 and Table 1, one can determine the following truth values:

p_1 = *truth* of (8.5 = SMALL) = 0.2
p_2 = *truth* of (8.5 = LARGE) = 0.8
q_1 = *truth* of (55 = RATHER-LESS-THAN-60) = 0.6
q_2 = *truth* of (55 = MUCH-LESS-THAN-60) = 0.2

Finally, using Equation 9, the truth of Pattern B can be calculated as follows:

$$truth\ of\ B = \min \begin{cases} \min(1, 1 - \min(0.9, 0.2) + 0.6) \\ \min(1, 1 - \max(0.1, 0.8) + 0.2) \end{cases} = 0.4$$

Therefore, the "degree (truth) of fulfillment of Pattern B" is rather small. Simple analysis of data enables one to find reasons that explain this result, that is, the information density is too high and the item group size is too big.

Pattern B can be applied to actual screen formats presented by Tullis (1988) who tested two configurations of screen format with respect to information loading. The first configuration had screen density of about 31% and no groups. The second configuration was grouped with the mean visual angle equal to 4.8;18 and had similar screen density (see Figure 3 in Tullis, 1988). Assuming that the *truth* of (information items are properly grouped) = 1, the grouped configuration can be assessed according to Pattern B as follows:

$$truth\ of\ B\ (grouped) = \min \begin{cases} \min(1, 1 - \min(1, 1) + 1) \\ \min(1, 1 - \max(0, 0) + 0.6) \end{cases} = 1.0$$

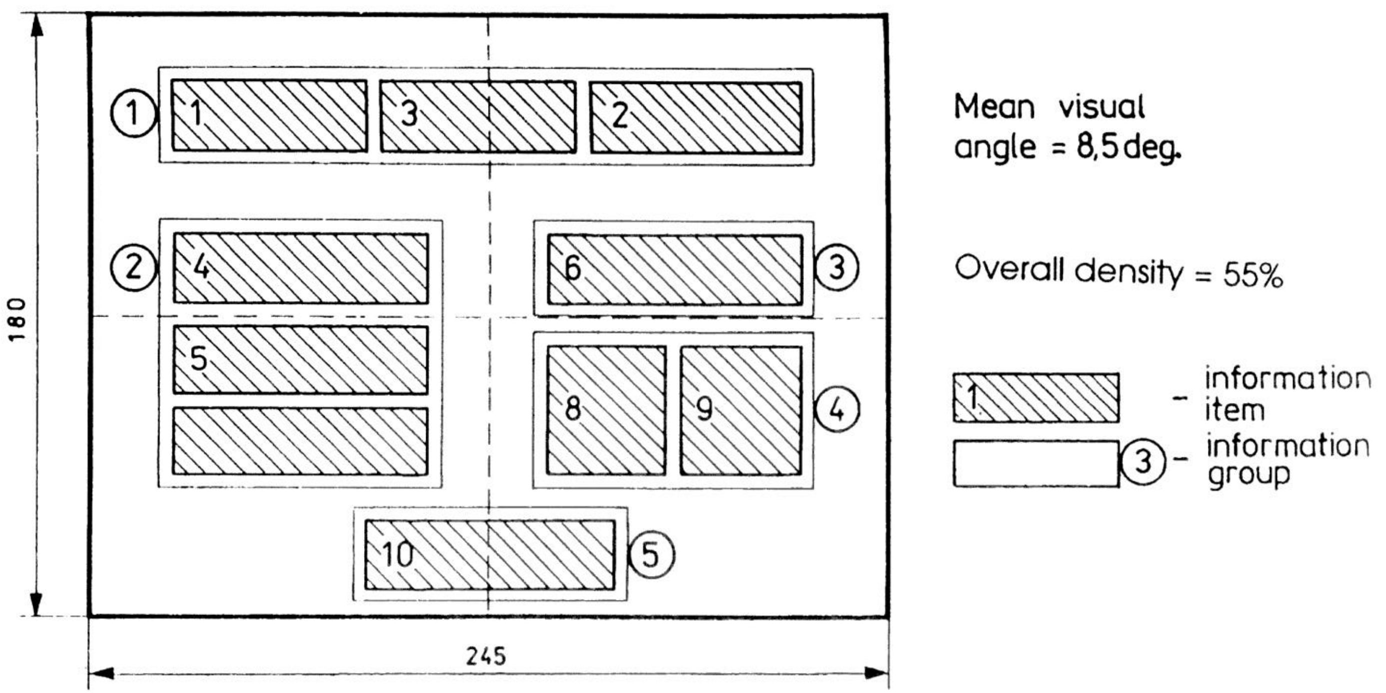

Figure 3. An exemplary screen layout scheme.

and the configuration without groups as follows:

$$\textit{truth of B (without groups)} = \min \begin{cases} \min(1, 1 - \min(0, 0) + 1) \\ \min(1, 1 - \max(1, 1) + 0.6) \end{cases} = 0.6$$

Therefore, according to Pattern B, the computer screen format with grouped information items is optimal. In empirical tests, the searching times for the grouped format were about 70% shorter than for the ungrouped ones.

Finally, it should be noted here that the proposed methodological framework for computer screen design will significantly augment, not impair, the efforts of the human designers who will be using it. The human designers will not be required to perform any analytical work, as this will be done by the computer-based system with appropriate fuzzy algorithms. Therefore, the proposed framework will be much more precise and effective than application of the rules of thumb, improving the quality of computer screen design with greater productivity level.

4. LOGICAL INFORMATION LINKS AND THE SCREEN LAYOUT

The rules for searching visual information on the computer terminal constitute an important criteria of screen layout. A study by Streveler and Wasserman (1984) showed that the natural human scanning patterns during reading (left–right, up–down) influence the visual searching process on a VDT. Therefore, the upper left part of the screen should be treated as a prominent location, and the lower right as least desirable. Given these findings, the most desirable or frequently used information should be placed in a prominent location. By analogy to Patterns A-B, the following propositions constitute a formal optimal screen model which reflects these remarks:

(C) IF frequency (of a given item) is BIG *THEN* location (of this item) is PROMINENT,

(D) IF importance (of a given item) is BIG *THEN* location (of this item) is PROMINENT.

One can determine to what degree a given screen format satisfies Patterns C and D by defining the limits for the BIG and PROMINENT categories in appropriate universes. Variables appearing in C and D are very different if one wants to "measure" their realizations, because unlike the "importance" of a given item, its "frequency" and "location" are physically measurable quantities. One can determine the percentage frequency of possible system functions in which a given item is or will be used and find a location using the coordinates of the screen. However, the intangible level of importance should be determined by an expert user in an arbitrary manner.

Some of the arbitrary definitions of limits for the BIG and PROMINENT categories in appropriate universes of discourse are shown in Table 3 and Figure

4. Due to the lack of precise data, the linear function shapes were assumed. In addition, it was proposed that the importance has the same "percentage" universe as the frequency, even though these two variables have different measurement procedures.

Since Patterns C and D represent individual items, the formula that enables one to assess the general screen format can also be proposed. A simple formula can be an "average truth" for all information, that is,

$$truth\ of\ C = \frac{\sum_{i=1}^{n} truth\ of\ (C, i)}{n} \qquad (10)$$

$$truth\ of\ D = \frac{\sum_{i=1}^{n} truth\ of\ (D, i)}{n} \qquad (11)$$

where n denotes a number of information items, and *truth* of (C,i) means truth value that fulfills Pattern C by the i-th element that can be calculated according to Formula 1.

Some authors also emphasize another kind of screen layout analysis which takes into account the links between information and their layouts. For example, Tullis (1988) pointed out that it is necessary to keep "natural" sequences of information in the screen format. Often this criterion is simple to interpret and apply, especially in screen formats that are designed to display flows of well-structured information such as filling in standard forms in banks. However, the problem appears in screen formats designed for highly interactive multifunction programs where sequences appear "partially" (i.e., some items are used after others very frequently, some rather rarely, etc.). In both of these situations, the patterns can constitute a "general frame" for a frequency criterion which enables one to determine the quantitative assessment of the screen. For example, one can propose the following information pattern:

(E) IF element j is used after i VERY OFTEN *THEN* i and j are ADJACENT *AND* i GOES BEFORE j (on the screen)

The explanation of the above pattern is simple. Each pair of information that is often used sequentially should be placed adjacent to one another with respect to the "natural scanning" of visual information searching (left–right, up–down).

Table 3. Examples of Frequency of Use and Importance of Information Item in the Percentage Scale

Element Number	1	2	3	4	5	6	7	8	9	10
Frequency of use (%)	56	56	25	25	25	25	25	10	10	65
Importance (%)	25	10	10	10	25	50	10	10	10	60

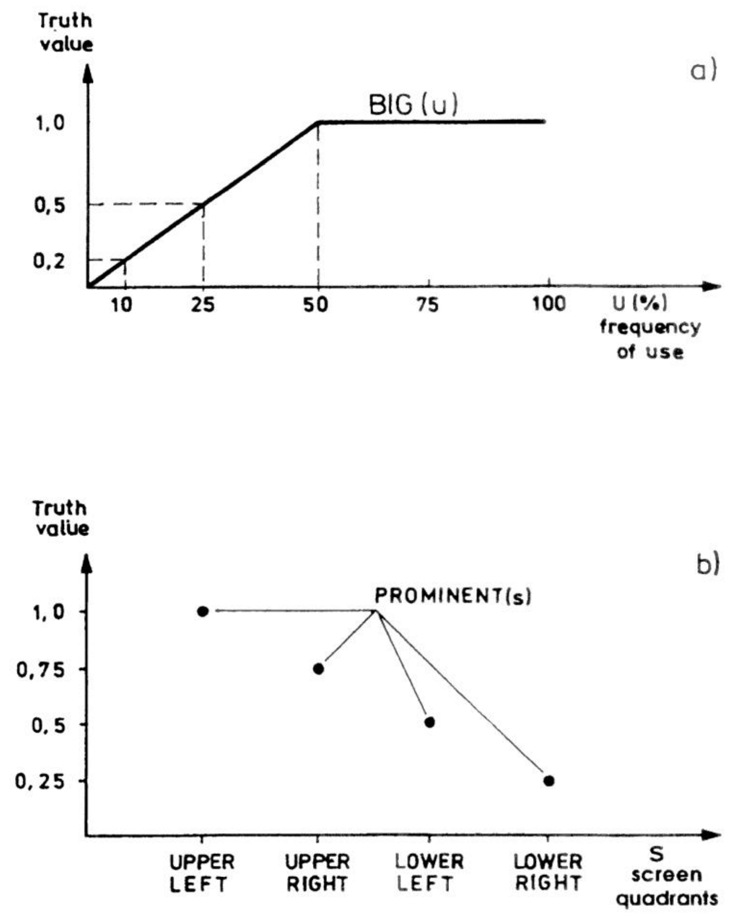

Figure 4. Truth value functions of limit definitions:(a) BIG in the frequency of use space, and (b) PROMINENCY of screen quadrants.

To put Pattern E into practice, the limits (VERY OFTEN, ADJACENT, GOES BEFORE) must be defined, as before, in appropriate universes. Possible propositions are illustrated in Figure 5. The universe for the VERY OFTEN limit definition is assumed to express a percentage of cases in which j appears in sequences directly after i. In a sense, the definition of i GOES BEFORE j reflects the results of research on visual information searching (scanning left–right, up–down). However, this proposal needs further empirical support and perhaps should be more precise.

Because Pattern E is defined for one pair of items, by analogy to Pattern B, the general assessment of screen design can be calculated according to the following formula:

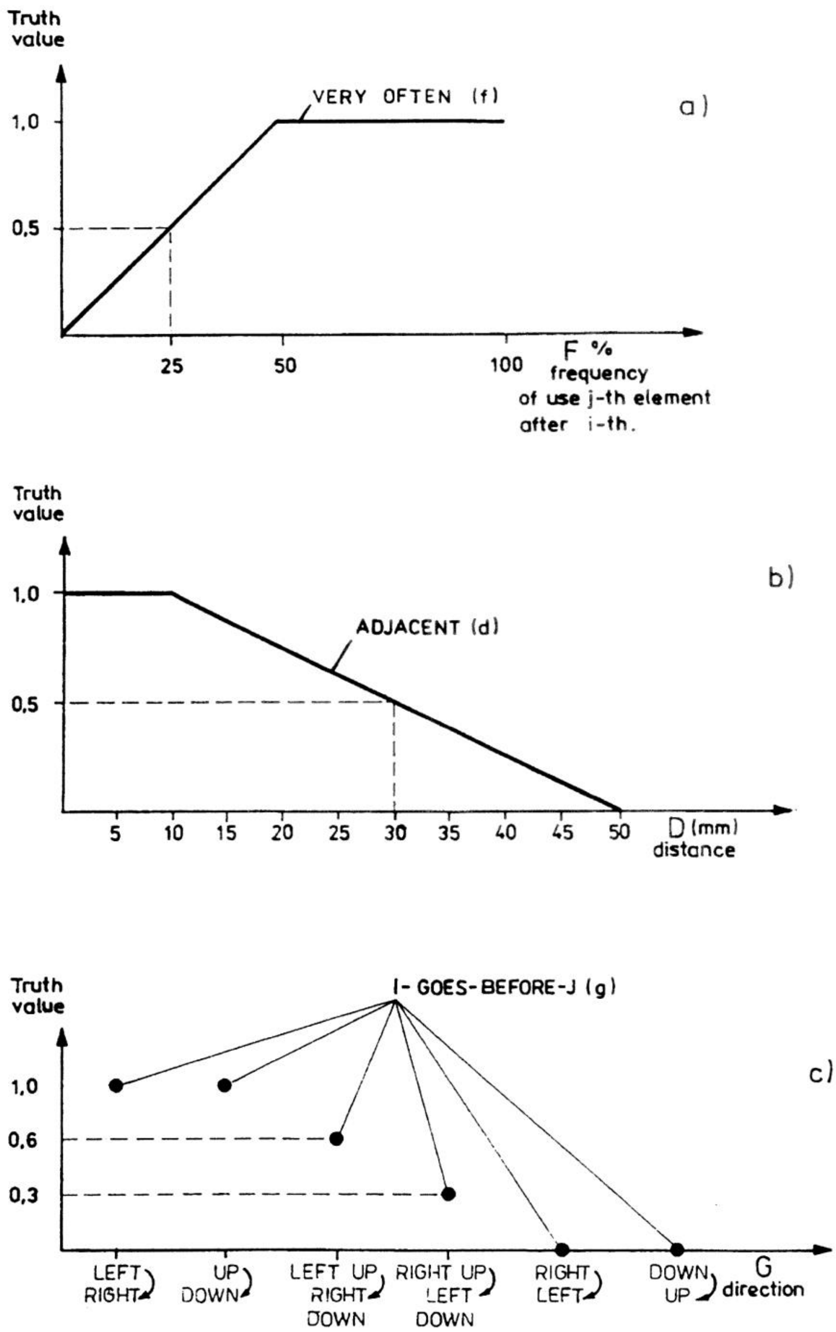

Figure 5. Propositions of limit definitions for Pattern E.

$$truth\ of\ E = \frac{\sum_{all\ pairs\ i,j} truth\ of\,(E, i\text{–}j)}{\text{number of pairs}} \qquad (12)$$

where *truth* of (E, i–j) stands for a truth value of E for the i–j pair. If p denotes the truth value that fulfills the limit "element j is USED VERY OFTEN AFTER element i" by the given pair i–j, q_1 and q_2, respectively, truth of "i–j are ADJACENT" and "i GOES BEFORE j" then

$$truth\ \text{of}\ (E, i\text{–}j) = \min(1, 1 - p + \min(q_1, q_2)). \qquad (13)$$

Formula 13 stems directly from 1 and 5.

5. EXAMPLE

The following numerical example illustrates how one can assess a given screen by implementing the proposed patterns. Assuming the screen format from Figure 3, one can calculate degrees satisfying Patterns C, D, and E using definitions from Figures 4 and 5, as well as data gathered in Tables 3 and 4. The first exemplary step of computations for Pattern C may be as follows.

The frequency of use of information item labeled 1 (Table 3) is calculated to be 56%. This indicates that Item #1 is used in 56% of all functions realized (performed) by the use of the screen schematically depicted in Figure 3. One may also determine that the analyzed information item should be placed in the upper left quadrant. Based on Figure 4, one can calculate that (a) BIG(56%) = 1 and (b) PROMINENT (UPPER LEFT) = 1, so that the *truth* of (C,1) = min (1,1 − 1 + 1) = 1.

Analogically, using the same scale of importance for Pattern D, one can determine that the importance for Item #1 is equal to 25%, and the *truth* of (D,1) = min(1,1 ;12 0.5 ;11 1) = 1. Because BIG(25%) = 0.5 and PROMINENT (UPPER LEFT) = 1, consequent calculations performed in this manner yield the following:

— *truth* of (C, 1 . . . 10) = (1,0.75, 1,1,1,1,1,1, 0.25), and
— *truth* of (D, 1 . . . 10) = (1,1,1,1,1,0.75,1,1,1,0.25).

From Equations 10 and 11, one can calculate that the *truth* of C = 0.9 and the *truth* of D = 0.9. Pattern E is defined for a pair of information items. Using Tables 4 and 5 and Figure 5, one can calculate pair 1–2 using the following three steps:

1. From Table 4 and Figure 5a, determine: VERY-OFTEN (25%) = 0.5.
2. From Table 5 and Figure 5b, determine: ADJACENT (80 mm) = 0.0.
3. From Figure 3 and Figure 5c, determine: i GOES BEFORE j (left-to-right) = 1.0.

Table 4. Observed Percentages of Sequences for the Analyzed Example.

Element Number i	j: 2	3	4	5	6	7	8	9	10
1	25	10	25	10	5	5	0	0	0
2		10	25	10	5	5	0	0	0
3			25	10	5	5	0	0	0
4				10	15	15	0	0	0
5[a]					0	30	0	0	0
6						0	50	10	0
7							0	0	25
8								30	20
9									30

[a]Observed percentage of usage i just before.

This analysis shows that the general fulfillment of Pattern E is

$$truth \text{ of } (E, 1\text{–}2) = \min(1, 1 - 0.5 + \min(0, 1)) = 0.5.$$

Calculations for all pairs give the following matrix:

truth of (E, 1–2, . . . , 1–10) =	0.5,	1.0,	1.0,	1.0,	0.6,	0.9,	0.6,	0.6,	1.0
		0.0,	0.3,	0.3,	1.0,	0.3,	1.0,	1.0,	1.0
			1.0,	1.0,	1.0,	0.9,	0.6,	0.6,	1.0
				1.0,	1.0,	1.0,	0.6,	0.6,	1.0
					0.0,	1.0,	0.6,	0.6,	1.0
						0.3,	0.55,	1.0,	1.0
							1.0,	1.0,	1.0
								1.0,	1.0
9–10)									0.3

From Equation 12, one can obtain the *truth* value of Pattern # E = 0.77. Therefore, the degree satisfying Pattern E is lower than the degrees calculated for Patterns C and D.

Table 5. Approximate Distances Between Each Pair of Information Items Placed on the Screen From Figure 3.

Element Number	2	3	4	5	6	7	8	9	10
1	80	20	10	25	60	80	90	100	120
2		20	50	65	10	80	75	75	90
3			10	25	10	80	75	75	90
4				5	30	25	40	50	60
5[a]					40	5	30	40	50
6						50	25	25	40
7							30	50	25
8								5	25
9									30

[a]Distances i–j [mm].

6. OPTIMIZATION PROBLEMS

A formal approach to screen design presented in the form of Patterns A through E enables one to express different aspects of assessment in the same truth value categories. The proposed system of patterns constitutes a consistent set of criteria according to which a given screen format can be evaluated. From a formal point of view, the task of a screen designer is to resolve a multicriteria optimization problem. If one assumes that the general measure of project quality can be defined as

$$\textit{truth} \text{ of (screen = optimal)} = \frac{\textit{truth of } B + \textit{truth of } C + \textit{truth of } D + \textit{truth of } E,}{4} \tag{14}$$

then the designer's task is to maximize this measure through an appropriate screen configuration.

The designer is faced with a choice of different optimization methods. The designer needs to know the procedures or algorithms which allow him/her to attain the maximal level of expression (14). Because the task defined by Patterns A through E is closely related to facilities layout problems (FLP), some results from the FLP sphere can be utilized in the screen design domain. The ideas presented by Grobelny (1987a, 1987b, 1988) enable one to build a formal suboptimal algorithm based on the "maximal truth theorem." This theorem can be shortly outlined as follows:

> Let A and B denote linguistic limit expressions of a pattern "IF X is A THEN Y is B," and $\{A_1 \ldots A_n\}$, $\{B_1 \ldots B_n\}$ are sets of possible realizations of X and Y, respectively.

If $|A_1|$ and $|B_i|$ denote truth values satisfying A and B, respectively, then the "mean truth value" for a given realization's set can be expressed as:

$$\textit{truth of } (A_1 \ldots A_n, B_1 \ldots B_n) = \frac{\sum_{i=1}^{n} \textit{truth of } (\textit{IF } A_i = A \textit{ THEN } B_i = B)}{n} \tag{15}$$

where *truth* of (IF A_i = A THEN B_i = B) is calculated according to Formula 1, that is, *truth* of (IF A_i = A THEN B_i = B) = $\min(1, 1 - |A_i| + |B_i|)$.

The maximal truth theorem says that Equation 15 is maximal for such ordered sets of $A + \ldots A_n$ and $B_1 \ldots B_n$ in which $|A_i| > |A_{i+1}|$ and $|B_i| > |B_{i+1}|$. This means that the above sets are ordered in a decreasing way according to the degrees to which they fulfill limits.

In case of simple individual patterns, this theorem is simply a recipe for an optimal search for a solution. For example, taking into account only Pattern C, one can sequentially locate the most frequently used items in most prominent available screen fragments. A similar algorithm is valid for a separately used Pattern D. The problem with general optimization of screen design is the fact that simple applications can be given completely different *optimal* screen formats. In order to maximize Formula 14, one cannot maximize B, C, D, and E separately. In light of the *maximal truth theorem*, the general approach can be based on calculations of common mean of truth degrees for all items with respect to left sides of all patterns, and the sequential location of best evaluated items that are located in the most prominent available places which satisfies the appropriate sequential configuration.

Even in the form of a formalized algorithm, this recommendation should be treated as an interactive design process aid, rather than an automatic problem solver (Grobelny, 1988). This point needs emphasis because the problem under discussion has no analytical solution (Grobelny, 1987a). In view of the above explanations, the proposed approach provides tools which can support designers' decisions while improving existing formats. For example, one can calculate how a degree of general truth value expressed by Formula 14 changes when replacing an item's pair locations or moving an item in a given direction on the screen.

7. CONCLUSION

The linguistic design patterns proposed in this study enable one to construct a desired computer screen format model using an existing structured knowledge in the human–computer interaction domain. The described ideas will support the screen design process when they are implemented on a computer. Even a nonexpert and an average programmer can evaluate his/her ideas when he/she uses the pattern's model at different steps of screen design. The proposed category of truth value (degree of truth, degree of pattern fulfillment, etc.) constitutes the measure quantifying screen format quality with respect to an ideal project, defined by a set of patterns. Therefore, any two projects can be compared in a quantitative way. The degree of precision and sensitivity of the model will depend on the quality of implemented knowledge, its mapping in patterns, and interpretations of limits. The flexibility of the proposed approach to computer screen design seems appropriate given the imprecise knowledge in the human–computer interaction domain (Karwowski et al., 1990). Linguistic patterns create a possibility for a convenient knowledge acquisition from human experts. The quality of the linguistic patterns-based models should improve with the development of human–computer interaction knowledge.

The linguistic patterns which allow for representation of sentences in a manner close to a natural language were used in this study to represent formal description of the requirements for optimal design of selected structural aspects of the computer screens. The source of knowledge for exemplary applications of the proposed framework can be the experimental data and the well-accepted general guidelines for screen design. This study showed that it is possible to achieve a rational and easy to interpret assessment of the given screen design in the form of the degrees of truth. Such evaluation criterion reflects the compatibility of a computer screen's design with an optimal one based on the current knowledge represented in the proposed framework.

It should be noted that the proposed methodological framework should significantly augment the efforts of the human designers. The designers will not be required to perform any analytical work, as this will be done by the computer-based system with appropriate fuzzy algorithms. Therefore, it is believed that the proposed framework will be much more precise and effective than traditional application of the rules of thumb, improving the quality of computer screen design and assuring greater productivity of design efforts.

Obviously, the choice of types of variables in this study does not permit use of the proposed framework as a tool to analyze all of the related human–computer interface design problems, but rather illustrates one of the many potential applications of the proposed approach. The selected examples also illustrate the essence of the proposed approach when using different types of knowledge, from precise physiological data (like the visual angle), through variable information about the effect of screen density on ease of information searching, to generally accepted rules of information placement. Finally, the concepts illustrated in this article constitute a basis for development of the computer-based system that would augment efforts of the designers of human–computer interfaces. The proposed modeling framework should also enhance the integration of current knowledge about computer interface design.

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