Modelling the Quality of Adapted Textbooks for People with Low Vision

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***Abstract*— People with low vision are one of the primary demographics that make use of accessible content. These users often face difficulties when trying to use regular publications, and the wide variety of vision impairments means the issue of adapting printed publications for this category of readers is far from solved. In this study, we develop a formalized model of adapting textbooks with the help of a semantic network. We then create two multi-level models of factors that influence the quality of adapted textbooks – one with the help of hierarchical modelling, and the other by ranking and determining predicate weights. These models can serve as a baseline for further research into designing a fully optimized model of textbook adaptation.**

Keywords*— *low vision; vision impairment; accessibility; semantic network; modelling

I. Introduction

In recent years, information systems have established themselves as an essential component of established publishing and printing technologies. The widespread development of information technologies has radically changed the nature of data collection, processing, storage and transmission, affecting all parts of a publication or other printed product. In particular, significant progress has been achieved in the area of electronic publications – their advantages over printed literature in terms of production, volume and distribution speed made them gain popularity all over the world. Their digital nature means they can be presented not only as text, but as a multimedia combination of text, graphics, sound, animation and video all in one publication.

However, for people with low vision or vision impairment, these publications present the same challenges as printed ones. For them, the size and structure of the texts they consume are of utmost importance. The legibility of literature to this category of consumers and their suitability for technical use is affected by several technological requirements. These include, among other factors, the structuring of books, printed or digital alike; appropriate font design; a carefully selected color gamut; and ensuring a proper contrast between different elements on a page, especially images and graphics. Particular attention should be paid to literature in our focus area – textbooks designed for students who may not have access to easily configurable electronic publications.

In this study, we develop an informational model that assesses the overall quality of a textbook's adaptation to the needs of readers with low vision. In this model, the factors influencing the quality of textbook adaptation become either generalized informational or linguistic variables. As a result of this modelling process, it becomes possible to use methods and techniques of system analysis, hierarchical modelling and multi-criteria optimization to establish the highest-priority factors, and calculate the optimal process for adapting a publication. Additionally, fuzzy set theory can be further used to predict a publication's level of quality.

II. Literature Review

Much scientific research in the area of adapting educational resources for people with low vision are general overviews and reports. One example of such literature reviews is the work of researchers from Mexico [1], which provides a wide range of strategies that can be used for experimental sciences – that is, biology, chemistry and physics. Its suggested educational materials include devices that can output their readings as sound, and accessible tactile models. The authors suggest that learning resources used by both sighted and visually impaired students should be one and the same; in other words, a textbook printed in Braille could still have regular printed text and color illustrations. Other reports such as [2] and [3] investigate de-facto adoption of accessible technologies; their findings suggest that learning institutions have both a legal obligation and high enthusiasm about establishing equal access to learning materials, yet textbook publishers do not always follow best practices for adapted publications.

Several published papers focus on adapting small isolated components of textbooks to readers with low vision. In one study [4], the authors focus on representing elements that are frequently used in physics textbooks when describing mechanical problems – ropes, pulleys, blocks and surfaces – as a series of symbols accessible to blind students.

This method is tested at a specialized school with satisfactory results. Another paper touches upon the periodic table, an essential tool in a chemistry class; its authors design two freely accessible electronic periodic tables, one designed for screen readers, the other – digital audio devices and Braille displays [5]. A study by a team of German researchers deals with a more generalized method of adapting accessible graphics, developing a software tool that helps make them more accessible without the need of manual transcription [6]. However, comprehensive mathematical models that deal with adapting whole textbooks rather than individual sub-components have not been previously developed, to the best of our knowledge.

III. Semantic Network for Adapted Textbook Parameters

The set of factors related to the process of adapting textbooks for people with vision problems is defined by eight main parameters. These requirements were defined after reviewing several international standards for printed publications adapted to people with low vision, otherwise known as "large print" publications, and aggregating them into a novel accessibility standard. While some parameters are defined with the help of parametric numerical characteristics, others utilize a linguistic variable. Their full set is defined as follows [7]:

$$X = \{x_1, x_2, \ldots, x_8\} \quad (1)$$

Here, x_1 refers to text color; x_2 – hyphenation (separating syllables of a single world); x_3 – font size of the publication's main body; x_4 – font characteristics such as font family and italicization; x_5 – page formatting, particularly margins; x_6 – size of graphics; x_7 – contrast of graphics; and x_8 – saturation of a page's background.

In order to numerically express the degree (weight) of the influence of the specified factors on the textbook adaptation process, we present connections between them using a semantic network. It is considered a subtype of a directed graph. The nodes and vertices of it reflect the semantics of informational factors in the process, whereas the edges represent functional relations between pairs of vertices [8]. The directions of the edges represent the nature of the connection between two factors, i.e., whether one of them directly influences the other.

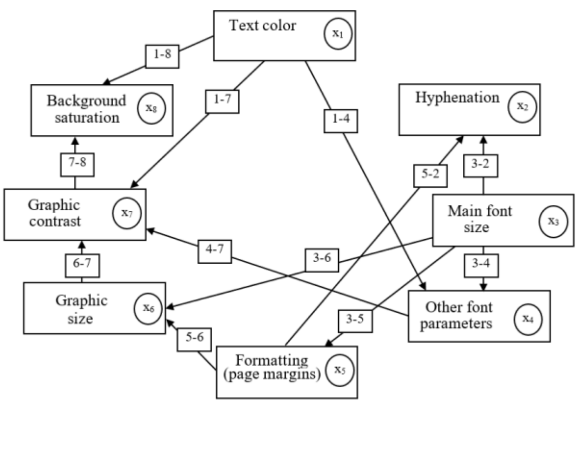

Fig. 1. Semantic network of textbook adaptation factors

Besides the two connecting nodes and an edge, each of the edges in a semantic network is associated with a natural-language predicate describing the nature of the connection. These are defined by an auxiliary set of logical relations as described below. Here, ∧ refers to a logical "and", ∨: logical "or", ←: logical "if", ∀ - universal quantification ("for each"), ∃ - existential quantification ("at least one").

- $(\forall x_i)$ [∃ (x_1, text color) ← conditions (x_1, x_4) ∧ influences (x_1, x_7) ∧ forms (x_1, x_8)];
- $(\forall x_i)$ [∃ (x_2, hyphenation) ← based on (x_2, x_3) ∧ influenced by (x_2, x_5)];
- $(\forall x_i)$ [∃ (x_3, font size) ← is basis of (x_3, x_2) ∧ predicts (x_3, x_4) ∧ conditions (x_3, x_5) ∧ predicts (x_3, x_6)];
- $(\forall x_i)$ [∃ (x_4, other font parameters) ← conditioned by (x_4, x_1) ∧ predicted by (x_4, x_3) ∧ forms (x_4, x_7)];
- $(\forall x_i)$ [∃ (x_5, formatting, page margins) ← influences (x_5, x_2) ∧ conditioned by (x_5, x_3) ∧ defines (x_5, x_6)];
- $(\forall x_i)$ [∃ (x_6, graphic size) ← predicted by (x_6, x_3) ∧ defined by (x_6, x_5) ∧ defines (x_6, x_7)];
- $(\forall x_i)$ [∃ (x_7, graphic contrast) ← influenced by (x_7, x_1) ∧ formed by (x_7, x_4) ∧ defined by (x_7, x_6) ∧ conditions (x_7, x_8)];
- $(\forall x_i)$ [∃ (x_8, background saturation) ← formed by (x_8, x_1) ∧ conditioned by (x_8, x_7)].

This formal representation combines linguistic descriptions and formalized representation of relationships between different factors in the form of a graph. Thus, it enables the use of hierarchy modelling methods to model the hierarchies within the graph and rank each factor in order of importance, and the use of fuzzy logic to mathematically evaluate a publication's adaptation quality.

IV. Multi-Level Model of Textbook Adaptation Using Mathematical Hierarchy Modelling

The priority levels of each factor are determined using the method of mathematical hierarchy modelling, starting with a square matrix built on the basis of direct connections between each node [9, 10]. Its binary elements are formed on the basis of a logical reachability rule:

$$\alpha_{ij} = 1 \text{ if a path from node } i \text{ to node } j \text{ exists} \quad (2)$$

$$a_{ij} = 0 \text{ otherwise} \quad (3)$$

TABLE I. Reachability Matrix of the Semantic Network

	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8
X_1	1	0	0	1	0	0	1	1
X_2	0	1	0	0	0	0	0	0
X_3	0	1	1	1	1	1	0	0
X_4	0	0	0	1	0	0	1	0
X_5	0	1	0	0	1	1	0	0
X_6	0	0	0	0	0	1	1	0
X_7	0	0	0	0	0	0	1	1
X_8	0	0	0	0	0	0	0	1

The next step is to use iterative tables, creating the first of them according to the following rules: the number of rows is determined by the number of factors; the first column contains factor numbers, the second – the numbers of elements of the reachability matrix that correspond to the rows reachable from this element (denoted as $R(m_i)$), and the third – elements of the reachability matrix's columns, denoted as $S(m_i)$. The final column represents an intersection of the previous two sets. In this iterative table, the highest-priority tables must meet the condition:

$$S(m_i) = R(m_i) \cap S(m_i) \quad (4)$$

TABLE II. FIRST-LEVEL ITERATIVE TABLE FOR FACTOR WEIGHTS

i	**R(mᵢ)**	**S(mᵢ)**	**R(mᵢ)∩ S(mᵢ)**
1	1,4,7,8	1	1
2	2	2,3,5	2
3	2,3,4,5,6	3	3
4	4,7	1,3,4	4
5	2,5,6	3,5	5
6	6,7	3,5,6	6
7	7,8	1,4,6,7	7
8	8	1,7,8	8

The condition (4) – i.e., matching third and fourth columns in the table – is fulfilled for factors 1 and 3; text color and text size respectively. These factors are therefore considered to have the highest priority level. The next step of the iterative process is to remove the rows corresponding to these factors from the previous table, and omit the numbers 1 and 3 from the second and third columns.

TABLE III. SECOND-LEVEL ITERATIVE TABLE FOR FACTOR WEIGHTS

i	**R(mᵢ)**	**S(mᵢ)**	**R(mᵢ)∩ S(mᵢ)**
2	2	2,5	2
4	4,7	4	4
5	2,5,6	5	5
6	6,7	5,6	6
7	7,8	4,6,7	7
8	8	7,8	8

Checking each row for compliance with condition (4), we see that the second highest priority level is created by the factors 4 (font characteristics) and 5 (page formatting & margins). We repeat the iterative process again.

TABLE IV. THIRD-LEVEL ITERATIVE TABLE FOR FACTOR WEIGHTS

i	**R(mᵢ)**	**S(mᵢ)**	**R(mᵢ)∩ S(mᵢ)**
2	2	2	2
6	6,7	6	6
7	7,8	6,7	7
8	8	7,8	8

The factors 2 (hyphenation) and 6 (graphic size) therefore belong to the third priority level. Repeating the iterative process for a further two levels suggests that graphic contrast belongs to priority level 4, and page background – to level 5. The implemented iterative procedures, well-defined in the theory a system analysis [9, 10], enable us to determine the levels of importance of a number of factors related to adapting textbooks for people with low vision. As a result, we create a multi-level model (Fig. 2), which will further become the basis of obtaining numerical priorities for textbook adaptation factors.

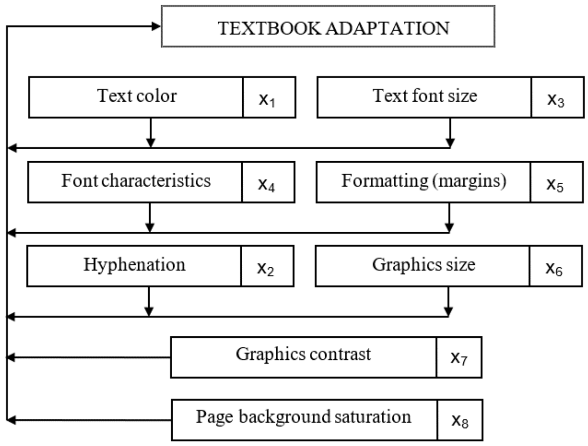

Fig. 2. Model of factors influencing textbook adaptation (hiearchical)

V. MODEL OF TEXTBOOK ADAPTATION USING RANKING AND DETERMINING PREDICATE WEIGHTS

An alternative method of ranking of a semantic model is to calculate the ranks of each of its nodes. The prerequisite for this method is to calculate numeric weights for each node regardless of the presence of predicates [11]. To create a model using this method, we present a brief mathematical interpretation of it.

Let z_{ij} be the number of connections between the i-th connection type and j-th node in the graph; w_i – the weight of the i-th connection type. Connection types refer to the direction of the edge in the semantic network: $i = 1$ means that the source node of the edge is influencing the target node, whereas $i = 2$ refers to the inverse connection, showing a dependency of the source node on the target node. Additionally, influence edges have positive weights, whereas dependency edges have negative weights; in other words, $w_1 > 0$, $w_2 < 0$. The total weight of the influence of different factors on the quality of adaptation, taking into account different connection types, is denoted by the variable S_{ij}, the value of which is obtained from (5):

$$S_{ij} = \sum_{i=1}^{2}\sum_{j=1}^{n} z_{ij} w_i \quad (5)$$

Since, according to these prerequisites, $S_{2j} < 0$, the values obtained in our calculations must be corrected by the value of $\Delta_j = max|S_{2j}|$, $j = 1, 2, \ldots, n$. This makes the previous equation take the following form:

$$S_{Fj} = \sum_{i=1}^{2}\sum_{j=1}^{n}\left(z_{ij} w_i + \max\left|S_{2j}\right|\right) \quad (6)$$

Our next step is to calculate these values for the semantic network defined in figure 1. Initially we do not account for predicate weight coefficients, instead setting $w_1 = 10$ and $w_2 = -10$. After calculating S_{Fj} for each node in the network, we determine its priority level by sorting these values in ascending order. The results of this ranking method are as follows:

TABLE V. INITIAL RANKING OF ACCESSIBILITY FACTORS

j	Z_{1j}	Z_{2j}	S_{1j}	S_{2j}	S_{Fj}	*Priority*
1	3	0	30	0	60	2
2	0	2	0	-20	10	5
3	4	0	40	0	70	1
4	1	2	10	-20	20	4
5	2	1	20	-10	40	3
6	1	2	10	-20	20	4
7	1	3	10	-30	10	5
8	0	2	0	-20	10	5

The results obtained by this ranking method are similar to those determined by mathematical hierarchy modelling, but they are not yet final. They serve as the basis for the method of determining the weight of predicates, which establishes their final priority levels and determines the weight values of each priority factor.

Not all connections in a semantic network are made equal. To account for this, we introduce an indicator of the influence of a predicate in the form of a weight coefficient k_{ip}. It determines the strength of the connection between factors for the i-th connection type and p-th predicate, where a predicate is a qualitative (non-numeric) variable describing the nature and, in particular, strength of a connection. The full set of possible predicate values and their corresponding weight coefficients is given in the table below:

TABLE VI. PREDICATE WEIGHT COEFFICIENTS

l	*Predicate (influence)*	$k_{1,pi}$	*Predicate (dependency)*	$k_{2,pi}$
1	defines	4	defined by	4
2	forms	4	formed by	4
3	conditions	3	conditioned by	3
4	is basis of	4	is based on	4
5	suggests	2.5	suggested by	2.5
6	considers	2.5	considered by	2.5
7	influences	3	influenced by	3

Our next step is to form a set for each of the network's notes such that its elements correspond to the weighting coefficients of its connected predicates. This will then make it possible to calculate integral numerical values of factor weights with the use of predicate weight coefficients. We mark these sets as M_{ij}, where *i* is the type of a connection, and *j* – the number of the node. For the "influence" relationship type, the specified sets assigned to factors will look as follows:

$$x_1 \subset M11 = \{k_{1,p_2}; k_{1,p_3}; k_{1,p_7}\};$$

$$x_2 \subset M12 = \{0\};$$

$$x_3 \subset M13 = \{k_{1,p_3}; k_{1,p_4}; k_{1,p_5}; k_{1,p_5}\};$$

$$x_4 \subset M14 = \{k_{1,p_4}\};$$

$$x_5 \subset M15 = \{k_{1,p_1}; k_{1,p_7}\}; \quad (7)$$

$$x_6 \subset M16 = \{k_{1,p_1}\};$$

$$x_7 \subset M17 = \{k_{1,p_3}\};$$

$$x_8 \subset M18 = \{0\}.$$

A similar list for the "dependency" relationship type looks as follows (here, we pre-fill the predicate weight coefficients as given by the previous table):

$$x_1 \subset M21 = \{0\};$$

$$x_2 \subset M22 = \{4;\ 3\};$$

$$x_3 \subset M23 = \{0\};$$

$$x_4 \subset M24 = \{3; 2,5\};$$

$$x_5 \subset M25 = \{3\}; \quad (8)$$

$$x_6 \subset M26 = \{4; 2,5\};$$

$$x_7 \subset M27 = \{3; 4; 4\};$$

$$x_8 \subset M28 = \{4; 3\}.$$

Each of the sets labelled (7) to (8) contains one or several elements. However, we reduce them to one average value, which is referred to as the "strengthening" or "weakening" coefficient pertaining to a node in the graph or, in other words, a factor in adapting textbooks for people with low vision. These calculations are performed by the equation

$$d_{ij} = \sum_{r=1}^{z_{ij}} \left(\frac{mij_r}{z_{ij}}\right) \quad (9)$$

The final weight values of the factors will be obtained after multiplying the weight priorities of table VI by the strengthening or weakening coefficients. Similarly to the mathematical hierarchy modelling method, we correct the weight values by the value of $\Delta_j = max|S_{2j}|,\ j = 1,\ 2,\ \ldots,\ n$, which leads to the following final weight value:

$$W_{Fj} = INT\left(\sum_{i=1}^{2}\sum_{j=1}^{8}\left(d_{ij}S_{ij} + \Delta_j\right)\right) \quad (10)$$

The final results of this method are presented in the following table, and its multi-level model is further visualized in the graphic below.

TABLE VII. FINAL RANKING OF ACCESSIBILITY FACTORS

j	Z_{1j}	Z_{2j}	S_{1j}	w_{1j}	S_{2j}	w_{2j}	w_{Fj}	*rank*	*prior*
1	3.3	0	30	99	0	0	60	7	2
2	0	3.5	0	0	-20	-70	10	3	5
3	3	0	40	120	0	0	70	8	1
4	4	2.75	10	40	-20	-55	20	5	4
5	3.5	3	20	70	-10	-30	40	6	3
6	4	3.25	10	40	-20	-65	20	4	4
7	3	3.66	10	30	-30	-109	10	1	5
8	0	2.5	0	0	-20	-70	10	3	5

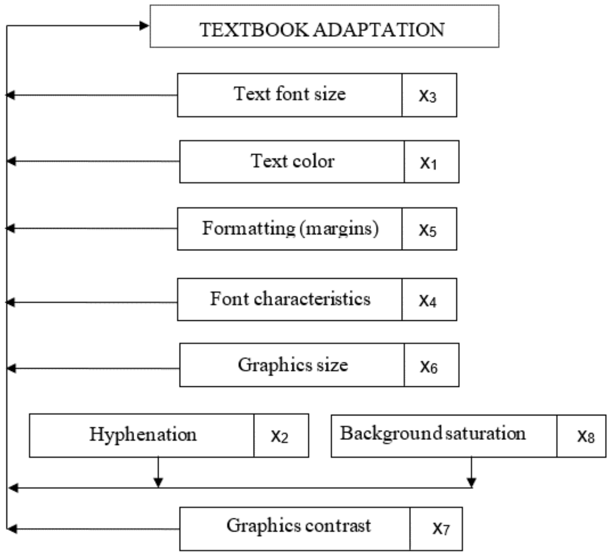

Fig. 3. Model of factors influencing textbook adaptation (ranked method)

VI. Conclusion

In this study, we touch upon a formalized mathematical model of adapting textbooks for people with low vision, which is defined as a semantic network with factors of textbook adaptation as nodes and their influences on each other as edges. This enables us to use two methods – hierarchy modelling and weight ranking – to quantify the influence of each of these factors on the overall quality of an accessible publication.

The outcome of both of these methods is quite similar and, intuitively, suggests that the most important factors of textbook adaptation is text font size as well as text color. Indeed, publications for people with low vision are sometimes referred to "large print" publications due to a larger-than-average text size being their defining feature. However, font characteristics (which we define as font family, x-weight, italicization etc.) closely follow in both of our models, suggesting that these should be prioritized after proper characteristics of baseline text has been established. Finally, parameters pertaining to graphics and page background size are on the lowest priority levels.

Further work in this area would include additional optimized modelling of the textbook adaptation process, alternate variants of implementing this process, as well as a concrete real-world workflow for turning a regular publication into one adapted for low-vision readers.

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