Assistive Technology from Adapted Equipment to Inclusive Environments
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A Design-for-All Approach Towards Multimodal Accessibility of Mathematics

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Abstract. In this paper we present a novel approach for the multimodal accessibility of mathematical expressions in inclusive learning. This methodology combines the capabilities and functionalities of MathML and a real-time XML-based architecture that supports audio, tactile and visual accessibility of mathematics on the board and the presentations in the classroom. This language and content independent system accepts also science expressions from books, or other educational material, either in printed or in electronic format. The multimodal rendering of typographic elements and mathematical notation is based on the semantic extraction.

Keywords. MathML, multimodal accessibility, design-for-all, inclusive learning

Introduction

Nowadays teachers, instructors as well as pupils use computer technology and WWW content during the learning process. The educational/presentation documents reveals promising functionalities for the instructor and the audience, but also sets new discussion issues on the accessibility of the presented content. There is a great need for the design of new and versatile applications that conform to the Design-for-All approach towards an inclusive learning.

A printed or electronic text document consists of three views [1]: *Logical view* that associates content with architectural elements such as headings, titles/subtitles, chapters, paragraphs, tables, lists, footnotes and appendices, *Layout view* that associates content with architectural elements related to the arrangement on pages and areas within pages, such as columns and margins and *Typographic view* that includes font (type, size, colour, background colour, etc.) and typesetting (such as bold, italics, underline).

Science educational documents include several mathematical expressions. W3C proposed MathML [2] for the representation of mathematics. The aim of MathML is to formalize the structure of mathematical expressions for tasks such as, processing, distribution and presentation through the WWW. MathML is a low-level specification for describing mathematics as a basis for machine-to-machine communication.

This paper presents a design-for-all architecture that supports multimodal accessibility of mathematical expressions during their presentation on board in the

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classroom. The approach incorporates a document analysis through semantic/logical information extraction and the presentation of the document's elements into auditory, haptic and/or visual (with local variable size and color) modality using this information.

1. Accessibility and MathML

MathML encodes both mathematical notation using *Presentation Markup* and mathematical meaning using *Content Markup*. In many cases the mapping relation between Presentation and Content Markup is M:N. A mathematical meaning can be represented in visual modality in multiple ways and vice-versa. For example, the meaning of "x times y" can be visually rendered either as xy, $x \bullet y$, $x \times y$ or even as $\frac{x}{y^{-1}}$. The same notation of $D_x^k u$ has the meaning of "kth power of D_x times u" and someone already familiar with Faa de Bruno's formula, means "k th derivative of a function u with respect to x".

Content Markup (strongly supported by OpenMath Society [3]) can be easily converted to Presentation Markup and seems to be ideal for audio rendering of mathematical expressions [4]. But, it is limited by the fact that: a) it includes a restricted set of math operators and functions and b) it is supported by a rather small number of editors. However, MathML provides an option to authors to choose any of these two markups, or even both of them in a hybrid mode.

Accessibility is one of the fundamental principles in MathML supporting: rendering into the acoustic modality by appropriate applications for reading maths (e.g. MathPlayer [5], MathTalk [6] and AudioMath[7]) that feeds common Text-to-Speech systems [8] [9], interpretation into any Mathematical Braille code (e.g. Nemeth [10]), print on a Braille embosser, display on a refreshable Braille display and navigation functionality in a mathematical expression. Today, MathML is an accepted standard in math applications, for example Maple and Mathematica. Thus, it is supported by various document standards like DAISY/NISO, ODF and Microsoft DOC.

2. The proposed architecture

Figure 1 presents the proposed architecture [11]. The system, following the client-server architecture in order to increase the device independency, is distinguished into two basic modules: Document Explorer and Student Interface. *Document Explorer* handles: i) the document processing and preparation for the multimodal presentation, ii) the navigation tasks and iii) the student and device modeling. *Student Interface* supports: a) the visual, acoustic and/or haptic presentation of the document to the student and b) the collection of student and device preferences. The navigation tasks are supported only by the teacher's interface for the visual presentation of the document e.g. on the interactive whiteboard and the navigation and/or document editing (e.g. highlighting a phrase in the content or a mathematical expression).

The pre-Processing module (Figure 2a) is responsible for the document's parsing to accessible format conforming to DocumentML's specifications. As proposed in [1] the elements included in DocumentML are: Text Formatting (bold, italics, font size …), Text Structure (chapter, title, caption …), Text Layout (columns, headlines, borders …), Non-Textual (figures, drawing, graphs …) and the Mathematical Notation (following MathML specifications).

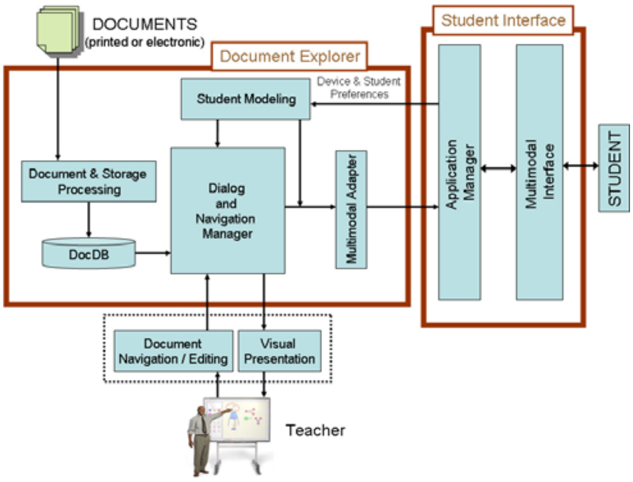

Figure 1. The proposed system architecture

Printed documents, through scanning and OCR, are digitized and exported in a tagged format. For documents including mathematical expressions, InftyReader [12] is an appropriate OCR application, exporting the result in MathML.

All non-tagged documents can be processed by the Markup Normalization module, which converts them into tagged documents conforming to DocumentML Annotation Rules. Moreover, tagged documents not conforming to DocumentML Rules can also be processed by this module. The functionality of the module can be by-passed in case the document fulfils the system's requirements for document annotation.

Due to multiple formats of mathematical encoding (e.g. LaTeX, Presentation MathML, a hybrid of Presentation and Content MathML and their several versions) the math document content is converted to a well formed Presentation MathML. Content MathML by-passes this module since audio or haptic rendering can be unambiguous.

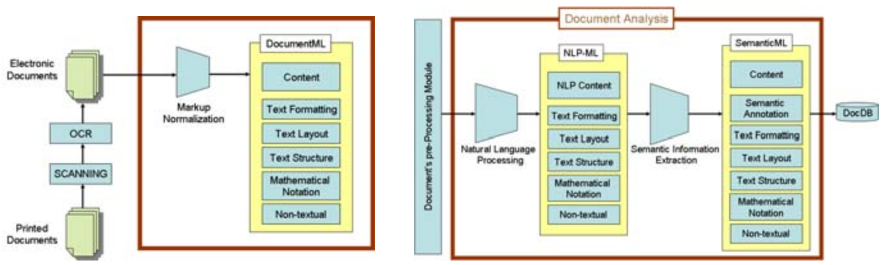

Figure 2. The pre-Processing (a) and the Document Analysis (b) modules

Document Analysis module (Fig. 2b) is responsible for the: a) semantic/logical information extraction (through Natural Language processing of the content and the mapping of the document's elements into specific semantic/logic elements using machine learning algorithms) and b) the semantic/logical annotation of the document. The mapping rules for document's elements derive from a series of experiments, that the participants specify how the document's elements can be mapped, e.g. bold can be represented either as emphasis but also as strong emphasis.

Presentation MathML is processed by the Semantic Information Extraction module. In order to achieve an unambiguous multimodal rendering (focusing on acoustic modality) of mathematical expressions, it is important to add semantic/logic information as well as some kind of "intelligence" resulting to an "enriched" Presentation MathML. In case of Content MathML, this process is by-passed.

The interaction with the document is distinguished into: a) the presentation task and b) the navigation task, controlled by the Dialog and Navigation Manager. The navigation tasks are handled by the instructor. Each student's computer supports multimodal presentation through appropriate Assistive Technologies. According to the student's preferences and the device specifications, presentation tasks are accomplished by selecting the appropriate module for each modality (visual, haptic, acoustic or their combination). The manager feeds the selected module(s) with content for the later process into each modality.

Figure 3 presents the Multimodal Adapter, consisting of three modules, one for each modality (visual, haptic and acoustic respectively). The student is able to change the visual presentation of document's content including mathematical expressions. MathML allows changes e.g. to the size and the color of the encoded expressions, as well as their background color, meeting the student's preferences. The haptic rendering of the mathematical expressions is supported by the conversion of "enriched" Presentation or Content MathML in any Mathematical Braille code, e.g. through the Universal Math Conversion Library (UMCL) [13]. Focusing on the acoustic presentation, the mapping is obtained using the Document-to-Audio platform [14]. The Adaptation module (Figure 3) combines information about student's preferences and the rules for the acoustic mapping of the document's elements (CAD script) and the mathematical expression (Math script). The CAD and Math scripts include the mapping rules of the semantic/logic representation of document's elements and the mathematical expressions (using "enriched" Presentation or Content MathML) respectively into acoustic features so the results can be used by the e-TSA Composer.

The DtA platform gives higher priority to student preferences (using Student's Modelling) than the default CAD or Math rules. For example, the preferred verbosity level of the student can be different from the default verbosity of the rules (Math Script), or changing the speech rate of a phrase (CAD Script).

3. Conclusions

In this paper we have presented an XML-based architecture for the multimodal accessibility of documents focusing on the acoustic representation of mathematical expressions for an inclusive learning. The multimodal accessibility of documents, including mathematical expressions, is based on a methodology of using the automated semantic/logic extraction and annotation of typographic elements and mathematical notation. This real-time system is language, content and device independent.

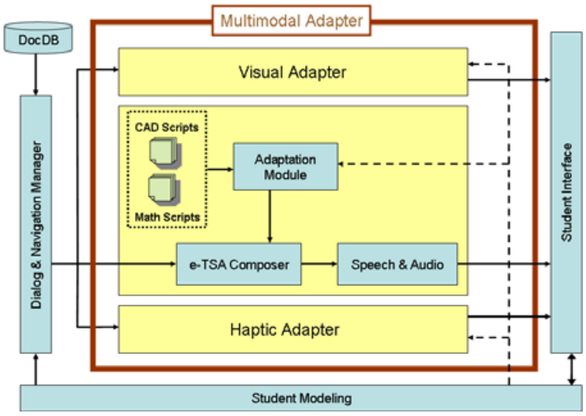

Figure 3. The Multimodal Adapter

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