Online Nemeth Braille Input/Output Using Content MathML

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ABSTRACT
Access to high-quality braille materials for mathematical content is one of the most challenging obstacles faced by visually-impaired students. The need for visually-impaired students to communicate their work to sighted instructors often prevents them from participating in mainstream classrooms in STEM subjects. Backward translation from Nemeth Braille to print mathematics is a difficult and time-consuming process even for teachers of the visually impaired, who may not have an extensive understanding of the mathematical concepts underlying the notation.

The goal of this current work is to provide a software system that supports the automatic generation of Nemeth Braille output, and the automatic backward translation of Nemeth Braille input, in the context of a WYSIWYG equation editor designed for sighted math users. This software lets a sighted math user, who need not know Nemeth Braille, produce high-quality braille materials for math in a fraction of the time, and at a fraction of the expense, of current best practices for print-to-braille translation. It also allows a Nemeth Braille user who is unable to access the printed form of an equation to produce high-quality print mathematical formulas in a fraction of the time, and at a fraction of the expense, of current best practices for braille-to-print translation.

This software supports automatic, two-way conversion from printed math notation into Nemeth Braille, including reverse translation from Nemeth Braille into printed math notation. Using this software, a sighted user can communicate mathematics online and in real-time with a visually-impaired Nemeth Braille user. This kind of instantaneous interaction has the potential to reduce, or even eliminate, many of the communication barriers that inhibit visually-impaired students from participating in mainstream math and science classrooms.

CCS Concepts

• Human-centered computing → Accessibility → Accessibility systems and tools  
• Information systems → World Wide Web  
→ Web data description languages → Markup languages.

Keywords
Mathematical User Interfaces; Equation Editors; Nemeth Braille; Content MathML; Braille Translation Software.

1. OBJECTIVES
The W3C Math Markup Language has now been used for over fifteen years to represent structural forms (Content MathML) and print notations (Presentation MathML) for online mathematical expressions. Nemeth Braille has now been used for over sixty years as a means to capture print math notation for tactile reading by low-vision and blind users. While Nemeth Braille has much in common with Presentation MathML in its intent to capture the appearance of print math notation, the design of its coding rules shares in common with Content MathML its desire to preserve the structural form of the expressions it encodes.

Content MathML provides a common source representation that can be translated into multiple parallel output representations using an operator-based transformation rule framework to effect the translations [1]. Using this framework, Content MathML can be transformed into Presentation MathML for print users, and can be transformed into Nemeth Braille for visually-impaired users, who may access the Braille output by means of refreshable braille devices or other tactile printing methods.

Content MathML also provides a common target representation that can be created by keyboard input events using a key event-based transformation rule framework to effect the construction of mathematical expressions [1]. Using this framework, input key event sequences from a braille keyboard may be used to invoke input transformation rules to create, delete, and/or modify a current expression in a manner that simulates Nemeth Braille mathematical expression entry, but which creates Content MathML expressions as the output of the keying process. In this fashion, a common framework may be used to create Content MathML using a QWERTY keyboard for sighted users, and using a braille keyboard for visually-impaired users.

These two frameworks enable the input from a sighted user to be displayed in a format that can be read by a visually-impaired user, and vice versa, where the simultaneous print and braille displays are updated upon receipt of each keystroke event, regardless of the type of keyboard used to produce the event.

2. CONTENT MATHML TO NEMETH BRAILLE
As described in [1], operator-based transformations from Content MathML to Presentation MathML are well understood, and represent a specific case of the more general approach to the separation of structure and style found in other web languages.
These transformations allow math content forms to be translated into any number of presentational forms, including Presentation MathML, and Nemeth Braille.

A large majority of the encoding rules for Nemeth Braille are structural in nature, and can be implemented using the same transformation rule framework used to generate Presentation MathML. These rules include virtually all of the most common mathematical operators (signs of operation, comparison, special symbols) as well as many that are beyond the scope of Content MathML (arrows, shapes, circled and squared operators), but that can be represented using extensions to Content MathML.

Other Nemeth encoding rules are contextual in nature, and require specialized techniques. Nested structure indicators for fractions and radicals can be supplied by a special routine to traverse the content expression tree to determine the number of indicators. A similar procedure is used to determine the proper encoding for nested combinations of superscripts and subscripts, and over and under scripts. More specific procedures are needed to determine the circumstances dictating the use of spacing rules, numeric and alphabetic indicators, and the multipurpose indicator.

This framework has been implemented as an extension to an existing equation editor for Content MathML markup [2]. The testing regimen for the transformation from Content MathML to Nemeth Braille was implemented as a special test page that embeds the equation editor, which generates the Nemeth Braille encodings for a sequence of test cases. Each test case is displayed on the page so the correspondence between the presentation forms can be verified by a sighted user. Hand-generated alternate text for each test case is displayed and marked so it can be announced by a screen reader, and the braille encoding is marked so it may be displayed on a refreshable braille device. Using this test page, a blind tester was able to verify the correspondence between the hand-generated alternate text, and the machine-generated braille output, for 948 separate test cases, within two days, and provide specific feedback to improve the generated braille.

3. NEMETH BRAILLE TO CONTENT MATHML

As described in [1], key-based transformations that modify one Content MathML expression to create a new Content MathML expression may be used to allow a QWERTY keyboard to create mathematical structures. These rules allow an equation editor to create, on each keystroke, the Content MathML markup that corresponds to the user’s input. The Content MathML may then be translated to Presentation MathML or Nemeth Braille as described in the previous section.

The input events generated by a braille terminal typically encode six- or eight-dot braille cells in ASCII braille, which allows each braille dot pattern to be treated as if it were a single character input event. These input events are transmitted from the hardware, via the user's screen reader software, to the equation editor. Then the same key-based transformation framework used to interpret key events from a QWERTY keyboard can be used to interpret braille events from a braille terminal.

For a large majority of the input rules for a QWERTY keyboard, one key event is enough to effect an immediate transformation in the current expression. In a similar fashion, a single braille cell that represents a specific symbol can be immediately encoded to create that symbol in the equation editor. Other Nemeth Braille encoding rules consist of sequences of braille cells that cannot be distinguished from each other by a single initial cell. As a result, the transformation rule framework for expression entry is augmented by a finite-state machine to track the state of the current input sequence while waiting until the end of the sequence to effect a transformation in the current expression. The finite state machine uses named input states to describe input sequences.

In some cases, one valid input sequence may be contained as a prefix to a longer input sequence for a different operator. For example, the input sequence for the less-than operator may be extended by the horizontal bar character to form the less-than-or-equal operator. In these cases, the equation editor effects the input rule to create the less-than operator after receiving less-than, then replaces it with the less-than-or-equal operator after receiving the horizontal bar.

The input-rule transformation framework to create Content MathML from Nemeth Braille input has been implemented as a special browser test page that embeds the equation editor [2], which receives key events from the QWERTY keyboard for visual users, and braille cell events encoded as ASCII braille from a refreshable braille device for visually-impaired users. The braille cells are received from the braille device via screen reader device drivers that deliver the input events to the equation editor embedded as a JavaScript component in the browser. Through this arrangement, input streams from the braille keyboard or the QWERTY keyboard can both be directed to the same instance of the equation editor.

4. CONCLUSIONS

As time goes on, more and more of the means and methods by which math and science are taught are being transformed into electronic and/or online forms. Online math instruction and assessment are now high-profile lines of business for major publishing companies and consortia, and are transforming education at all levels. Electronic textbooks and other materials are increasingly replacing paper-based alternatives, and teacher-student interactions are taking place using social media, online meeting rooms, and distance learning systems. As these transformations take place with increasing speed, the accessibility of these solutions lags behind due to the inherent difficulty of providing accessible math software in an online world. Online math software presents unique challenges that are not found in text-based software, further compounding the difficulty in making such software accessible. Moving forward, the need for access to online math content will override all other concerns related to the communication of mathematics. If visually-impaired students are to succeed in mathematics in the classroom at all grade levels, their participation needs to be fully online and fully interactive. By reducing the time and cost involved in braille translation, this work has the potential to produce a truly level playing field for visually-impaired students in mainstream STEM classrooms.

5. REFERENCES
