Mathoid: Robust, Scalable, Fast and Accessible Math Rendering for Wikipedia

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Abstract. Wikipedia is the first address for scientists who want to recap basic mathematical and physical laws and concepts. Today, formulae in those pages are displayed as Portable Network Graphics images. Those images do not integrate well into the text, can not be edited after copying, are inaccessible to screen readers for people with special needs, do not support line breaks for small screens and do not scale for high resolution devices. Mathoid improves this situation and converts formulae specified by Wikipedia editors in a \TeX\-like input format to MathML, with Scalable Vector Graphics images as a fallback solution.

1 Introduction: browsers are becoming smarter

Wikipedia has supported mathematical content since 2003. Formulae are entered in a \TeX\-like notation and rendered by a program called \texttt{texvc}. One of the first versions of \texttt{texvc} announced the future of MathML support as follows:

“As of January 2003, we have TeX markup for mathematical formulas on Wikipedia. It generates either PNG images or simple HTML markup, depending on user prefs and the complexity of the expression. In the future, as more browsers are smarter, it will be able to generate enhanced HTML or even MathML in many cases.”\textsuperscript{[11]}

Today, more then 10 years later, less than 20\% of people visiting the English Wikipedia, currently use browsers that support MathML (e.g., Firefox)\textsuperscript{[27]}. In addition, \texttt{texvc}, the program that controls math rendering, has made little progress in supporting MathML. Even in 2011, the MathML support was “rather pathetic” (see\textsuperscript{[17]}). As a result, users expected MathML support within Wikipedia to be a broken feature. Ultimately, on November 28, 2011, the user preference for displaying MathML was removed\textsuperscript{[24]}.

Annoyed by the Portable Network Graphics (PNG) images, in December 2010, user Nageh published a script, \texttt{User:Nageh/mathJax.js}, that enables client-side MathJax rendering for individual Wikipedia users\textsuperscript{[23]}. Some effort and technical expertise was required to use the script. The user had to install
additional fonts on his system manually, to import the script, into his Wikipedia account settings and to change the Math setting in his Wikipedia user account page to “Leave it as \( \text{TeX} \)”. With client-side MathJax rendering, the visitor was able to choose from the context menu of each equation with the PNG image being replaced by either: (1) a Scalable Vector Graphics (SVG) image, (2) an equivalent HTML + CSS representation, or (3) MathML markup (this requires a MathML capable browser).

MathJax needs a significant amount of time to replace the \( \text{TeX} \)-code on the page with the above replacements. This amount of time is dependent on the operating system, browser, and hardware configuration. For instance, we measured 133.06 s to load the page \textit{Fourier transform} in client side MathJax mode, as compared to 14.05 s for the page loading without math rendering (and 42.9 s with PNG images) on a typical Windows laptop with Firefox. However, improvements in the layout motivated many users to use that script, and in November 2011, client-side MathJax became an experimental option for registered users.

As of today, there are almost 21M registered Wikipedia users, of which 130k have been active in the last 30 days. Of these users, 7.8k use the MathJax rendering option which causes long waiting times for pages with many equations. Also 47.6k users chose the (currently disabled) HTML rendering mode, which if possible, tries to use HTML markup to display formula, and the PNG image otherwise. Furthermore, 10.1k users chose the MathML rendering mode (disabled in 2011). Thus, the latter 57.7k users are temporarily forced to view PNG images, even though they explicitly requested against this. This demonstrates that there is an significant demand for math rendering, other than for the use of PNG images.

Currently, the MediaWiki Math extension is version 1.0. Our efforts have been to make an improvement on that extension. We refer to our update of the extension as version 2.0. Furthermore, we refer to Mathoid as all the ingredients mentioned in this paper which go into developing Math 2.0. One essential ingredient in Mathoid, is what we refer to as Mathoid-server. This is a tool, which we describe in this paper, which converts the \( \text{TeX} \)-like math input used in MediaWiki to various formats that we describe in this paper. Our paper is organized as follows.

In Section 2 we list the requirements for Math rendering in Wikipedia, explain how one may contribute to these requirements, and elaborate on how one may make math accessible for people with special needs. In this section we introduce the Mathoid-server. In Section 3 we explain how by using Mathoid-server, math can be displayed in browsers that do not support MathML. In Section 4 we discuss how math rendering can be offered as a globally distributed service. In Section 5 we discuss and compare the performance of reviewed rendering tools.

\footnote{The measurement was done on a Lenovo T420 Laptop with the following hardware: 8GB RAM, 500GB HDD, CPU Intel Core i7-2640M, Firefox 24.0 on Windows 8.1, download speed 98.7 MB/s upload speed 9.8 MB/s, ping to \texttt{en.wikipedia.org} was 25(\( \pm \)1) ms.}
in regard to layout and speed. Finally, in Section 6, we conclude with results from our comparison and give an overview of future work.

2 Bringing MathML to Wikipedia

For Wikipedia, the following requirements and performance measures are critical.

coverage: The converter must support all commands currently used in Wikipedia.

scalability: The load for the converter may vary significantly, since the number of Wikipedia edits heavily depends on the language. Thus, a converter must be applicable for both small and large Wikipedia instances.

robustness: Bad user input, or a large number of concurrent requests, must not lead to permanent failure for the converter.

speed: Fast conversion is desirable for a good user experience.

maintainability: A new tool for a global site the size of Wikipedia must be able to handle tasks with a large management overhead. Therefore, active development over a long period of time is desirable.

accessibility: Providing accessible content to everyone is one of the key goals of Wikipedia.

There are a large variety of \TeX{} to MathML converters [2]. However, most of them are no longer under active development, or their licenses are not compatible with MediaWiki. In 2009, [22] showed that $\LaTeX/XML$ has the best coverage (but not a very high conversion speed) as compared to the $\LaTeX$ converters which were analysed in that paper. Since 2009, a new converter, MathJax [3], has become popular. After negotiations with Peter Krautzberger (of MathJax) and his team, we regard MathJax (executed in a headless browser on a web server), as a useful alternative to $\LaTeX/XML$. One strong point about MathJax with regard to coverage, is that it is already used by some Wikipedia users on the client-side (as described in Section 1). Therefore the risk of unexpected behavior is limited. For $\LaTeX/XML$, Bruce Miller has written a set of custom macros for MediaWiki specific \TeX{} commands which supports the MediaWiki \TeX{} markup. A test using these macros based on a Wikipedia dump, has shown very good coverage of the mathematics commands currently used in Wikipedia. $\LaTeX/XML$ is maintained by the United States Department of Commerce Laboratory, the National Institute of Standards and Technology (NIST) and MathJax is maintained by the MathJax project which is a consortium of the American Mathematical Society and the Society for Industrial and Applied Mathematics. We analyze and compare MathJax and $\LaTeX/XML$ in detail, since these are the most promising tools we could discover.

In regard to accessibility, we note that Wikipedia has recently made serious efforts to make the site more accessible. However, images which represent equations are currently not accessible. The only available information from PNG images (which is not very helpful) is the alt-text of the image that contains the \TeX{} code. Based upon recent unpublished work of Volker Sorge [21], we would like to provide meaningful semantic information for the equations. By providing this, more people will be able to understand the (openly accessible) content [5].
One must also consider that there is a large variety of special needs. People with blindness are only a small fraction of the target group which can benefit from increased accessible mathematical content. Between 1 and 33\% \cite{6, 7} of the population suffer from dyslexia. Even if we calculate with the lower boundary of 1\%, 90,000 people per hour visit the English Wikipedia and some of them could benefit from improvements of the accessibility while reading articles that contain math. However, our the main goal with regard to accessibility is to make Wikipedia accessible for blind people that have no opportunity to read the formulae in Wikipedia today.

Furthermore, the information provided in the tree structure of mathematics by using MathML, helps one to orientate complex mathematical equations, which is useful for general purpose use as well. With regard to accessibility, a screen reader can repeat only part of an equation to provide details that were not understood. PNG images do not give screen readers detailed related mathematical information \cite{4, 11}. In 2007, \cite{10} states that MathML is optimal for screen readers. \textit{The Faculty Room} website, lists four screen readers that can be used in combination with MathPlayer \cite{20} to read Mathematical equations. Thus Mathoid-server and \LaTeX server \cite{8} that generate MathML output, contribute towards better accessibility within the English Wikipedia.

3 Making math accessible to MathML disabled browsers

For people with browsers that do not support MathML, we would like to provide high quality images as a fallback solution. Both \LaTeX and MathJax provide options to produce images. \LaTeX supports PNG images only, which tend to look rasterized if they are viewed using large screens. MathJax produces scalable SVG images. For high traffic sites like Wikipedia with 9 million visitors per hour, it is crucial to reduce the server load generated by each visitor. Therefore rendered pages should be used for multiple visitors. Rendering of math elements is especially costly. This is related to the nested structure of mathematical expressions. As a result, we have taken care that the output of the MediaWiki Math extension should be browser independent. Since MathJax was designed for client-side rendering, our goal is to develop a new component. We call this new component the Mathoid-server. Mathoid-server, a tool written in JavaScript, uses MathJax to convert math input to SVG images. It is based on \texttt{svgtex} \cite{9} which uses \texttt{nodejs} and \texttt{phantomjs} to run MathJax in a headless browser. It exports SVG images. Mathoid-server improves upon the functionality of \texttt{svgtex} while offering a more robust alternative. For instance, it provides a restful interface which supports \texttt{json} input and output as well as the support of MathML output. Furthermore, Mathoid-server is shipped as a Debian package for easy installation and maintenance. Many new developments in MediaWiki use JavaScript. This increases the probability of finding volunteers to maintain the code and to fix bugs. For general purpose, Mathoid-server can be used as a stand-alone service which can be used in other content management platforms such as Drupal or Wordpress. This implies that Mathoid-server
will have a larger interest group for maintenance in the future. The fact that Mathoid-server automatically adapts to the number of available processing cores, and can be installed fully unattended via tools like Puppet, indicates that the administrative overhead for Mathoid-server instances should be independent of the number of machines used. In the latest version, the Mathoid-server supports both \LaTeX and MathML input and is capable of producing MathML and SVG output.

To support MathML disabled browsers, we deliver both MathML markup, and a link to the SVG fallback image, to the visitor’s browser. In order to be compatible with browsers that do not support SVG images, in addition, we add links to the old PNG images. In the future those browsers will disappear and this feature will be removed.

To prevent users from seeing both rendering outputs, the MathML element is hidden by default, and the image is displayed. For Mozilla based browsers (these support MathML rendering), we invert the visibility by using a custom CSS style, hide the fallback images and display the MathML-markup. This has several advantages. First, no browser detection, neither on the client-side (e.g., via JavaScript) nor on server-side is required. This eliminates a potential source of errors. Our experiments with client-side browser detection showed that the user will observe a change in the Math elements if pages with many equations are loaded. Second, since the MathML element is always available on the client-side, the user can copy equations from the page, and edit it visually with tools such as Mathematica. If the page content is saved to disk, all information is preserved without resolving links to images. If afterwards the saved file is opened with a MathML enabled browser, the equations can be viewed off-line. This feature is less relevant for users with continuous network connections or with high-end hardware and software. However, for people with limited resources and unstable connections (like in some parts of India [1]), they will experience a significant benefit.

The current Firefox mobile version (28.0) passes the MathML Acid-2 test, indicating that there is generally good support for MathML on mobile devices. This allows for customized high quality adaptable rendering for specific device properties. The W3C MathML specification [3] discusses the so called best-fit algorithm for line breaking. According to our experiments, Firefox-mobile (28.0) does not pass the W3C line break tests. However, as soon this issue is fixed, mobile users will benefit from the adjusted rendering for their devices. Note that there is active development in this area by the Mathematics in ebooks project [4] lead by Frédéric Wang.

4 A global distributed service for math rendering

To use \LaTeX and Mathoid-server for Math rendering within Wikipedia, we have changed the MediaWiki Math extension (see Fig. 1). While preserving

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3 [http://www.w3.org/TR/MathML/chapter3.html](http://www.w3.org/TR/MathML/chapter3.html)

4 [http://www.ulule.com/mathematics-ebooks](http://www.ulule.com/mathematics-ebooks)
Fig. 1. System overview. The 2.0 release of the MediaWiki Math extension offers new ways to render Math input in MediaWiki. It communicates to \( \LaTeX \) servers and to instances of our MathJax-based development of the Mathoid-server. Note that we preserve backwards compatibility to the MediaWiki Math extension 1.0.

backwards compatibility, we pursue our current development \([19]\) by integrating \( \LaTeX \) and Mathoid-server. System administrators can choose which rendering back-ends are selectable in a MediaWiki instance by logged in users. All rendering modes can be active at the same time, and it is possible to use Mathoid-server to generate SVG images based on the output of the \( \LaTeX \) server.

For \texttt{texvc}, rendering requires one to install a full \( \LaTeX \) distribution (about 1GB) on each web server. This is a huge administrative overhead and the management of files and permissions has caused a lot of problems. These problems were hard to solve and resulted in inconsistent behavior of the website from a user perspective \([12, 13, 15, 16]\). Furthermore, for MediaWiki instances run by individuals, it is difficult to set up math support. Therefore, one of our major requirements is that future versions of the MediaWiki Math extension should not need to access the file system. Also, one should not need to use shell commands to directly access the server. This has the potential to introduce major security risks. With our separation approach, rendering and displaying of mathematics no longer needs to be done on the same machine. However, for instances with a small load, this would still be possible. Furthermore small MediaWiki instances can now enable Math support without any configuration or shell access. By default, public \( \LaTeX \) and Mathoid-server instances are used. These will be provided by XSEDE\(^5\) With this method, no additional security risk is provided for individuals. For Mathoid-server, the security risk for the host is limited as

\(^5\)https://www.xsede.org
This is because the Mathoid process runs on a headless browser on the server without direct access to the file system.

Caching. There are two main caching layers. In the first layer, the database caches the rendering result of the math conversion, i.e., the MathML and SVG output in the database. The second caching layer is browser based. Similar to the SVG rendering process for ordinary SVG images, the MediaWiki Math extension uses cacheable special pages to deliver SVG images. On the server side, those pages are cached by squid servers. In addition, even if images occur on different pages, the browser will only load that image once.

5 Performance analysis

As a first step towards a visual analysis, we compared our impressions of output from \( \LaTeX \) and MathJax using Firefox 24.0. Except for additional \texttt{mrow} elements in \( \LaTeX \), the produced presentation MathML is almost identical. The differences that we did notice had no influence on the rendering output. In rare cases, MathJax uses \texttt{mi} elements, whereas \( \LaTeX \) uses \texttt{mo} elements. In contrast to \( \LaTeX \) which uses UTF-8 characters to represent special symbols, MathJax uses HTML entities. However, there still remain some minor differences (see Fig. 2).

To illustrate performance differences, we chose a random sample equation, namely

\[
\frac{(x - h)^2}{a^2} - \frac{(y - k)^2}{b^2} = 1.
\]

With 10 subsequent runs\(^7\), the following conversion times were measured:

- \( \LaTeX \) : \LaTeX \rightarrow \text{MathML} (319ms/220ms);
- Mathoid-server : \LaTeX \rightarrow \text{SVG + MathML} (18ms/18ms);
- texvc : \LaTeX \rightarrow \text{PNG} (99ms/71ms).

Thus compared to the baseline (texvc), Mathoid-server produced a speedup of 5.5 whereas \( \LaTeX \) is 3.2 times slower. \( \LaTeX \) and PNG seem to benefit from multiple runs, whereas the rendering time with Mathoid-server stays constant.

We also converted all of the English Wikipedia articles and measured the conversion times for each equation therein. The most time consuming equation was the full form of the Ackermann function \( A(4, 3) \). \( \LaTeX \) needs 147 s to convert.

\(^6\) To keep the lookup time for equations constant, the key for the cache entry is a hash of \LaTeX \ input.

\(^7\) All measurements were performed using virtual Wikimedia labs instances, with the following hardware specifications: number of CPUs 2, RAM size 4096 Mb, allocated Storage 40 Gb

\(^8\) \texttt{ltxpsgi} (\LaTeX version 0.7.99; revision ef0405)
Fig. 2. This figure displays a comparison of possible rendering outputs for the MediaWiki Math extension rendered with Firefox 24.0. Mathoid-server allows one to use either a \texttt{LaTeXML} or MathJax renderer to generate MathML output with SVG fallback. The investigation of the listed corner cases shows that the Mathoid-SVG rendering option, that uses server-side MathJax rendering via \texttt{phantomjs}, produces the best results.

Remark: The authors thank Bruce Miller. He improved the \texttt{LaTeXML} implementation based on a preprint version of this paper. This final version of the paper uses the \texttt{LaTeXML} version of 24th of April 2014.
answer the HTTP request for $A(4,3)$. According to the self reported \texttt{B\LaTeX-XML-}
log, approximately 136.18 s was used for parsing. The same request was answered
by Mathoid-server in 0.393 s, which is approximately 374 times faster. The old
rendering engine needed 1.598 s to produce the image. This does not include the
41 ms it took to load the image from the server.

6 Conclusion, outlook and future work

In the scope of Mathoid, we updated the retrograde MediaWiki Math extension,
and developed Mathoid-server which replaces the \texttt{texvc} program. This enhanced
the security of MediaWiki as proposed in [19]. It is no longer necessary to pass
user input via shell access using the command-line. Nor is it necessary to move
files on the server via PHP. The MediaWiki Math extension is now capable of using
\texttt{B\LaTeX-XML} and Mathoid-server to convert \texttt{T\LaTeX}-like input to MathML + SVG.
Based on the requirements, the user can choose if he prefers to use \texttt{B\LaTeX-XML} for
the MathML generation (this has the advantage of content MathML output),
or he can use Mathoid-server which is much faster (but does not produce content MathML).
Mathoid-server takes advantage of \texttt{B\LaTeX-XML} since it produces
MathML. The MediaWiki math extension, through Mathoid-server, converts
MathML to fallback SVG images. For Wikipedia itself, with only a few semantic macros,
and no real applications for content MathML produced by \texttt{B\LaTeX-XML},
Mathoid-server alone seems to be the best choice.

Table 1. Overview: comparison of different math rendering engines.
Values based on articles containing mathematics in the English Wikipedia.

|                  | \texttt{texvc} | \texttt{B\LaTeX-XML} | Mathoid |
|------------------|----------------|-----------------------|---------|
| relative speed   | 1              | 0.3                   | 5       |
| image output     | PNG            | PNG                   | SVG     |
| presentation MathML coverage | low   | high                  | high    |
| content MathML output | no     | no                    | yes     |
| webservice       | no             | yes                   | yes     |
| approximate space required on webserver | 1GB    | 0                     | 0       |
| language         | OCaml          | Perl                  | JavaScript |
| maintained by    | nobody         | NIST                  | MathJax  |

We did exhaustive tests to demonstrate the power of Mathoid-server with regard
to scalability, performance and enhancement of user experiences. Those test
results are summarized in Table 1. Our implementation was finished in October
2013 and is currently being reviewed by the Wikimedia foundation for production
use. Our work on the MediaWiki Math extension and Mathoid-server establishes
a basis for further math related developments within the Wikimedia platform.

\footnote{This integral feature of Math 2.0 does not require additional source modifications,
and is demonstrated for example at \url{http://demo.formulasearchengine.com}}
Those developments might be realized by individuals or research institutions in the future. For example, we have considered creating an OpenMath content dictionary \[18\] that is based on Wikidata items \[26\]. This will augment mathematical formulae with language independent semantic information. Moreover, one can use gathered statistics about formulae currently in use in Wikipedia to enhance the user interface for entering new formulae\[10\]. This is common for text input associated with mobile devices.

In regard to future potential work, one may note the following. There is a significant amount of hidden math markup in Wikipedia. Many of these have been entered using HTML workarounds (like subscript or superscript) or by using UTF-8 characters. This markup is difficult to find and causes problems for screen readers (since they are not aware that the mode needs to be changed). If desired by the community, by using gathered statistics and edit history, we would be able to repair these damages.

The MediaWiki Math extension currently allows limited semantic macros. For example, one can use \(^\text{\texttt{\textbackslash Reals}}\) to obtain the symbol \(\mathbb{R}\). At the moment, semantic macros are seldomly used in the English Wikipedia (only 17 times). One could potentially benefit by increased use of semantic macros by taking advantage of the semantic information associated with these. In the future, one could use this semantic information to take advantage of additional services, such as MathSearch \[19\], a global search engine which takes advantage of semantic information. Also, the use of semantic macros would provide semantic information, which would provide improved screen reader output.

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