MaugVLink: Augmenting Mathematical Formulas with Visual Links

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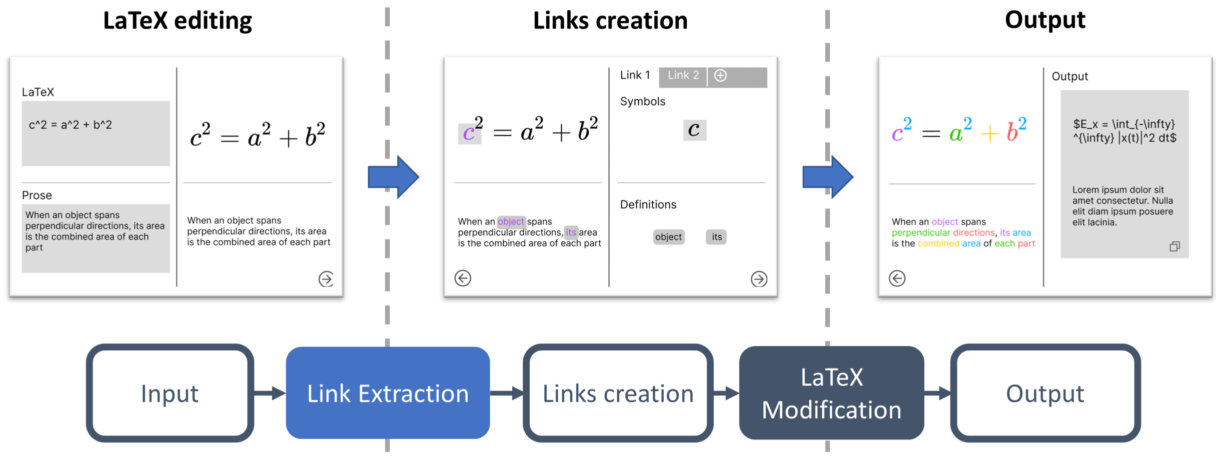

Figure 1: System overview of MaugVLink. Above is the user interface wireframe, which comprises three parts: LaTeX editing, links creation, and output, corresponding to the three main steps to create math augmentation. Below is the flow chart of the system.

Abstract

While mathematical formulas are widely applied across various fields, the abundance of information they contain poses challenges for comprehension. Understanding the meanings of individual symbols in formulas is a significant obstacle for readers. They have to shift their attention between formulas and their accompanying descriptions frequently. Colorizing the symbol and its corresponding definitions in the same color can build visual links to guide the readers' attention and reduce the cognitive load, which is one of the most pervasive designs that can enhance the readability of formulas. However, the colorization process is tedious and time-consuming since the authors must manually locate these symbols and definitions and change their colors one by one. Therefore, we propose MaugVLink, a prototype of LaTeX-based and AI-assisted authoring tool, to expedite these processes. With easy-to-use symbol selection UI design and human-AI collaboration mechanism, the author can rapidly build the visual links to augment the formulas. We also conduct a preliminary two-part user study with eight participants to evaluate the effectiveness and usefulness of MaugVLink.

Index Terms: Human-centered computing—Visualization—Visualization systems and tools—Visualization toolkits; Human-centered computing—Visualization—Visualization application domains—Information visualization

1 Introduction

With the advancement of academic research, people accumulated more and more knowledge. However, when researchers do not comprehensively elucidate their research findings and proposed concepts, subsequent researchers are compelled to invest more effort in understanding them [11, 19, 22]. This contributes to a rising threshold for future research, referred to as research debt [32]. Consequently, improving the readability of published research is essential for fostering overall academic development.

Mathematical formula is a classic and prevalent method for expressing complex concepts. In addition to mathematics, formulas are widely used in many fields, such as physics and computer science. However, the abundance of information in these formulas poses numerous challenges for readers to comprehend, with understanding each symbol in the formulas being one of them [19].

The meanings of symbols in mathematical formulas often rely on contextual explanations, lacking absolute definitions. Even some common symbols may carry significantly different implications in various fields, making interpreting these symbols challenging for readers. In some literature, these terms with flexible and context-dependent meanings are called nonce words [19, 30]. Shifting attention between formulas and their accompanying descriptions is a frequent task for the readers [20, 27]. In such a scenario, if we colorize the symbols and their corresponding definitions in the same color, these visual links can guide the readers' attention and reduce the cognitive load [17, 20, 24, 36].

However, it is tedious and time-consuming to add these visual links. Not only do the authors need to locate these corresponding symbols and definitions manually, but if they want to modify the color for each link, they need to modify each symbol and term individually [20]. The output format also has compatibility issues and may not be able to be smoothly transferred to a different medium.

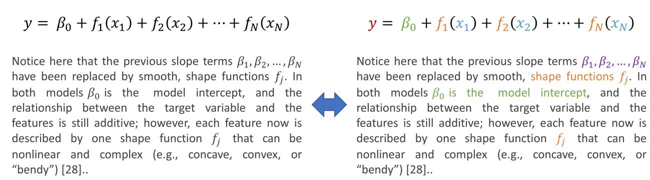

Figure 2: Comparison between with and without colorization. The content is excerpted from [23].

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Therefore, we propose MaugVLink, a prototype of LaTeX-based and AI-assisted authoring tool, to help the authors add these visual links with colors. With an intuitive and user-friendly symbol selection design, authors can easily select symbols and terms, creating visual links between them and their definitions. With human-AI collaboration design in the user interface, the authors can modify the draft automatically generated by the tool, speeding up the overall editing process. Besides, due to the widespread use of LaTeX in academia, MaugVLink is user-friendly for researchers, and its output can be effortlessly converted for use in various mediums, including web pages, printed documents, and presentation slides.

To evaluate the design of MaugVLink, we conducted a preliminary two-part user study with eight participants. In the first part, the participants had to replicate a given colorization design, and in the second part, they had to colorize their own formulas and the corresponding explanations. The questionnaire responses and participant feedback indicate the effectiveness and usefulness of MaugVLink. The participants gave positive feedback to the UI design, and the SUS scores reached 76.25 and 74.69 in each part. While the AI suggestion system does not perform well in some cases, its crucial role in successful cases highlights its significant potential.

In summary, this work makes two contributions. First, we introduce MaugVLink, a prototype of a LaTeX-based and AI-assisted authoring tool that aids authors in augmenting mathematical formulas with visual links. Second, we present a preliminary user study of MaugVLink that demonstrates the value of its design and serves as inspiration for developing similar tools.

2 Related Work

2.1 Math Understanding

One reason that makes mathematical formulas difficult to read is that symbols within the formulas often lack absolute meanings and rely on contextual explanations. These terms with flexible and context-dependent meanings are known as nonce words [19, 30]. Shepherd and Sande [34] conducted a study to explore the variations in reading strategies between students and experts, suggesting that grasping unfamiliar idioms and terminology may pose a significant challenge for less experienced readers. Kohlhase et al. [27] conducted an eye-tracking study to explore how formula understanding interacts with the surrounding text in mathematical documents, finding several patterns in the gaze plots, including Declaration Lookup, which describes the gaze back-jumps to the declaration of the symbols. These findings imply that visual designs guiding readers' attention can assist in comprehending mathematical formulas.

2.2 Reading Augmentation In Mathematical Formula

Enhancing the reading experience is a longstanding topic in the field of human-computer interaction. Some researchers have attempted to improve the readability of mathematical formulas through interactive articles. ScholarPhi [19] is an augmented reading interface for scientific papers, which exposes the definition of symbols with interactive tooltips and equation diagrams. Idyll [15, 16] is a domain-specific language designed for authoring interactive narratives, which allows formulas to respond to the reader's actions. Although these interactive articles are effective and engaging, they are limited to the reading medium and cannot be applied to static mediums, such as PDF files and printing materials.

Head et al. [20] defined math augmentation as the embellishment of mathematical notation with novel visual designs and provides a detailed qualitative analysis of it. Math augmentation includes interactive and static visual designs; colorization is the most pervasive. This ability is evident in numerous examples in terms of guiding the reader's attention through color. One prominent instance is found in modern programming editors such as VSCode [6], where color is employed to assist programmers in quickly distinguishing between different types of terms. In addition, SCIM [17] is an intelligent interface that helps researchers skim a paper by highlighting salient paper contents with different colors.

Miogatto [8] is an annotation tool that can annotate each math identifier with a math concept and annotate grounding sources. This work aligns closely with our objectives, as it aims to assist users in extracting links between symbols and definitions. However, it does not integrate a language model for providing suggestions. Moreover, the tool produces a JSON file containing links instead of generating colorized mathematical expressions directly. To showcase the colorization designs, users must open the file using Miogatto. In contrast, MaugVLink integrates a language model to expedite link extraction and generates LaTeX files that can be applied to other LaTeX engines, such as Overleaf [3].

In addition, Heer et al. [21] presented a language toolkit, Living Papers, for producing augmented academic articles that span multiple mediums and can provide math augmentations. Although it can create visual links in formulas with colorization, the authors must manually locate symbols and definitions.

2.3 Link Extraction

Mathematical language processing encompasses various sub-fields, among which the one most closely related to our goal is identifier-definition extraction, which aims to pair up math identifiers with their counterpart descriptions. However, this task has not converged to a canonical form and does not have a benchmark dataset, making the comparison of performance difficult [31]. Jo et al. [25] propose two notation prediction tasks, notation auto-suggestion and notation consistency checking tasks, to predict notation given context, which is quite different from our task. HEDDEx [26] utilizes syntactic features, transformer encoders, and heuristic filters to detect definitions of terms in scholarly papers, but it has poor recognition of mathematical symbols. MathAlign [7] is a rule-based approach based on Odin grammar [35] to extracts LaTeX representations of formula identifiers and links them to their in-text descriptions, but its input has to be PDF file and the location of the formula.

Symlink [28] is a SemEval [4] shared task of extracting mathematical symbols and their descriptions from LaTeX source documents, which attracted seven participant teams. Lee et al. [29] propose a two-stage pipeline model based on SciBERT [12] and achieved first on the leaderboard for all the subtasks in Symlink. Therefore, we use this model in our link extraction pipeline and use a rule-based method to convert its output into the format required by the MaugVLink. The details will be discussed in Sect. 3.3.

3 MaugVLink

In this section, we begin by outlining the design goals that shape the development of MaugVLink (Sect. 3.1). Then, we present an overview of the system (Sect. 3.2), delve into the automatic link extraction pipeline (Sect. 3.3), and conclude with an explanation of the UI design (Sect. 3.4).

3.1 Design Goals

As we mentioned above, if we colorized the symbols and their corresponding definitions in the same color, the readers can easily locate them, reducing readers' cognitive load [17, 20, 24, 36]. However, the colorization process is tedious and time-consuming, which prevents these designs from being widely promoted in the academic field. Therefore, the overall objective of MaugVLink is to speed up the colorization process.

In addition to this overall objective, we distilled the following four design goals from the literature to guide the entire subsequent development process.

- **G1: Minimize distraction** Inspired by ScholarPhi [19], we realized that there should not be too many distracting elements on the interface. However, the links in a formula are usually multiple. The author may be easily distracted by plenty of symbols and terms. Hence, the user interface of our tool should be able to make the authors focus on the link they are editing and minimize the distraction.

- **G2: Support multiple kinds of medium** According to Heer et al.'s work [21], researchers often must present their research findings across various mediums, from traditional printed documents to web pages. Therefore, the output of our tool should be sufficiently flexible and can be easily transformed and adapted for different mediums.

- **G3: Extract links automatically** Before colorizing, the authors must first locate the target symbols and their corresponding definitions. This process is cumbersome, time-consuming, and requires repeated modifications and adjustments, especially in the case of relatively long documents. Inspired by Head et al.'s study [20], it would alleviate the user's burden and expedite the editing process if we could automatically generate user preliminary drafts.

- **G4: Support error recovery** According to Fok et al.'s work [17], the accuracy of visual designs to enhance readability is crucial. For instance, if the highlighted portions in an article do not correspond to significant content, readers may lose confidence, and these highlights will become meaningless. However, the results generated by the language model may not always be correct; our tool must allow users to modify the design.

3.2 System Overview

MaugVLink is a LaTeX-based authoring tool, meaning its input and output are in the LaTeX language. There are two reasons for this. First, LaTeX is the dominant language for authoring and augmenting formulas and is widely used to write scientific and technical documents, making it familiar to researchers worldwide. In Head et al.'s study [20], they interviewed the authors who had previously designed custom math augmentations and found that nearly all of them created formulas with LaTeX. MaugVLink enables the user to create a formula with LaTeX, lowering its threshold. Second, the LaTeX output is flexible and can be easily transformed and adapted for different mediums (G2) with various existing packages and tools, such as Overleaf [3] and Beamer [1].

The output generated by MaugVLink is a piece of LaTeX code that can render both colorized formulas and prose, as illustrated at the bottom of Fig. 3. This piece of code is complex and hard to read and modify [20], while MaugVLink can visualize the entire editing process, making it easier to edit and modify the code (G4).

The system overview of MaugVLink is illustrated in Fig. 1. Head et al. [20] segmented the editing process of math augmentation into three steps: create a formula, create math augmentation, and embed the formula in the document. Inspired by these steps, we have similarly divided the workflow of our system into three stages: LaTeX editing, links creation, and output. As Fig. 1 shows, our user interface comprises three corresponding pages. Within these pages, our system utilizes a language model to extract links and employs a rule-based method to generate the final output.

3.3 Link Extraction Pipeline

In terms of visual link creation, one challenging aspect is the manual location of symbols and their definitions, which is time-consuming and mentally demanding. Fortunately, with the development of natural language processing, language models can now extract links from formulas and prose with a certain level of precision (G3).

In MaugVLink, we use the model developed by Lee et al. [29] since it had the best performance in Symlink [28], which is highly

Rendered Formula & Prose:

$$e = \lim_{n\to\infty} \left(1 + \frac{1}{n}\right)^{1\cdot n}$$

The base for continuous growth is
the unit quantity earning unit interest for unit time,
compounded as fast as possible

LaTeX code:

```
\newcommand{\growth}{\color{c1}}
\newcommand{\unitQuantity}{\color{c2}}
\newcommand{\unitInterest}{\color{c3}}
\newcommand{\unitTime}{\color{c4}}
\newcommand{\perfectly}{\color{c5}}
\newcommand{\compounded}{\color{c6}}

$$
\growth e \plain = \perfectly \lim_{n\to\infty} \plain \left(\unitQuantity 1 + \unitInterest \frac{1}{\compounded
n} \plain \right) \unitTime^{1 \cdot \compounded n}
$$

\growth The base for continuous growth \plain is \unitQuantity the unit quantity \unitInterest earning unit
interest \unitTime for unit time, \compounded compounded \perfectly as fast as possible
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Figure 3: An example of colorized formula and corresponding prose from [9]. Above is the rendered result, and below is the original LaTeX code.

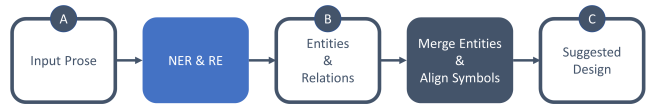

Figure 4: Links extraction pipeline. The blue step is the Symlink [28] task, which is composed of two sub-tasks, Named Entity Recognition (NER) and Relation Extraction (RE). We use Lee et al.'s model [29] to achieve this task.

related to our use case. Symlink aims to extract pairs of mathematical symbols and their corresponding descriptions from scientific documents. This involves two sub-tasks: Named Entity Recognition (NER) and Relation Extraction (RE). In NER task, the model will extract entities from the input prose. These entities include mathematical symbols and terminology descriptions, with three tags: SYMBOL, PRIMARY, and ORDERED, corresponding to the categories of mathematical symbols, standalone definitions, and descriptions of multiple terms, respectively. In RE task, the model will identify the relationships between these entities. The relations have four types: DIRECT, establishing a link between a symbol and its definition; COUNT, connecting a description with a symbol that represents the number of instances; COREF-SYMBOL, linking co-referred symbols; and COREF-DESCRIPTION, linking co-referred descriptions.

With Lee et al.'s model, we can extract links automatically. Take Fig. 5B as an example; the prose has two DIRECT relations, each with a SYMBOL and a PRIMARY entity. We will merge all the entities in the same relation and treat them as a single link. Thus, "total instantaneous power usag" and "p_i" will be a link, and "graphics cards" and "p_g" will be another. A DIRECT or COUNT relation has a symbol and a definition entity, so merging them is reasonable. As for COREF-SYMBOL and COREF-DESCRIPTION relations imply that multiple symbols or descriptions have a relation, so we will merge them as well. We can use a rule-based method to locate these selected symbols in prose in the formula. In the end, we will assign distinct colors from Tableau 10 [5] to each link, creating the auto-suggested design, as illustrated in Fig. 5C.

As the model's results may not be entirely accurate, this automatically generated draft will be presented on the links creation page, allowing users to make adjustments freely (G4). If users find that the generated draft deviates significantly from their ideal and causes distraction (G1), they can switch to manual mode to clear the

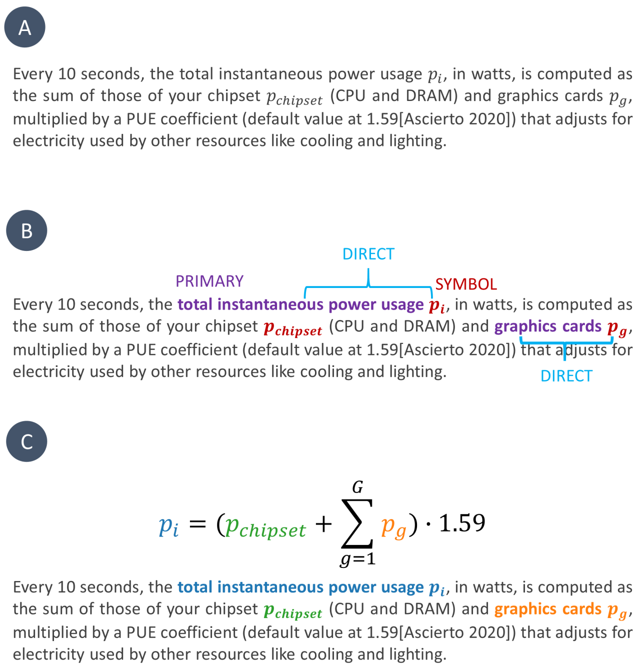

Figure 5: An example of links extraction pipeline. A: the input prose form [33], B: the output of Lee et al.'s model [29], C: the auto-suggested design by the MaugVLink.

suggested links.

3.4 User Interface

In the LaTeX editing page, the user can input the formula and the prose in LaTeX language, and the result will be rendered on the right with KaTeX library [2] simultaneously. Before going to the next page, users can use the switch to decide whether to utilize AI assistance for recommending visual links.

The user can select the target symbols and terms on the links creation page with a direct mouse click on the rendered result. We modified the approach of Gobert et al. [18] to customize KaTeX, enabling tracking of the source LaTeX snippet by the rendered HTML node. On the right half window, the user can select, add, or delete a link, and all the symbols and terms in the selected link will be shown independently (G1). Although symbols and terms in other links are still visible in the left half window, their colors are faded (G1). If MaugVLink is in AI mode, several AI-selected links will be shown on this page (G3), and the user can modify them in the same way as handling manually selected links (G4). The user can modify the color of each link with the color pickers below.

In the output page, MaugVLink will generate a piece of LaTeX code that can render both colorized formulas and prose (G2) as illustrated in the bottom of Fig. 3. This output code will be shown on the right half window, where the user can copy it directly. Since the output result is still LaTeX code, users can directly make corrections if there are any issues (G4).

4 User Study

To evaluate MaugVLink, we conducted a preliminary user study. Our goal was to answer two research questions: First, is the design of MaugVLink for creating links reasonable, user-friendly, and easy to learn? (S1) Second, is MaugVLink robust enough and applicable to users' practical needs? (S2)

As a result, our study consisted of two parts. In the first part, we asked the participants to use MaugVLink to replicate a given colorization design (S1). In the second part, we had the participants provide their own target formulas and corresponding explanations and asked them to use MaugVLink for colorization (S2).

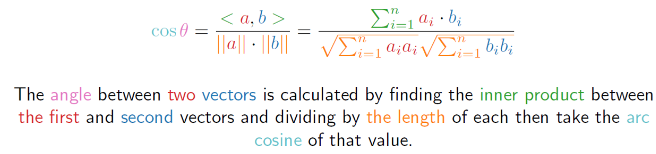

Figure 6: The colorization design participants had to replicate, which is from [14].

4.1 Methodology

Participants We recruited 8 participants (4 women and 4 men, aged 22 to 29) via an internal lab mailing list. One was a PhD student; the others were MSc students. Most of them were beginners with LaTeX (6/8).

Procedure We started the study with a short introduction and a tutorial on MaugVLink. Then, we had the participants practice using MaugVLink to complete two simple specified examples. Once they felt ready, we asked the participants to replicate a given colorization design shown in Fig. 6. Then, the participants were asked to fill out a questionnaire. After that, we had the participants provide their own formulas and corresponding explanations then use MaugVLink to colorize them. They were asked to fill out another questionnaire as well. After that, we interviewed the participants for a few questions.

Measures We did not conduct a comparative study as no widely available and appropriate baselines exist. Therefore, we use the system usability scale (SUS) [13] to evaluate the usability of MaugVLink. In addition, we referred to the study conducted by Wang et al. [37] and utilized three questionnaires to evaluate MaugVLink's UI design, AI suggestion, and output quality on a 7-point Likert scale. Note that, in the first part of the study, the designs provided to the participants were predetermined by us. Therefore, the questionnaires for the first part only address the UI design and do not include evaluations of AI suggestions and output quality.

4.2 Results and Discussion

After each part of the study, we had the participants complete the SUS questionnaire individually. The average reached 76.25 ($min = 60$, $max = 90, \sigma = 11.46$) in the first part and 74.69 ($min = 55$, $max = 97.5$, $\sigma = 15.68$) in the second part. The scores in the second part are more dispersed, and the average is slightly lower. This variation is attributed to the diverse nature of cases in the second part. The SUS scores for both parts exceeded 70, which is acceptable [10].

The participants' ratings for various UI elements are shown in Fig. 7. There is no obvious difference in the scores between the two parts. Most participants scored positive for the overall UI design ($\mu_{Q_1,part1} = 5.88$, $\mu_{Q_1,part2} = 5.75$), expressing that they found the UI design is easy to learn ($\mu_{Q_2,part1} = 6.00$, $\mu_{Q_2,part2} = 6.13$) and easy to use ($\mu_{Q_3,part1} = 5.75$, $\mu_{Q_3,part2} = 5.88$). The UI element with highest rating is the symbols selection area ($\mu_{Q_4,part1} = 5.88$, $\mu_{Q_4,part2} = 6.00$), and the one with lowest rating is the symbols and terms in the selected link ($\mu_{Q_8,part1} = 4.75$, $\mu_{Q_8,part2} = 4.88$). The average scores for each UI element are all above the median value of 4, indicating generally positive evaluations.

Ratings for AI suggestion and output quality were only conducted in the second part, and the results are shown in Fig. 8. The ratings for AI suggestion were quite polarized, reflecting the AI system's strong performance in some cases but weaker performance in others. The details will be discussed in Sect. 5. As for the evaluation of output quality, most participants provided positive feedback ($\mu_{Q_{12}} = 5.75$). They agreed that the output results, while aesthetically pleasing

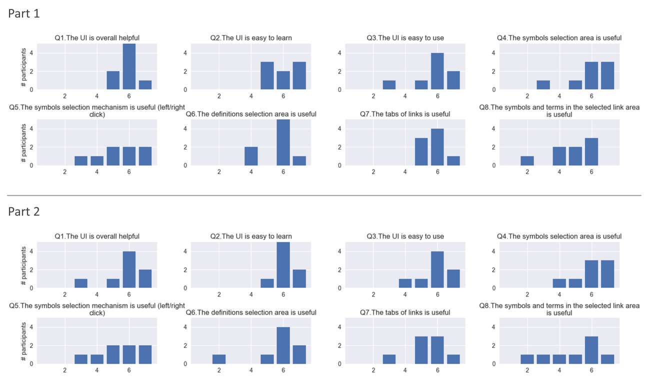

Figure 7: Participants' ratings on UI design, on a 7-point Likert scale (1 = "strongly disagree" and 7 = "strongly agree").

Figure 8: Participants' ratings on AI suggestion and output quality in the second part, on a 7-point Likert scale (1 = "strongly disagree" and 7 = "strongly agree").

($\mu_{Q_{14}} = 6.13$), also enhanced the readability of the formulas ($\mu_{Q_{13}} = 6.25$).

5 Limitation and Future Work

5.1 Limitations of the AI model

As mentioned in the Sect. 3.3, Lee et al.'s model [29] can handle text, as shown in Fig. 5, providing explanations for each symbol individually. If a brief description of the formula is given directly, the model will not be able to extract links. Fig. 9 shows augmented formulas created by two participants in the second part of the study. While the designs of these two formulas may appear similar at first glance, the ratings for AI suggestions from the two participants differed significantly. In the above one, the AI performed well because the text provided individual explanations for each symbol, such as G, M, and c. As a result, the participant completed the design in the links creation page in just 23 seconds and gave a high rating of 7 to the AI suggestion (Q_9). On the contrary, in the below one, as there were only brief explanations for the entire formula, the AI failed to identify any links. Consequently, the user took 173 seconds in the links creation page and gave a rating of only 2 to the AI suggestion (Q_9). These two examples highlight two conclusions. First, the current AI in MaugVLink struggles with handling text without explanations to each symbol. Second, if AI can provide good suggestions, it has the strong potential to reduce editing time significantly. With the rapid development of natural language processing techniques in recent years, such as large language models, current technological limitations are likely to be effectively addressed, which is a promising direction for future research.

$$r_s = \frac{2GM}{c^2}$$

The Schwarzschild radius is given as, where G is the gravitational constant, M is the object mass,and c is the speed of light.

$$\nabla \cdot E = \frac{\rho}{\mathcal{E}_0}$$

The net electric flux through any hypothetical closed surface is equal to $\frac{1}{\mathcal{E}_0}$ times the net eletric charge enclosed within that closed surface. The closed surface is also referred to as Guassian surface.

Figure 9: Two examples of participants' own augmented formulas. The participant above rated high for AI suggestions, while the one below rated the opposite.

5.2 Limitations of the evaluation

As mentioned in the Sect. 4, we did not conduct a comparative study since there are no appropriate baselines. However, a comparison with direct manual LaTeX writing, as shown in Fig. 3, is feasible. This comparison may provide a clearer illustration of MaugVLink's effectiveness in speeding up the editing process.

In addition to the comparison with manual writing, learning efficiency is another topic worthy of exploration. As an interactive authoring tool, MaugVLink is expected to be more user-friendly than a language toolkit because users don't need to memorize its syntax. However, these differences require further experimental validation.

5.3 Remedial Measures for Incorrect AI Suggestion

The AI suggestion in MaugVLink doesn't always be correct, and it struggles with handling text without explanations to each symbol. While MaugVLink allows users to freely modify AI suggested drafts, further remedial mechanisms is a potential directions for the future work. When the AI suggestion system does not perform well, the remedial mechanisms should alleviate the user experience degradation.

6 Conclusion

MaugVLink is a prototype of a LaTeX-based and AI-assisted authoring tool that can help the authors add visual links to augment mathematical formulas. With easy-to-use symbol selection UI design and human-AI collaboration mechanism, the author can easily select symbols and terms to create links with the draft automatically generated by the tool. A preliminary two-part user study with eight participants showed that the UI design is user-friendly and straightforward to learn. The participants all agreed that their augmented formulas with visual links are aesthetically pleasing and have higher readability. In addition, the polarized scores for AI suggestions indicate the strong potential for future AI developments in similar authoring tools.

Acknowledgments

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