Integrating Formal Methods into LaTeX Workflows

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While some mathematicians have begun actively adapting formal methods for their work, there is a prohibitively large discrepancy between the way new mathematical results are developed, presented and published in mathematical practice, and the way they are formalized and implemented in formal systems.

This discrepancy is primarily due to the respective surface languages and the logical foundations used in theorem prover systems. The former tend to be more reminiscent of programming languages with strict formal grammars than (informal) mathematical language, whereas the latter are most prominently variants of type theories – both of which require considerable effort to learn and understand for users unfamiliar with them.

Consequently, many mathematicians complain that

- formal systems are difficult to learn and use, even if one is well acquainted with the (informal) mathematics involved,
- they require a level of detail in proofs that is prohibitive even for "obvious" conclusions,
- their libraries are difficult to grasp without already being familiar with the system's language, conventions and functionalities.

Consequently, the utility of formalizing mathematical results can be too easily (and too often *is*) dismissed in light of the additional time and work required even for experts. This is despite the fact that many services available for formal mathematics are already enabled by *semi*-formal (or *flexiformal*) representations, such as semantic annotations in natural language texts, or formal representations containing opaque informal expressions (see e.g. [Koh13], [Lan11a], [Ian17], [Koh+17a], [CS17], [Deh+16]). Therefore, we need to invest into methods for bridging the gap between informal mathematical practice and (semi-)formal mathematics.

However, the vast majority of mathematicians can safely be assumed to be comfortable with using LaTeX and do so on a regular basis.

The second author developed the sTeX package [Koh08] for LaTeX, specifically for annotating mathematical documents with structural and formal semantics. In particular, sTeX is based on an OMDoc [Koh06] ontology, which is foundation-agnostic in the sense that it does not favor a specific foundation (such as type or set theories) over any other. This approach is consequently best suited for semantifying informal documents, where foundations are often unspecified, left implicit or switched fluently.

Furthermore, sTeX allows markup both on the level of mathematical expressions as well as on a structural level, such as declarations, definienda/definientia and theorems.

The *SMGloM* library [Koh14] (*Semantic Multilingual Glossary of Mathematics*) contains hundreds of sTeX-annotated concepts and definitions, providing LaTeX-macros for their symbolic *notations* (i.e. presentation as pure LaTeX) in *signature* files. These are documented in various *natural language* dictionary entries, defining and describing the concepts in a flexiformal manner. Besides natural languages, the SMGloM could conceivably be extended to cover controlled languages such as Naproche [Cra+09], or fully formal languages such as those associated with interactive theorem provers.

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In addition to being valid LaTeX compilable via `pdflatex`, sTeX-documents can be transformed to OMDoc using the LaTeXML-software [Gin+11], yielding a formally disambiguated representation of the document and in particular the symbolic expressions therein.

sTeX itself is integrated, and shares an underlying OMDoc ontology, with the Mmt system [RK13; HKR12; Rab17] – a foundation-independent meta-framework and API for knowledge management services. This integration makes the generic services provided by Mmt– e.g. type checking, library management/browsing, translation – available to informal mathematical texts. Using *alignments* [Mül19; Mül+17], OMDoc-expressions can be translated between different libraries, languages and foundations. This allows for e.g. translating (originally) sTeX-content to a typed setting in order to e.g. check expressions and run type inference.

Additionally, several theorem prover libraries have been translated to OMDoc and integrated in the Mmt system, e.g. [Koh+17b; MRS19] (for a detailed overview, see [Mül19] and [KR20]). Extending these integrations to enable exporting from Mmt as well (and in conjunction with natural language processing), this could enable verifying informal mathematics imported via sTeX using external state-of-the-art theorem prover systems.

We propose to

1. extend the sTeX package to be compatible with arbitrary LaTeX document classes and packages, as well as dedicated macros covering a multitude of common styles of presentation and linguistic phenomena in scientific documents

2. aligning the (ever growing) SMGloM concepts with their counterparts in formal languages, so that the SMGLoM can serve as a true Math-in-the-Middle [Deh+16] library for translation between languages,

3. develop an IDE that specifically supports and suggests sTeX macros to significantly lower the entry barrier and allows accessing Mmt's formal services directly, and

4. extend Mmt by new helpful services for sTeX content.

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