NNexus Reloaded

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Abstract. Interlinking knowledge is one of the cornerstones of online collaboration. While wiki systems typically rely on links supplied by authors, in the early 2000s the mathematics encyclopedia at PlanetMath.org introduced a feature that provides automatic linking for previously defined concepts. The NNexus software suite was developed to support the necessary subtasks of concept indexing, concept discovery and link-annotation. In this paper, we describe our recent reimplementation and revisioning of the NNexus system.

1 NNexus 1.0 – Introduction

PlanetMath.org is a mathematics digital library, built “the commons-based peer production way” \cite{Kro03}. Like Wikipedia, which launched the same year, PlanetMath has been created by volunteer contributors from around the world. However, unlike Wikipedia, PlanetMath focuses solely on mathematics. Since its launch, it has used custom software both to support the display of mathematical expressions, and to facilitate the integration of new user-contributed content.

One of the features designed to assist in content integration was an \textit{autolinking service}. This service allowed authors to write without concerning themselves with wiki-style links to technical concepts that had already been added to the corpus. Instead, these links would be added automatically – and links would be recalculated and adjusted automatically as the encyclopedia grew, using a sophisticated caching and expiry system. The system provided an example of named entity recognition \cite{NS07}, where the entities to identify in submitted text are article titles, the names of terms defined in the articles, and any known synonyms. The process of adding links to named entities in text has come to be known as “wikification” \cite{Rat+11}.

In 2006, NNexus 1.0 began the process of decoupling autolinking from PlanetMath, and provided integration with other corpora (Wikipedia, Mathworld) on a demonstration basis \cite{GKX06}, an effort that has matured with the current release.

2 NNexus 2.0 – Reload, Refresh, Refactor

The primary goal of our rebuild was to decouple fully from the old Noosphere system on PlanetMath.org. A strong contributing motivation was that Noosphere was in the process of being deprecated on PlanetMath and replaced by
the new Planetary system [CD12]. The new NNexus works with Planetary, but also functions in a stand-alone fashion, and is published as a software library on the Comprehensive Perl Archive Network (CPAN). It has been refactored to operate either as a web service, or programmatically via an API. NNexus accepts arbitrary HTML input and performs concept discovery against its concept index, followed by a serialization of the mined data, either as stand-off metadata or by in-place embedding.

Concept indexing is performed by NNexus’ built-in web crawler. It is based on a plugin architecture. Every indexed web resource requires its own indexer class, which contains the custom rules for detecting the concept definitions in the page. For example, PlanetMath’s key terms are found in RDFa metadata that has been deposited in the encyclopedia pages, whereas the Digital Library of Mathematical Functions lists its defined concepts in its index as bold-anchored elements.

The current NNexus release ships with a database that integrates the concepts from seven web resources for mathematical concepts. These include the three best-known web resources for mathematics – Wolfram’s MathWorld; PlanetMath.org; and Wikipedia – as well as Springer’s Encyclopedia of Mathematics; the Digital Library of Mathematical Functions (DLMF); the nLab (which focuses on category theory); and the recently created MathHub.info.

At the time of writing, the NNexus index contains just under 50,000 unique concepts in its index. With the introduction of client-side tools for embedding NNexus [Gin13], we can also report successful auto-linking in third-party platforms such as arXiv.org and Zentralblatt MATH.

3 Concept Discovery

The NNexus implementations to date have only scratched the surface of the knowledge discovery problem. NNexus performs longest-token matching, aided by classic preprocessing techniques (stopword lists, morphological normalization) to discover all possible concept candidates. Concepts are considered discovered if there is an exact match between the linguistically normalized input document and the identically normalized concept index. When a concept \( A \) is a substring of a concept \( B \), since they both match at the same starting point of the input, preference is given to the longer string \( B \). To demonstrate, take \( A \) to be “fundamental groupoid” and \( B \) to be “fundamental groupoid functor”.

This simplistic approach leads to false positive hits, for instance, in words that have multiple part-of-speech uses or words that have both technical and everyday meanings. Accordingly, each of the following examples becomes a candidate for linking, even though the words in the right-hand column are not being used in a technical sense.

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3 Run `cpan NNexus` to install the software locally.
4 A demonstration instance is available at `http://nnexus.mathweb.org`.

Sending an HTML snippet as the body of a POST request will return the link-annotated snippet back, embedded in a thin JSON wrapper.
"Let $G$ be a group"  
"group the numbers in rows"

"chain in a graph"  
"chain made of steel"

"permanent of a matrix"  
"using a permanent marker"

This particular phenomenon is less observable as the length of the concept grows, both because longer words are less frequently overloaded and because multi-word concepts rarely have non-technical meanings. Inversely, the problem is particularly challenging in concepts with short single-word names.

Another challenge is disambiguating between overloaded concept names, used differently in different scientific areas. To address that, NNexus does not immediately return all of the named entities it discovers. Instead, it first uses a clustering algorithm, based on a distance metric between the classes of the MSC [Ame09] categorization scheme, which determines a kernel of closely related concepts. We have observed our distance metric is effective in separating concepts from typically disjoint subfields of science, but less successful in making fine-grained distinctions in subfields that tend to have a lot of mutual connections. For example, “entanglement” is a concept both in quantum mechanics and graph theory. NNexus is able to tell which meaning is intended by contextually clustering with the rest of the discovered concepts. However, generic concepts such as “equivalence” tend to be redefined in closely related subfields, and NNexus cannot tell these apart.

In addition to these technical limitations, NNexus is limited by the quality of the metadata provided by its indexed sources. For example, as pointed out by one of the reviewers of this paper, PlanetMath currently has no article on “classical logic”, and links to this term are currently being directed to PlanetMath’s article on quantum logic. This looked like a rather strange error until we realized that the quantum logic article includes a definition of the term “classical logic”, in contravention of the “one main concept per article” norm.

4 NNexus 3.0 Revolution – an Outlook

Auto-linking continues to be a useful tool around PlanetMath. For instance, Planetary added support for contributing problems and problem sets, and technical terms in problems are linked to definitions drawn from the encyclopedia. We plan to add a PlanetMath feature where, given a contributed piece of text, a small “course packet” of preliminaries would be built on the fly, created out of auto-linked encyclopedia articles. Thanks to the metadata in the links provided by NNexus, we will be able to consider both “incoming” and “outgoing” links – this means we can discover applications of a concept as well as simpler concepts.

Some other efforts that we plan to explore include autolinking in math blogs, such as the blogs indexed on http://mathblogging.org/. NNexus could build a “term cloud” of technical terms from across the math blogosphere, providing a useful access method that parallels the familiar tag cloud.

The main challenge ahead is to solve the problem of reliable concept discovery. The immediate goal is to achieve reliable disambiguation of overloaded concept words (such as “set” or “group”), possibly by employing the help of a
part-of-speech tagger. A complementary idea is to improve precision by augmenting longest-token matching with weights derived by statistical term-likelihood analysis. As statistical term-likelihood methods do not depend on an a priori fixed lexicon, they could also be used to detect concepts that are not yet included in the index. That would allow us to enable another desirable feature—the automatic creation of dangling links (similar to Wikipedia’s “red links”).

Deeper scrutiny of mathematical formulas and terms will allow us to link occurrences of math constants in MathML, both globally, for symbols like the reduced Planck constant $\hbar$, and locally, following the annotation of the corresponding natural language term, such as “Assume a cyclic group $\mathbb{Z}_{mn}$ . . .”.

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