Math Information Retrieval: User Requirements and Prototype Implementation

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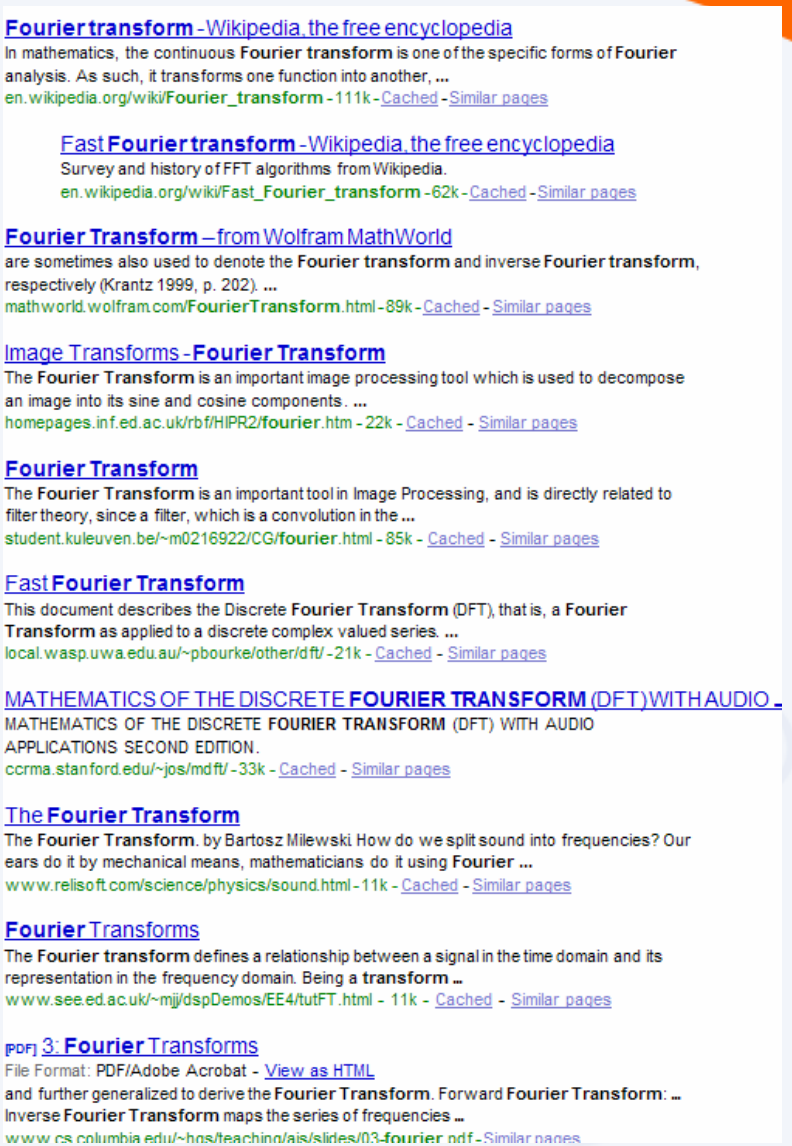
Why Math Information Retrieval?

Examples:

- Looking for formulas
- Collect teaching resources
- Keeping updated on research development

Generic search engines ineffective in such situations

- Unaware of user needs and math expressions



Fourier transform - Wikipedia, the free encyclopedia
In mathematics, the continuous **Fourier transform** is one of the specific forms of **Fourier** analysis. As such, it transforms one function into another, ...
en.wikipedia.org/wiki/**Fourier_transform** - 111k - Cached - Similar pages

Fast **Fourier transform** - Wikipedia, the free encyclopedia
Survey and history of FFT algorithms from Wikipedia.
en.wikipedia.org/wiki/Fast_**Fourier_transform** - 62k - Cached - Similar pages

Fourier Transform – from Wolfram MathWorld
are sometimes also used to denote the **Fourier transform** and inverse **Fourier transform**, respectively (Krantz 1999, p. 202). ...
mathworld.wolfram.com/**FourierTransform**.html - 89k - Cached - Similar pages

Image Transforms - **Fourier Transform**
The **Fourier Transform** is an important image processing tool which is used to decompose an image into its sine and cosine components. ...
homepages.inf.ed.ac.uk/rbf/HIPR2/**fourier**.htm - 22k - Cached - Similar pages

Fourier Transform
The **Fourier Transform** is an important tool in Image Processing, and is directly related to filter theory, since a filter, which is a convolution in the ...
student.kuleuven.be/~m0216922/CG/**fourier**.html - 85k - Cached - Similar pages

Fast **Fourier Transform**
This document describes the Discrete **Fourier Transform** (DFT), that is, a **Fourier Transform** as applied to a discrete complex valued series. ...
local.wasp.uwa.edu.au/~pbourke/other/dft/ - 21k - Cached - Similar pages

MATHEMATICS OF THE DISCRETE **FOURIER TRANSFORM** (DFT) WITH AUDIO ...
MATHEMATICS OF THE DISCRETE **FOURIER TRANSFORM** (DFT) WITH AUDIO APPLICATIONS SECOND EDITION.
ccrma.stanford.edu/~jos/mdft/ - 33k - Cached - Similar pages

The **Fourier Transform**
The **Fourier Transform**. by Bartosz Milewski How do we split sound into frequencies? Our ears do it by mechanical means, mathematicians do it using **Fourier** ...
www.relisoft.com/science/physics/sound.html - 11k - Cached - Similar pages

Fourier Transforms
The **Fourier transform** defines a relationship between a signal in the time domain and its representation in the frequency domain. Being a **transform** ...
www.see.ed.ac.uk/~mjj/dspDemos/EE4/tutFT.html - 11k - Cached - Similar pages

[PDF] 3: **Fourier** Transforms
File Format: PDF/Adobe Acrobat - View as HTML
and further generalized to derive the **Fourier Transform**. Forward **Fourier Transform**: ... Inverse **Fourier Transform** maps the series of frequencies ...
www.cs.columbia.edu/~hgs/teaching/ais/slides/03-**fourier**.pdf - Similar pages

pythagorean theorem Search Advanced Search Preferences

Search: the web pages from Singapore

Linked Expression: $a^2+b^2=c^2$

Filter by > resource category, experience, specificity

Tutorials, Slides, Problem Solution Set, Applets, Tools, Data, Algorithms

Pythagorean theorem - Wikipedia, the free encyclopedia

Definition...

If we let *c* be

other two sid

$a^2 + b$

en.wikipedi

Pythagor

Pythagoras

www.cut-the

Goal: a *user-centric* and *math-aware* DL

The **Pythagorean Theorem** Lesson

Tutorial

A lesson on the **pythagorean theorem** with the objective that the student discovers or figures out by him or herself the actual **theorem**.

www.arcytech.org/java/**pythagoras**/ - 5k - Cached - Similar pages

Pythagorean Theorem -- from Wolfram MathWorld

Proof

The various proofs of the **Pythagorean theorem** all seem to require application of some version or consequence of the parallel postulate: proofs by dissection ...

mathworld.wolfram.com/**PythagoreanTheorem**.html - 52k - Cached - Similar pages

Outline

- Introduction
- **Literature Review**
  - Domain-specific Information Seeking Studies
  - Current Math Resources
  - Math Information Retrieval
- **User Study**
- **Prototype Implementation**
- **Conclusion**

Domain-Specific Information Seeking Studies

- **Brown 1999**
  - Monograph being the major source of information for math
  - Predat… …sources
- **Wiberley**
  - Techno… …or contains relevant conten…
- **Tibbo 20…**
  - Growing importance of online resources acknowledged but coupled with usability and accessibility problems

Key requirements:

Usefulness, Usability, and Accessibility

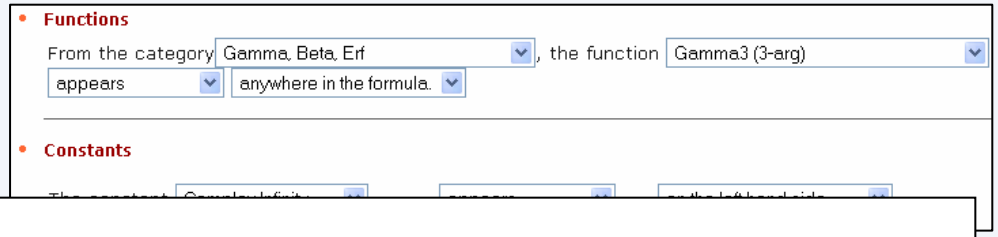
Current Math Resources Online

From Math Web Search

```
<mq:query xmlns:mq="http://mathweb.org/MathQuery">
  <math xmlns="http://www.w3.org/1998/Math/MathML">

    <apply><int/>
        <domainofapplication mq:generic="domain"/>
        <bvar> <ci>t</ci> </bvar>
        <apply><power/>
            <apply><ci mq:generic="fun"/>
```

From Wolfram Function Site



1. Hamper Accessibility

2. Limited search capability and hard to judge usefulness

1. Lack of cross-reference and subscription required

2. Different degree of math-awareness

- **Math-unaware**
- **Syntactically Math-aware**
- **Semantically Math-aware**

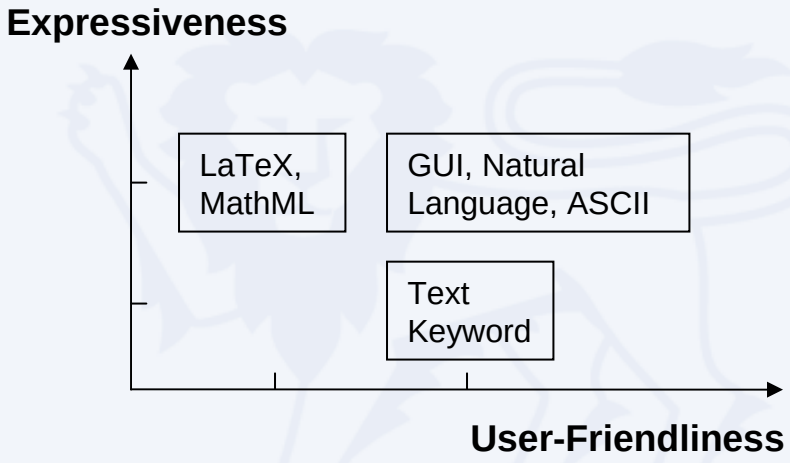
Current Math Information Retrieval

Expression Matching

- **Text-based approaches**
  - Match expressions on the surface
  - Notational Variation Problem: "$a^2+b^2=c^2$" $\neq$ "$x^2+y^2=z^2$"
- **Non-text-based approach**
  - Tree matching

Query language

- Text keywords
- Math authoring language
- Expression-input friendly language



Unanswered Issues

Whether the information needs of the users are satisfied by such resources

- What do the user really need?
- How do they perform information seeking?
- What are the difficulties encountered?

Whether the current research focus is appropriate

- Do they really need/prefer expression search?

Further study needed

Outline

- Introduction
- Literature Review
- **User Study**
  - Study Design and Consideration
  - Findings
  - Desiderata in Math Information Retrieval
- **Prototype Implementation**
- **Conclusion**

User Study

Study Design and Considerations

- Qualitative feedbacks for system design
- Pilot for future user study
- Small scale
- Semi-structured interviews
- Focus on profiling user behavior and analyzing needs
- Findings stabilized towards the end

User Study (Findings)

Three Approaches

- Keyword Search
  - Fast, available but disorganized
- Browsing
  - More effective but costly to compile or subscribe to
- Personal Contacts
  - Most effective but requires more effort and commitment

Trade-off between cost and benefit

User Study (Findings)

Expression Search

- Attractive but utility unknown
  - To find homework solutions?
  - Too specific
  - Less prevalent in certain domains
  - More convenient to use keyword

Keyword search still popular and preferred

User Study (Findings)

The multi-faceted user needs

- **Informational / Resource**
  - Definition, example, proof, etc.
  - Slides, tutorial, tools, etc.

- **Two implicit facets for filtering**
  - Specificity
  - Experience

- **The context**
  - Domain
  - Intent

Need to cater for specifically

Desiderata in Math Retrieval

Multi-collection search

- **Search through multiple collections on behalf of the user**

Enhance the usability and accessibility of collections

Resource Categorization

- **Automatically classify the materials according to the different facets of the user needs**

Return results that best suit the user needs

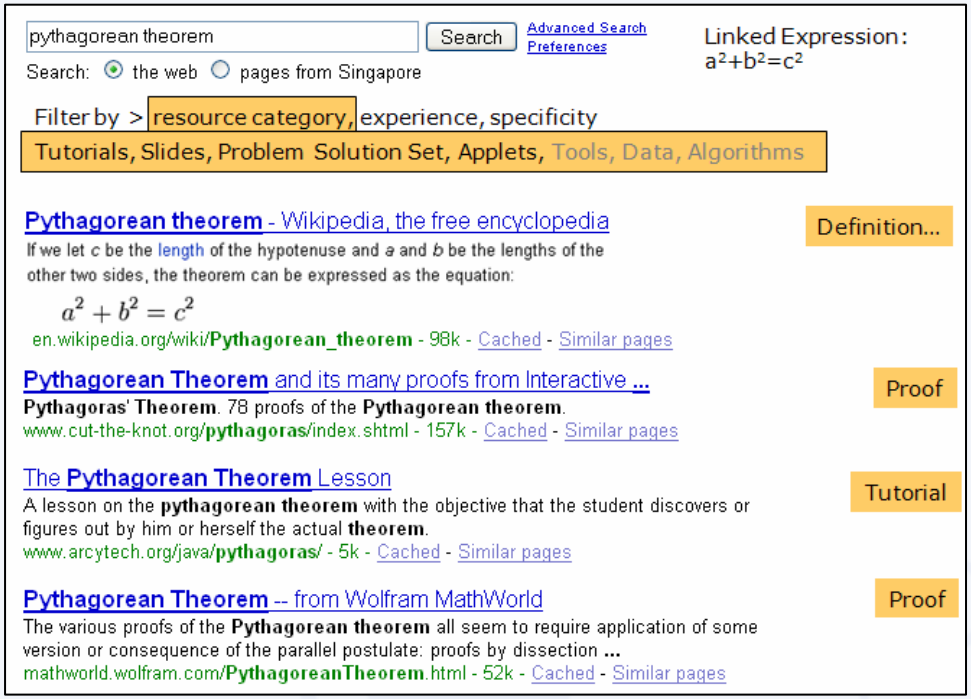
Outline

- Introduction
- Literature Review
- User Study
- **Prototype Implementation**
  - Focus on Resource Categorization
- **Future Work**

Prototype Implementation

Multi-collection Search

- Meta-search
- Offline indexing based on open source package
- Easier requirement to meet between the two



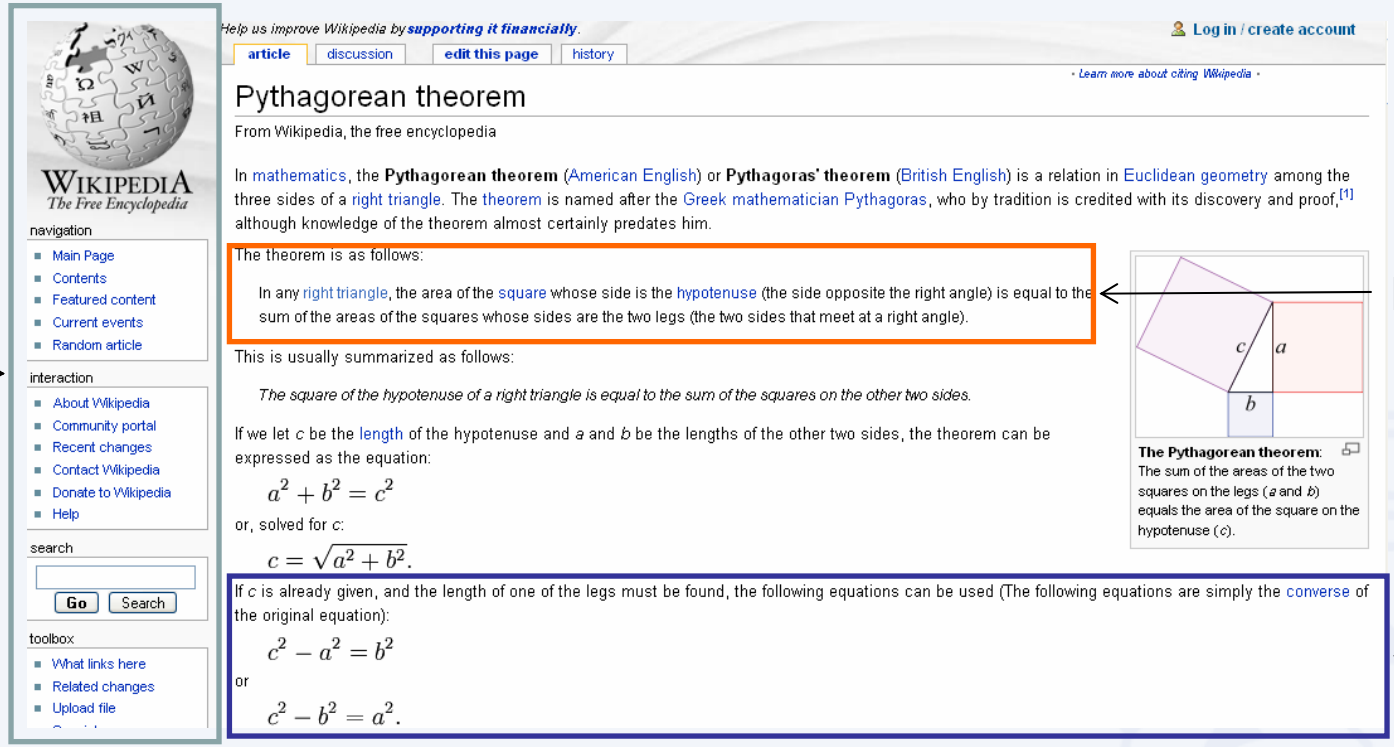
Resource Categorization

- Domain-specific text categorization on webpages
- More interesting as a research topic

Focus of the prototype is on **Resource Categorization**

Webpage Segmentation

Entire page is not a suitable unit for categorization



- Vision-based Segmentation (VIPS) used

Resource Categorization

Supervised Machine Learning Pipeline

- Labels
  - Math related / non-math-related
- Features
  - Word, Image, Formatting, Hyperlink, Layout, Context
- Machine Learner
  - SVM
- Training/Testing Data
  - Small corpus of webpages for 5 math topics
  - Manually annotated
  - Kappa-agreement: 0.87

Evaluation

Average accuracy: 0.36 on F_1

- Strength: separating math contents from the rest
- Weakness: identifying their exact type

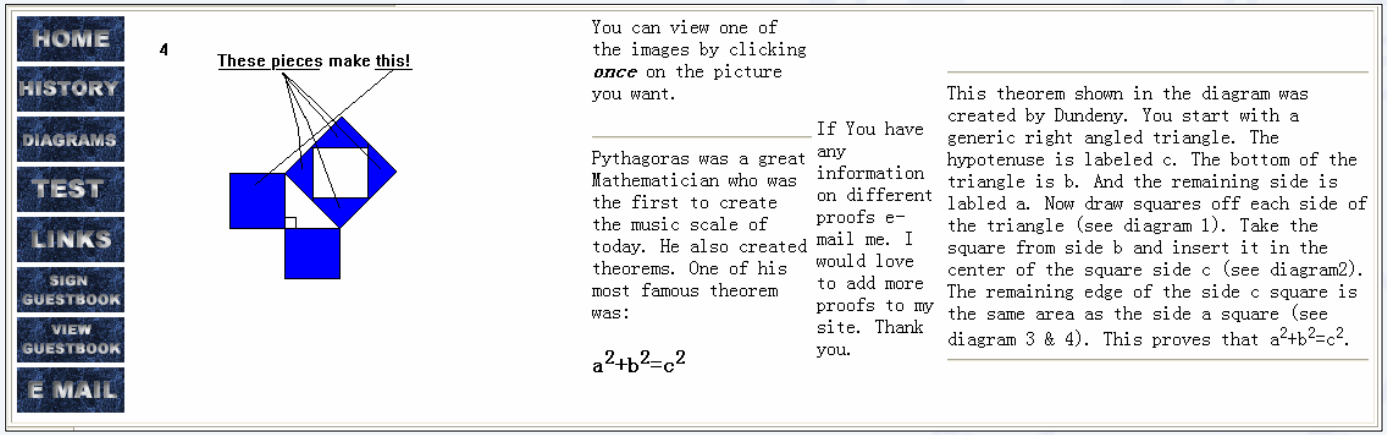
Feature Utility

- Text → competitive baseline
- Image → filter non-math information
- Formatting → identify section headings etc.
- Hyperlink → separate related concepts and resource from the rest
- Layout → improve precision at the cost of recall
- Context → not effective overall

Potential Sources of Error

- Training Data
  - **Insufficient examples**
  - **Skewed distributions**
- Segmentation
  - **Over- or under-segmented**

Operation on $x(t)$	Resulting signal $y(t)$	$Y(\omega)$
amplitude scale	$b\,x(t)$	$b\,X(\omega)$
time shift	$x(t-T)$	$e^{-j\omega T}\,X(\omega)$
time scale	$x(at),\ a \neq 0$	$\frac{1}{\lvert a\rvert}X(\omega/a)$
time reverse	$x(-t)$	$X(-\omega)$
derivative	$\frac{dx(t)}{dt}$	$j\omega X(\omega)$
running integral	$\int_{-\infty}^{t} x(\sigma)\,d\sigma$	$\frac{1}{j\omega}X(\omega) + \pi X(0)\,\delta(\omega)$



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Future Work

Iterative Development Process

- Enhance and extend categorization
- Prototype fielding after expanded user testing and requirement analysis

Text-to-Expression Linking

- **Resolve text keywords to expressions**

"Pythagorean Theorem" → : "$a^2+b^2=c^2$" & "$x^2+y^2=z^2$"

- Reduce the need for expression input
- Help to solve the notational variation problem
- Fit well with the rest of the desiderata

Conclusion

To create a *user-centric* and *math-aware* digital library on math materials

Two Desiderata:

- Multi-Collection Search, Resource Categorization

Prototype classification accuracy of 0.36 F_1

Future Text-to-Expression Linking

Thank you for listening
Questions?