The Global Digital Mathematics Library and the International Mathematical Knowledge Trust

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Abstract. We recall some of the reasons why we want and do not yet have a Global Digital Mathematics Library (GDML), both before and after the setting up of a GDML WG at the Seoul 2014 ICM. The recent founding of an International Mathematical Knowledge Trust (IMKT) in Waterloo ON, Canada is an important move in the right direction. The IMKT's form and initial efforts will be described, with attention to why the project is the way it is.

1 Introduction and History

It's been suggested that vignettes from history help to emphasize the way that members of the mathematics community have long wished better access to more of the world's mathematics. We have before mentioned G. Peano[Peano:1894], E. Schröder[Schröder:1897] and pasigraphy, then Georg Valentin's comprehensive bibliography [Ion:2016].

A World Library has long been a dream. Here let us remind ourselves of the long story of the Great Library of Alexandria in the Mouseion founded ca. 323 BCE by Ptolemy, a lieutenant of Alexander the Great, after the conquest of Egypt in 332 BCE; but it was gone during the Roman era in Egypt.[3] Perhaps it burned in 48 BCE during Julius Caesar's siege of the city of Alexandria; perhaps it remained around, but reduced, until some time after 391 CE, when the Christian Emperor Theodosius issued a decree that officially outlawed pagan practices. The details of the history are naturally complex, but it seems clear that the Biblioteca Alexandrina once housed as many as three quarters of a million books and scrolls, and was associated with some of the ancient world's most influential mathematicians. Archimedes (287-212 BCE) spent much time at the Mouseion. Eratosthenes (276-195 BCE) created the eponymous sieve for finding prime numbers; he also deduced the earth was spherical and measured

[3] Most of the ancient dates are to be taken as approximate at best, and much of the material can be found at [Mouseion].

its circumference to within about one per cent of the present measurement[4]. Apollonius (262-190 BCE) studied conic sections. Aristarchus of Samos (310-230 BCE) proved heliocentricity (i.e. not geocentricity) which influenced Copernicus. Hero (ca. 10 CE-70 CE) is known for Heron's formula for the triangle's area as well as for his amazing mechanical inventions. Hypatia, the daughter of Theon, the last director of the Mouseion and a brilliant mathematician was lynched by a rabble in 415 CE. There is now a new Bibliotheca Alexandrina [Bibliotheca Alexandrina][5]. One can only hope it lasts as long and makes such distinguished contributions to mathematics, science and culture as the ancient one did.

An important point here is that it seems in the internet culture remarkably easy to follow some trains of thought concerning history, but that corresponding meanderings for mathematics are not as easy by any means, although, often enough, much more available than they were half a century ago. We'd like that changed. Furthermore, the reported results of mathematics that one collects from elsewhere, such as the internet library, need to be well formulated and correct in a clear system. The little story above nowhere near meets those standards.

A World Digital Library has long been a dream and dates back at least to Vannevar Bush's [Bush, Vannevar:bio] imagined Memex from 1945[Bush:1945]. We have recently sketched the history from then to roughly the present in more than one place: [Ion:2016], [Watt:2016]. For the current purpose let us note the resolution of the International Mathematical Union (IMU) [IMU:2006]. A little later we have held with the support of the Alfred P. Sloan Foundation [Sloan], a 2012 symposium on *The Future World Heritage Digital Mathematics Library* [NAS:2012] and the thorough National Research Council report in 2014 by Ingrid Daubechies et al.[NRC/USA:2014]. More recent personal views include those of J. Pitman and C. Lynch, [Pitman & Lynch:2014] and Thierry Bouche [Bouche:2008][Bouche:2014].

There has been a change in our society and in the activity of the mathematical profession as a result of the widespread introduction of computing machinery. Modern mathematicians do communicate differently in our digital age. Until very recently the dominant technology for persistent communications has been printing. The businesses built up to provide printing and distribution services have controlled, with the collaboration of the leadership of the profession, the production of the literature we depend on. Being published in print was the ultimate goal for many a scientist, and, of course, without distribution there is no contribution to knowledge.

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[4] At least as remarked in a lecture by Cdric Villani [Villani:2014] or by Carl Sagan [Sagan:2015]. Of course, the scholarship required to justify this fully would be considerable and we cannot provide a reference for it presently. He is alleged to have arrived at a circumference of 40,000 km versus NASA's current value of 40,030. These items illustrate the variety of sources a GDML needs to take into account, as well as how easy it may be for some to get interesting material.

[5] A scholarly work on these matters is *Life And Fate Of The Ancient Library Of Alexandria* by Mostafa El-Abbadi, who was a moving force behind the new Library and died in 2017 [El-Abbadi:1986] [El-Abbadi:2017].

Thus the way to accumulate knowledge publicly, as opposed to within the understanding of an individual or team of individuals, was to aggregate collections of printed artifacts in libraries. Ideally scholars would visit such libraries, or local libraries would be held near places at which they worked. Cataloging and access tools, such as printed bibliographies, were then developed. We see the digital avatars of this printed material in PDFs and other electronic document forms, and online catalogs now with linking through the World Wide Web. So there is a whole system now again dominated by commercial publishing that looks rather like a virtual image, with some enhancements of the traditional publication and distribution of science from the last century or so. The copyright laws, and the odd notions going by the phrase 'intellectual property', arose in connection with such a business environment.

Of course, there's material that has been in print or penned manuscript that is in library collections and elsewhere that it will be a shame to lose. That should be digitized, collected and curated. For mathematics, whose results once proven are supposed to persist as truths (recognizing as we do nowadays that the underlying inference systems have to be preserved as well) this would seem obvious. Although the progress of mathematics is not entirely a matter of influential figures, even if we tend to name results after people, a recent example of interest, in direct connection with representation of mathematical knowledge, is that of notebook of Alan Turing's which has recently come to light with his "*Notes on Notation*"[Turing:1942]. Though mathematics as a subject is dependent on access to its literature, older documents are perhaps less valuable than is sometimes the case for other subjects. A recent *cri de coeur* for attention to the preservation of earlier material is nonetheless something that we need to pay attention to [Griffin:2017].

What seem to be changing us is the newer forms of scientific communication over electronic networks and the capability of individual authors to create documents of high technical sophistication themselves. For instance, mathematical authors not only do create, say using TEX, their documents involving the penalty copy of formulas that it used to cost so much extra in typesetting, they are asked by commercial publishers to do so as a cost-saving measure. This has advantages for the authors as well in providing a direct responsibility for the correctness of what is circulated.

But it does also mean that the nature of publication is changed. Many services that used to be provided by publishers are again the author's responsibilities. The culmination today of that change is the World Wide Web and the opportunities it offers for circulation of knowledge in forms different from print representations. Furthermore, now that much of the literature, especially the new part, is in digital form computers can be used to facilitate access and also by treating the literature as data to analyze what we have in new ways. It's not just that modern technology can realize much of the dream of Paul Otlet's Mundaneum [Rayward:1975] [Spiegel:2011] which was begun using large card catalogues.

The forms of document are changing since they are not limited by printing requirements. Color and visual complexity are comparatively easy to achieve, as are moving images and documents responsive to reader input which can be especially useful in education. The literature analysis aspect mentioned above has brought to the fore the developing notion of Mathematical Knowledge Management. In fact, that is likely ultimately to be the big change in a Global Digital Mathematical Library. A GDML is not be just a digital form of a collection of documents and manuscripts, it has to become a managed collection of mathematical knowledge, the nature of which is itself changing as the notions of proof and mathematical semantics evolve. That is how the International Mathematical Knowledge Trust go tits name.

2 GDML activity to Mar 2017

Ingrid Daubechies ended her term as President of the International Mathematical Union at the 2014 International Congress of Mathematicians in Seoul. There she convened a working group to consider the actions necessary to move the prospects forward for a Global Digital Mathematics Library (GDML[6]). This followed a panel session at the ICM [Seoul DML Panel]. The IMU Working Group resolved to create a not-for-profit organization, the International Mathematical Knowledge Trust (IMKT).

2.1 The Working Group

The GDML WG has worked hard and did not, like some earlier efforts in this area, give up when little happened fast. For instance, it conducted about 100 telcon meetings[7]. These were occasions for strategizing the approach to grant proposal writing and discussions of details of many possible suggestions. They ranged from forms of governance to technical aspects of projects leading to a digital library. The telcons all have minutes held on the WG's private wiki (powered by Wikipedia's MediaWiki).

The GDML wiki, employing MediaWiki software, also hosts various drafts documents connected with the WG's discussions and has about 200 pages. This figure is only mentioned as an indication of the WG's activity level. The drafts are often enough early attempts that were later superseded but helped a lot in analyzing situations, or explanatory pieces about WG member positions, suggestions or ideas. As such they are not finished documents, which means the wiki has been kept private. However, it has been used to make the work of the WG more persistent, along with DropBox files and even GitHub.

[6] This is not the Geometry Description Markup Language invented to enable description of events at the CERN Large Hadron Collider. However, that GDML certainly has a relationship with the capture of mathematical meaning, as does SVG for two-dimensional geometry.

[7] A telephone bridge has been kindly provided by Wolfram Research.

2.2 MediaWiki dangers

An example of the complications that occur when you decide to use modern technologies like wikis to enhance your communications can be given in the essentially toy context of the GDML WG involving about a dozen persons. When you think of trying to put together a GDML for the whole world then there are many more scenarios of difficulty you need to try to prepare for and mitigate. As the complexity goes up so do the resources required to deal with them. That is in part how simple services do in fact often cost a lot of money.

One of the dangers that results from use of MediaWiki for a support system for a small group is that MediaWiki installations can be the target of spammers. They use them to generate click traffic that produces revenue through, say, Google Ads. The GDML WG wiki is carefully restricted in its access. Only explicitly registered users can actually edit pages, only explicitly registered users can read anything except the splash page, and only special administrator users can create new users. This is naturally hardly what you want for a publicly useful wiki, where at least the general web user should be able to read the pages or otherwise it isn't public information. An example of a world-read but very restricted other access is the one used in revising the Mathematics Subject Classification to MSC2010 [MSC2010:MediaWiki]. The only persons to edit pages were editorial staff at Mathematical Reviews and Zentralblatt, but all could see the changes to the MSC as they were being proposed. The control of access to a MediaWiki installation is configured in a PHP file usually in a standard location within a site. An upgrade to the version of MediaWiki, which was done by the site's ISP did not preserve the cascade of rules that controlled access carefully.

The result was that for a couple of days the site behaved like a typical public wiki allowing new users to create new identities and write pages. This is after all the sort of behavior that a public wiki trying to organize a community should exhibit. Spammers know this and write scripts that create users, and provide a couple of junk pages for each user with almost plausible text on them, including links within the pages to sites for whom they are providing SEO (Search Engine Optimization) services. If the wiki is constantly being patrolled by its community, or by attentive administrators with clever bots, then unusual activity can be detected and reacted to by blocking and denying users and domains that seem nefarious.

As it was, in the case of MSC2010, in the course of about 4 days about 10,000 spurious users were created with about 20,000 associated pages. These users and pages did not interact with, or otherwise damage the usual business of MSC2010. However, the traffic caused by the linking activity for SEO purposes did make it look as though there was a great deal of new interest in MSC. Eventually, the activity generated caused the traffic limit for the site to be exceeded and the ISP's servers stopped answering queries. This was noted by the administrators of the online Encyclopedia of Mathematics who asked msc2010.org about the fact that the links they provided to background information on MSC codes were now often not working correctly. This led to the discovery of the malfeasance mentioned and to the not inconsiderable work needed to clean up the spammers work after reinstituting the intended access control.

It seems that this weakness in the access control mechanisms of wikis is a known problem, and the tools for combating the problem are only now being developed. There's an obvious sense in which open public goods are at risk of being co-opted or misused. A fortiori, developing a GDML is going to turn up other such difficulties. One area that the profession may need to be taking a lot more seriously in the digital world is likely to be the matter of authentication, authority and provenance trails.

2.3 Organized outreach

The GDML WG also mounted outreach activities to encourage the mathematical community to support the idea of a GDML and to contribute initiatives. A successful one on *Mathematical Information in the Digital Age of Science* was held at the JMM 2016 [JMM:2016]. A list of some goals that seemed to people there to be sensible [Watt:2016] does also serve to illustrate the range of topics that naturally play into trying to produce a GDML. There are, of course, more as well:

1. Determining whether a result is known, where the answer is hoped to be positive so the result can be used. Here, proofs, examples, counter-examples, applications, and so on would be desired.
2. Determining whether a result is known, where the answer is hoped to be negative thus confirming a discovery or avoiding unintentional duplication.
3. Accelerating the advancement of mathematics, both for itself and for science and technology.
4. Organizing knowledge to accelerate the learning of mathematics.
5. Enhancing collaboration.
6. Making existing tools more powerful.

More ambitious goals included:

1. Certifying (machine validation) of all mathematical knowledge.
2. Serving as a mathematical assistant, or as a teacher.
3. Identifying holes in our mathematical knowledge.
4. Generating conjectures.
5. Reflection—refactoring or reformulating mathematics for elegance or ease of application.
6. Expanding the mathematical capacity of humanity.

In addition, with Wolfram Research and the Fields Institute, the GDML WG was an organizer of a Semantic Capture Language Workshop (SCLW) held at the Fields Institute February 2016 [Fields:2016]. A White Paper promised as a result from the workshop was finally produced and videos of almost all the lectures there are also available on the Fields site. There is also there a long documentary [Fields:docu] of the workshop with many interviews of participants. The consensus about the desirable ultimate goals of a GDML resulting from the workshop can be seen as even more ambitious:

1. The library should contain the full mathematical literature (peer-reviewed research mathematics), including all published versions of each work. It has been estimated that more than 200,000 theorems are proved each year, which is a very large amount of mathematics, though small in relation to other corpuses treated today, such as medical records.
2. The library should be able to cope with all major systems for computer mathematics, not only symbolic computation systems and theorem provers, but also systems like LaTeX and MathML processors needed to process the documents.
3. All formulas (terms, statements) in the mathematics should be usable in various computer systems for doing mathematics.
4. All algorithms in the mathematics should be available in an executable form.
5. All structures in the mathematics should be made explicit. For example, links between articles, references within the articles, and the substructure of proofs (like scopes of variables and assumptions) are all to be explicit.
6. All mathematics should be available in a fully verified form, with verification to the highest possible standards.
7. The relation between the human- and machine-readable forms (including the fully verified form) of the mathematics should be clear and explicit.
8. The library should be fully accessible to the whole world, making the intellectual property rights of everything fully explicit and aiming for maximal availability.

3 IMKT, its draft charter and founding

In May 2016, the IMU's CEIC (Committee on Electronic Information and Communication) endorsed a Charter for an IMKT suggested by the WG. This has to be understood as a "guiding document" not a legally binding one. It is naturally important grist to the mill of the lawyers who will oversee the founding.

After many tentative approaches at different levels, founding IMKT was finally formally proposed to the Alfred P. Sloan Foundation as a project to support. It was funded in mid-December 2016. Letters of support that were added to the proposal in the final stage from a wide range of organizations show that part of the community has begun to get our message: software (NAG, MapleSoft), bibliography (EuDML, zbMATH), institutes (Fields, Waterloo).

The work of the GDML WG was mentioned twice in the international organ of the IMU: [IMU-Net 77:May 2016], Sloan funding [IMU-Net 81:January 2017].

3.1 An initial corpus for GDML

In addition, IMKT has to concern itself with starting to aggregate access to the corpus of known mathematics and the new mathematics that is being developed. The CEIC, and thus its GDML WG, have had contact with the important [arXiv.org] project. There is also a Chinese project with some similarity to arXiv, namely [MathSciDoc] based on Tsinghua University and a community of Chinese mathematicians [ICCM]. Mathematics is a large category (21.9%) within arXiv, and fast growing (26.4% present submissions). Most arXiv subjects are "mathematics heavy" in any case.

The other natural groups with whom to seek cooperation are the European digital math library project [EuDML] and [Project Euclid], based at the Cornell Library. Finally [HathiTrust] is another potential partner, but after initial favorable contacts (in Michigan) this has yet to be pursued further.

A final, and clearly current, strain of research in handling the scientific literature is machine learning. For mathematics this is already the matter of a large grant from Sloan to D. Blei and C. Lafferty [Lafferty & Blei: 2016] and we can look forward to the results. Another group with whom the GDML is in contact is also preparing a grant submission in this area. The IMKT will naturally welcome any good results coming out of this research, but will concentrate its own efforts elsewhere since these are developments that are underway and can expect results only in the longer term.

3.2 IMKT initiatives

Sloan also expects that an incipient IMKT be promoting initiatives that are clearly activities building toward parts of an eventual GDML. Therefore the IMKT proposal foresaw four specific projects that progress would be made on.

Special Function Concordance: This initiative was announced to the OPSFA community in January 2017[OP SF NET: 2017]. A first meeting involving stakeholders in the field, representing NIST's DLMF [DLMF] and DRMF [DRMF], INRIA's DDMF [DDMF], Maplesoft [Maple], Mathematica [Mathematica] and NAG [NAG], as well as other academics, was held even before the good news of funding from Sloan. The effort to broaden and mobilize the community working on this continues. It can be seen as an initial attempt to clarify the semantics of an area of mathematical research commonly considered well understood and of technological importance. This may be a baby step toward developing a semantic capture language as mentioned in the title of the Fields Institute workshop, but it promises to be something that can be useful to practical users of mathematics anyway.

FAbstracts: FAbstracts stands for Formal Abstracts and is a project envisaged by Tom Hales. The idea is to work out how to start by capturing more of the semantics of mathematical papers in a formal way and to use the organizational capacities offered by computers for this, without proceeding to try and provide full computer-checked formal proofs. Full machine-supported formal proofs, as carried out by Hales and an international team of collaborators for the Kepler Conjecture, or by Georges Gonthier and collaborators for the Feit-Thompson Theorem, are big projects. They require much work and lead to changes in proof argument structures that need to be developed.

FAbstracts will work with theorem statements and summary assertions about the mathematical content of an article. These assertions may even turn out to be wrong, but the important goal is the capture of a formal record of the key results of an item of the literature. This formal abstract can then be handled by programs looking for similarities and overlaps or possible implications between results. Once possible relationships are identified, for instance, then there may be an incentive to expand the level of formalization of a given item.

An essential part of FAbstracts is the intention to work out how to share and compare results in formalizing material. Typically, different teams may use different logical software bases, as in the cases of HOL Light and Coq for the two big achievements just mentioned. Though there have been comparisons and cross-walk efforts between systems before, there's a lot more experience to be gained by trying examples.

Harmonisation in the formal area: The proponents of several formal systems, meeting as they did at the Fields SCLW, expressed their willingness in principle to try and figure out the similarities and differences in their formalizations of some basic theorems in, say, Coq, HOL Light and Mizar, or even HoTT. Promoting this activity will be pursued.

Bibliographic ngram work: This sort of simple statistical exploration of the mathematical literature is made more difficult than for ordinary text by the presence of the formulas of our subject. It does offer some easier opportunities for involvement of researchers since NLP has been widely developed, just not for mathematical texts. Furthermore it may be important enough to interest the important secondary sources in mathematics such as Mathematical Reviews ([MathSciNet]) and [zbMATH], who have already shown interest.

3.3 IMKT governance development

Ultimately the long-term goal of the GDML WG and of the new trust being set up is as follows:

> The purpose of the International Mathematical Knowledge Trust, IMKT, is to establish a mathematical knowledge commons — a public resource consisting of mathematical knowledge represented in non-proprietary, machine-readable formats and an international network of knowledge providers, information systems, and semantic services based on it, that is, a global digital mathematical library.

In practice, we have to begin by setting up a legal entity. It was, perhaps fortuitously for international connections, decided to set up in Waterloo ON, Canada, where PI Stephen Watt is Dean of the Faculty of Mathematics and Computer Science with over 8,000 students[Waterloo Math]. Canadian Federal Law was chosen as the legal home, and Canadian charitable status will be sought. Under the present law it is not mandatory, but it is recommended that IMKT have about 25% Canadian residents on the governing Board. There will also be a Scientific Advisory Board (SAB). It is the "Members" of a Trust who elect the Board of Directors, and the important questions are who they are, and how they are created. There must be voting Members, and one can have non-voting ones too. The Directors on the governing Board lay out the criteria for membership, and a renewal procedure is recommended. We shall choose to have voting Members be the Board, SAB, and others invited. Non-voting Members can be other individuals, and possibly societies.

A retained lawyer started drafting by-laws in March 2017. With those finalized we shall found the trust with a skeleton crew for the Directors on the Board of Governors (BG) and Trust Members (the grant PIs and a couple of others) and get charitable status.

At a phone meeting, the initial Board of Governors will decide on invitations for new Members and Directors. They will begin to appoint additional GB and SAB members as they agree to serve. One consideration that will be built into the by-laws is whatever is necessary to have relationships with subsidiaries or associated organizations elsewhere that allow donations and payments with favorable tax statuses. There are constraints to be met in setting up boards for a non-profit with an avowed intention of doing public good internationally. The board members need to be experienced but have also to be representative of the community to be served. In this case, they clearly must be from international backgrounds with ties over the world, to be diverse in points of view and to show no gender bias. These things are a matter of common sense but were also explicitly mentioned by our funders, and are not trivial to satisfy simultaneously in as small a population sample as the boards represent.

In addition, certain expertise, such as with non-profit legal and accounting issues, and management of projects, such as those IMKT is intended to pursue, ought to be represented. One ends up making lists of persons known and annotating them with characteristics such as feeling for the science, feeling for the technologies that will be involved, experience in management or governance, nationality or locations of employment, or perceived relationships with possible patronage. The judgements such annotations are based upon are necessarily personal ones (though each person will be able to offer justifications for them) and made on the basis of limited information. Such lists are hardly the basis for an algorithm or in any way suitable for publication. Indeed, the persons you may obviously find desirable for your boards may well be unable or unwilling to serve for reasons you cannot know.

The current aim is for a "legally valid" Board to be in place by end of April 2017. Then we should have a credible Scientific Board, but with vacancies, by the end of June 2017. There will eventually be ca. 6-9 persons on the Board of Governors, with 2 or 3 Canadian residents. The Board of Governors must also appoint other Members who will make up the Scientific Advisory Board to a full complement of 12-15 depending on the acceptances of invitations to serve. Further election of Members and appointments to Boards will continue until full complements are achieved. The necessary meetings will be further telcons with some business carried out by e-mail, as foreseen in the Bylaws.

The IMKT will send reports to the Sloan Foundation and to the IMU EC, although it is not dependent on the IMU but just shares some of its goals.

4 Prognosis

The IMKT will be founded, and it will work toward spreading the ideas of cooperation to achieve a GDML. We should see other regional mathematical Knowledge Trusts formed. There will come a wider awareness of what well-organized mathematical knowledge resources can bring to both rich and poor communities. With better communication about how our subject's knowledge can be managed there will be a chance that it will not be lost to most, as could happen for plausible commercial reasons. If the mathematical community can organize a little better it can hope to avoid duplication of effort where it's not needed, and to achieve more. To a perhaps surprising extent many of the problems in implementing a GDML are social ones, though there are intellectual problems enough in trying to be clearer on what mathematical knowledge is, clear enough to make machinery to help us with it. There's certainly a lot to be done and a lot relevant going on.

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