Some thoughts on the near-future Digital Mathematics Library

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Abstract. The mathematicians' Digital mathematics library (DML) summarises the generous project that all mathematics ever published should end up in digital form so that it would be more easily referenced, accessed, used. This concept was formulated at the very beginning of this century, and yielded a lot of international activity that culminated around years 2002–2005. While it is estimated that a substantial part of the existing math literature is already available in some digital format, nothing looking like *one* digital mathematics library has emerged, but a multiplicity of competing electronic offers, with unique standards, features, business models, access policies, etc. The millenium's appealing idea has become a new Tower of Babel.
After a quick overview of the idiosyncrasies of mathematical literature with a historical perspective, we discuss strategies toward the implementation of a possibly tiny subset of the DML.

1 The Mathematical Literature

1.1 Stakes

Mathematics is unique among the sciences in its dependence on its scholarly literature. The old mathematical knowledge remains valid and important all over the time. Mathematical results published in the distant past are not superseded by newer results, but typically used by them as a trusted reference on which to settle. They often provide ideas and techniques for solving problems in all sciences as well as the development of new technologies.

A new mathematical result is always an addition over a logical tree of previously verified theorems. The main outcome of mathematical research is to decide whether a given statement is *true*, the very truth being what will be further exploited in all applications of this result. It is thus of paramount importance for the reliability of mathematical knowledge that published mathematical results be checked, and that the checked versions be stored indefinitely. Because users of mathematics do not necessarily rely on the *current* mathematical output, it should also be easily accessible over long periods of time.

The first evidence of mathematics' dependence on its scholarly literature, where it differs profoundly from most hard sciences, is the observation that the central infrastructure to all mathematics departments world-wide is a library. A recent study over French mathematical laboratories concluded that about one third of their expenditures went into their library's budget.

1.2 Milestones

We list below, for the convenience of the reader, some important dates for the growing mathematical literature.

1665 Birth of scholarly journals (*Journal des sçavans, Philosophical transactions*).
1800 About 200 scientific journals with some mathematical content are published.
1810 Publication of the first mathematics-only journal in Nîmes (*Annales de mathématiques pures et appliquées*, aka *Annales* de Gergonne).
1826 This model spans Europe (with almost the same title): *Journal für die reine und angewandte Mathematik*, edited by Crelle since 1826; *Journal de mathématiques pures et appliquées*, edited by Liouville since 1836; *Annali di Matematica Pura ed Applicata*, edited by Tortoloni and Brioschi since 1850.
1850 It is estimated that about 1,000 mathematical research articles are published each year.
1950 It is estimated that about 6,000 mathematical research articles are published each year.
2000 Some 75,000 items are reviewed that year by *Math. Reviews* or *Zentralblatt MATH* from 600 cover-to-cover journals and more than 1,500 other serials.

1.3 A note on geographical and linguistic span

From middle age to 19th century, Europe is the centre of natural sciences. The mathematical tradition started in Greece and India has come back through Arabic scholars and this is where the foundations of modern science will be shaped. This leaves us with numerous written records: manuscripts, books, private letters, transactions, serials. While Latin has been the *lingua franca* of all scholarly writings at the beginning of this story, vernacular idioms come soon into the picture, then structure themselves as national, regional or international depending on various factors.

The core mathematical knowledge, without which the current research can't be understood, has been produced and stored in Europe, spread across many countries and languages. It became truly international at the end of the 19th century, which is exemplified by the birth dates of the national mathematical societies (Bohemia: 1862, United Kingdom: 1865, France: 1872, USA: 1888, Germany: 1890, etc.). The first International Congress of Mathematicians was held in Zürich in 1897, with 197 members from 15 European countries plus 7 members from the USA. The International Mathematical Union was formed in 1920. Up to the end of the 20th century, virtually any mathematical journal would accept a paper written in English, German, or French.

2 The Electronic Mathematical Literature

2.1 New trends, new stakes

Today's working mathematicians have three main sources to perform their research: discussions with colleagues (mostly through email and face-to-face meetings), reading the incoming flow of preprints (which are now mostly self-archived eprints), and consulting reference works in the library (which is now a mixture of paper volumes on real shelves and electronic files downloaded at publisher's websites, or from various isolated digital repositories).

Indeed, the time scale and even the reasons to publish are also specific to mathematics. New results are circulated early in specialist circles, where they are discussed in details long before they are formally published. This is the function that is nowadays supported by the open archives which provide the relevant infrastructure for most of day-to-day work: instant dissemination and revision when needed. The actual journal publication happens after some time when the preprint is considered stabilised, and after a relatively long peer reviewing process. The main motivation for formal publishing is not to communicate the results, as this has already been done typically two years before, but to obtain some quality rating based on the reputation of the journal accepting the paper, and to secure the version of the paper that will serve for further reference to the results. A reference may last quite a long time: anecdotically, one can easily find seminal papers such as those of Évariste Galois referred to 150 years after their initial publication. More seriously, an American study over a large sample of recently published articles concluded that a quarter of the papers cited today are more than 20 years old. This is why mathematical work, hence all mathematics consumers, depend so crucially on both the preprint flow and a reliable reference library system.

These considerations lead us to the conclusion that a central infrastructure needed in order to perform mathematics-based research in the digital age is a trusted repository of mathematical knowledge. This is more or less the project that has been captured in the expression "Digital Mathematics Library", see Section 4.

2.2 Milestones

Let us remind some dates where steps toward an ever more digital environment have been achieved.

1978 This is the year when Donald E. Knuth published a preliminary version of a new typesetting system named TEX, which claimed to be able to handle mathematical expressions gracefully [1]. We can imagine that it prove so powerful and customisable, that the mathematical community got addicted to it and pursued a line of developments disconnected with that of mainstream publishing industry.

1986 With TEX at production stage, even ready for European languages, and LATEX introducing mildly structured technical documents, the most basic pieces for scientific electronic publishing are here. Moreover, they are free, and something happens that was probably not foreseen: they provide a format for direct information exchange among scientists (through bitnet email, telnet, ftp, etc.).

1992 An obvious consequence is the development of LANL preprint server, also known as the arXiv, where mathematical papers started to be posted, just a while after its inception in high energy physics, during August 1991.

1994 The next obvious consequence is the publication of the first non-specialised mathematics-only electronic journal (*New York Journal of Mathematics*). It is hosted at a university department server, it's free, the delivered format is. . . TeX's DVI!

1995 JSTOR [2] digitises 6 English speaking core mathematical journals (400,000 pages).

1997 Most commercial STM publishers propose an additional electronic version on the World Wide Web for their journals.

1998–2003 The ERAM project [3] digitises important journals and books from the period covered by the *Jahrbuch*. The NUMDAM project[4] is launched to digitise the whole run of 6 French serials and post them online. Access to the exposed metadata and full texts are free.

2002 Commercial STM publishers start digitising their backfiles and selling them as a separate product.

2005 Ulf Rehmann counts more than 4.5 million pages of digitised mathematical texts mostly freely accessible [5].

2007 The "AMS Digital Mathematics Registry" [6] lists around 1,000 mathematical serials with an electronic version. The coverage of the electronic versions compared to the paper ones is highly variable among providers, some have backfiles only, some recent born electronic only. Some electronic content is duplicated among various providers, with a wide range in business models and access policies.

2008 Jon Borwein claims that 65% of mathematics core journals are digitised [7]. Another estimation is that European publishers and digitisers account for more than 10 million mathematical pages in digital format.

3 The Impossible Catalogue

To cope with all the references needed to perform its work, the mathematical community developed its own tools for monitoring, classifying, assessing the ongoing research, the most advanced versions of which are known as the reviewing databases: the European *Zentralblatt MATH* (ZM), which has the largest coverage both along time and subject scales, and the American *Mathematical reviews* (MR), which has considerably expanded its activities and coverage, integrating e.g. 'contributed items' from digitisation centres, and linking to the digital full texts of reviewed items.

1868 The *Jahrbuch über die Fortschritte der Mathematik* was the first incarnation of the idea of a reviewing journal for mathematics.

1894 The *Répertoire bibliographique des sciences mathématiques* was edited under the supervision of Henri Poincaré at the turn of 20th century. It was supposed to register the "valuable" references from 19th century so as to be passed to future generations of mathematicians. When the project was completed in 1912, 2,000 files registered around 200,000 references dispatched according to a dedicated classification (see [8]).

1931 The *Zentralblatt für Mathematik und ihre Grenzgebiete* was launched, edited by Otto Neugebauer.

1940 The *Mathematical reviews* were launched in the USA by *Zentralblatt*'s editor who had escaped from Germany because of unpleasant political changes. The AMS mathematical subject classification schema appears on that occasion.

1990 The reviewing journals are converted to databases, allowing electronic versions on CD-ROM (MathSciDisc, CompactMath), and some crude online access (telnet...).

1996 Web access is enabled (MathSciNet [9], ZMATH [10]).

1999 The ERAM project digitises the *Jahrbuch* and makes it a database with 223,400 articles registered, which is then integrated into the ZM database. Reviews in MR going back to 1940 are keyed and integrated into the MathSciNet database.

2000 Links to original texts from reviews are added.

2002 Link to the corresponding reviews, from articles or articles cited in bibliographies, are starting to appear at publisher's and digital libraries' websites.

2004 The mini-DML demonstrates that it is easy to provide a one-stop access to the whole digital literature as soon as content providers agree to share a minimum part of their catalogue conforming to some standards [11]. Those who cooperate are not many.

4 The Digital Mathematical Library

4.1 Wishes

The mathematical community has expressed its wishes regarding the preferred directions for the digital future on many occasions. Of course, the mathematical community is not a single entity with a definite opinion on these subjects. Your point of view probably differs widely whether you are a researcher (typically pushing for open access to everything), a journal editor (open access to everything as long as it does not hurt quality and sustainability of your journal), a board member of a learned society with a publication house (securing long term operation, high visibility and attractivity of the activities of the society, and economic balance appears more important than too wide open access), an executive editor or publisher getting revenue for the hard job of having publications running smoothly (securing the incoming flow of money is the most important point that insures that quality and efficiency of your publication structure won't be down next year), etc. Not mentioning the reviewing databases and other portals to the whole mathematical literature, that gain more value from more accessibility to the items they refer to. As the same person can belong to all of these categories simultaneously, brain damage cannot be fully avoided.

Nevertheless, a set of general recommendations is usually agreed upon in mathematical circles. A reference document, endorsed by the International Mathematical Union, is the "Best practice recommendations" from the CEIC [12].

One should be able to seamlessly navigate the whole literature, discover mathematical texts and get their accurate description. This means that metadata should be essentially free, and shared among projects. Navigation devices which are much appreciated are links to reference databases and links in citations as a way to obtain the cited reference. Of course, the reviewing databases are seen as a core infrastructure on which the hyperlink network can be set up, as they already register a huge part of the literature to be interconnected, and contain carefully edited additional metadata for those items.

In order to make those citation links end up ultimately somewhere, eventual open access to the full texts is required. This can be implemented with the moving wall policy (which means that there is a wall preventing access to recent full texts which is moving with a fixed lag on the time line, hence any full text becomes free after a delay has expired). The moving wall lag value needs not be uniform over all the possible items, but the option to have a moving wall is the only one that currently insures us that the current digital production from some providers will not completely disappear any time in the future.

No economic, legal, technical barriers should prevent us to make use of the mathematical content over the long term. Let us mention some possible issues that make the whole system fragile.

– An important legal barrier is the way copyright is used in scholarly publishing when it is entirely transfered to publishers, which then control any possible use of the content as long as the copyright lasts (which is near to infinity in the scientific research time scale). Moreover, digitisation creates new rights over the media (or files) themselves, so that a text can be in the public domain, but its digital incarnation copyrighted. Associated with print-on-demand systems, this can make the copyright actually last for ever.
– As the technological environment is necessarily evolving continuously, it is obvious that any technological barrier (like access or usage restrictions enforced through digital rights management techniques) is bound to yield non-archivable content, that is content that cannot be recovered after the unavoidable death of its required exploitation environment.
– The worst economic barriers are not the subscriptions sometimes required to access mathematical content. Bankrupt or marketing priorities are to be taken into account more seriously. What happens if the only owner of some collection's digital backfile gets out of business, or discontinues a product which has gone out of fad or does not generate enough profit anymore? The recommendation is that the content should be secured by some not-for-profit organisation prior to such event.

Finally, all these requirements pave the way to something that people got used to refer to as "The Digital Mathematical Library" (DML).

4.2 The original vision

The first actual formulation of the DML concept goes back to the Cornell library's DML project [13], which was funded by the NSF in 2002, "toward the establishment of a comprehensive, international, distributed collection of digital information and published knowledge in mathematics". The careful wording of the project's vision is still the best description available for the envisioned effort. It is now part of the more specific (and slightly less ambitious) vision statement endorsed by the IMU [14].

> *"In light of mathematicians' reliance on their discipline's rich published heritage and the key role of mathematics in enabling other scientific disciplines, the Digital Mathematics Library strives to make the entirety of past mathematics scholarship available online, at reasonable cost, in the form of an authoritative and enduring digital collection, developed and curated by a network of institutions."* DML project vision, Cornell library, 2002.

Unfortunately, as it stands, this vision has not been implemented to the expected extent since its formulation. The overall aim certainly helped many individual projects to formalise, and succeed in bringing more mathematics scholarship online. But any attempt to coordinate a network of those projects in order to make them usable as a whole as a unique resource has failed so far. We propose below some simplifications of the project which are meant to help it starting in the real world, at a possibly much smaller scale. We also discuss some policies that are designed to help selecting relevant partners for the project, so that a minimum set of actions could be performed safely. The strategic plan is that these simplifications, although bearing a clear loss in generality, will permit to define a more straightforward system, to have it up and running quite rapidly, with sufficient performance and content so that a critical mass is attained.

4.3 A note on digital libraries

Mathematicians are rather conservative people. When they refer to a digital mathematics library, they mostly refer to a traditionally organised library with digital objects on its shelves. This means that the stress is on the traditional library functions, rather than on fancy digital stuff. The main outcome of the envisioned library service would be to set-up a network of institutions where the digital items would be physically archived. Each institution would provide its own contribution to the network through various interoperability devices (some socially oriented, like training or policy making; some technically oriented, like metadata harvesting). Each institution would take care of selecting, acquiring, developing, maintaining, cataloguing, preserving its own collections according to clear policies: it should have the role of a reference memory institution for a well defined part of the mathematical corpus. It would also control access to the full texts, when needed. The main operations on collections (acquisition and delivery) would be *local*, and entirely performed at the relevant institution (we are not talking of a virtual library referencing third party objects with no control over it). The network of institutions would make it possible to assemble a *global* virtual library providing a gateway to the distributed content through user-friendly discovery and retrieval interfaces.

That would fit well with the vision of a central (cyber)infrastructure of the global networked mathematics department, where the meeting room with a chalk board is a kind of blog, and the library has its collections ready for direct references when needed in the discussion.

5 Thoughts on Implementation

5.1 The big picture

If we think about implementing the DML idea, then we have to give up at once on the first key word in the original vision, namely: we won't absorb "the entirety of past mathematics scholarship". Let us call µDML (microscopic DML) the very small project that we should be able to launch soon in the real world.

We then should stress that online availability is an important feature of the library, but that it is not the only crucial one: offline preservation, and acquisition of new content securing online availability up to the distant future are also very important aspects of the project to be implemented, which is thus restricted to *past* content only in the sense that it would provide a backup to the publishing system which is expected to produce and deliver the *current* production, and transfer it to the library.

The µDML network would thus constitute a distributed digital repository of validated mathematical original research texts from many sources. The content gathered would be either retrodigitised from legacy paper publications, or born-digital contributed by its publisher to one of the µDML institutions. Let us recall that the main objective is to recreate most of the traditional functions of a legacy mathematics department library in the digital paradigm, while taking advantage of the format to set up unique services that would address the specific issues faced in the management of a heavily multilingual mathematical knowledge. The main service to the community would be the ability to discover easily, enjoy seamless access, and refer to a given text permanently. These services would be tailored for the end user (i.e. researchers), but also have automated counterparts in order to be interoperable with the other important research infrastructures (like reviewing databases, publisher's websites, institutional repositories. . .): it would be a major component of the emerging eScience paradigm where mathematical scholarship is needed.

5.2 Institution selection

The public presence of the µDML would be built on top of a unique database registering objects in the contributed *physical* digital libraries, each of these being hosted at one of the participating institutions. An institution should be a scientifically reliable, long-standing, not-for-profit organisation with a clear policy about long-term archiving and access. It would be the responsibility of each of these institutions to negotiate the licenses allowing them to work with the content they care for: archiving, indexing, possibly migrating formats and upgrading metadata, providing eventual open access.

A consequence of this policy is that a considerable part of the existing digital mathematical content could not be considered in the foreseen µDML implementation. This is a concern that should be addressed later on if the project succeeds at the point where lacks in coverage become noticeable.

5.3 Content acquisition

At the early days of electronic edition, we have witnessed a tentative enforcement of the idea that no content would ever be free anymore, like it had been the case for centuries with paper copies hold in academic libraries where no patron needed a valid license or a fresh subscription to access the volumes and read their inspiring content. It seems that this tentative has succeeded to the point where one can read in authoritative studies apparently objective statements like the following one: "In the print era, libraries were acquiring print journals and took in charge their preservation so that they remain accessible to their user community in the long term. In the digital era, libraries and their user community are licensed online access to electronic journals for a determined and limited duration." [15]

This situation is very unsatisfactory and dangerous for the long term preservation and access to the research published today. Moreover, backfile digitisation performed by commercial entities, which end up in packages that are marketed by those entities, might create "retro-privatisation" through new rights gained over collections while they did not necessarily own any rights over the old paper versions. For instance, access to a text that is in the public domain may become illegal to non-subscribers because the file that bears it is newly copyrighted, or a publisher that just acquired a long lasting independent first class journal makes all its intellectual heritage its property at once, when adding it to its online offer. When even very old texts become unavailable unless you have a specific subscription for each of them, this places the whole system of referencing and linking at risk. This places also a high burden on scholars from everywhere in the world to achieve their task.

This is why digital mathematics need a simple and reliable archiving system which is not aimed at profit, but at sustainability. This would be achieved by the µDML network of partners, acting like memory institutions, each one committed to acquire and curate a local subset of the mathematical corpus. It does not seem necessary to endow the above expression with a too precise definition. It suffices to acknowledge how the global DML effort has structured itself in this respect: national borders having an important impact on funding, languages, human proximity, many nation-wide projects have emerged. Many of those national projects deal with "foreign" content (content is typically internally deeply international anyway, as current mathematical research crosses boundaries) but, we have to reckon that national forces are still rather active (Göttingen's GDZ [16] digitised Swiss and Czech journals, which have then been shared with the "national" DML projects—SEALS [17] and DML-CZ [18], respectively—so that they can be bundled with the other sources from the same origin, or upgraded with newly published articles). On the other hand, other kinds of local projects are in existence, like: subject oriented (algebraic geometry, e.g., which has always been at the leading edge of the move to electronic literature), or author oriented (electronic collected works, e.g.).

The French example In the case of French mathematical content, we can identify many local digital libraries already conforming to a reduced version of our "big picture". For instance, the libraries of universities like those of Strasbourg, Lille, or École polytechnique, have some local content (Thesis, lecture notes, old and rare items...). The Gallica project [19] from the French national library has digitised a lot of public domain books, and few mathematical journals, usually with a 70 years moving wall with the notable exception of the *Comptes rendus de l'académie des sciences* which are there up to 1965 (years 1966–1996 will be soon posted as well). This means that the CRAS, series A has found its local dedicated institution. As Cellule MathDoc is an associated partner of Gallica for mathematical digitisation, it should try its best to refine the scarce Gallica metadata to a µDML-eligible level, possibly serving as a proxy for bringing this content to the µDML database.

Concerning mathematical serials published in France, the picture has dramatically changed during the recent years, as the NUMDAM programme has succeeded farther than initially expected. All but five currently alive journals have agreed on digitisation of their whole backfiles, acquisition of born-digital recent articles through export from their publisher's platform, and open access with a moving wall of 5 years.

The four platforms that transfer their born-digital articles are

- CEDRAM: This is a MathDoc project that was set up in order to enable full-featured electronic edition for independent and society journals, based on a robust, NUMDAM compliant platform [20,21]. It contributes the current content of 4 journals published by mathematics department at Bordeaux, Clermont-Ferrand, Grenoble, and Toulouse, one new electronic journal published by the French applied mathematics society (SMAI), and three seminar proceedings;
- Science Direct's electronic warehouse exports PDFs and XML metadata (header and footer of full texts) up to year 2007 for those three journals whose titles belong to a French academic institution and whose publication was outsourced with Elsevier: *Annales* edited by École normale supérieure and Institut Henri Poincaré. Two of them changed publisher in 2008;
- EDP Sciences exports in real time PDFs, LaTeX sources, and XML metadata for those journals edited by the SMAI, published in the ESAIM series;
- Springer-SBM exports in real time PDFs and XML metadata (header and footer of full texts) for the *Publications mathématiques*, which are edited by the I.H.E.S. and distributed by Springer-Verlag, Berlin-Heidelberg.

In accordance with the 5 years moving wall policy, the newer material is only present on the portal through exposed metadata, which offers already a good deal of visibility. Using the DOI or similar persistent URL schemes, a deep link to the article's location at publisher's site provides access under publisher's control.

The five "exceptional cases" are the already mentioned CRAS, handled by Gallica, two Elsevier journals whose titles are not currently owned by an academic institution (which are also handled by Gallica, with a 70 years moving wall. . .), The *Journal de l'institut de mathématiques de Jussieu*, published by Cambridge University Press since 2002 (which is too recent), and the *Bulletin* of the French mathematical society (SMF), whose retrodigitised version at NUMDAM enjoys a 10 years moving wall, and no plans for the update with recent articles.

5.4 Technical challenges

If we want to integrate content from a huge diversity of providers, with very different skills and operational models, we will have to face some real issues. I list here possible strategies to overcome them.

The metadata set, format, coverage, etc., are not at all uniform across existing collections We should decide on a "mother format" with the best granularity for metadata, providing enough room for all the useful features we expect to build on top of this. We should then decide of a minimum set of metadata for eligibility in the µDML database. When applicable, we should strive to use alternative sources of metadata so that more items would become eligible. To this end, automated tools should be developed, starting from math-aware OCR, structure recognition, artificial mathematical intelligence. . . But we would also consider partnering with other institutions having a share of the existing metadata on those items.

The resource is deeply multilingual. The existing metadata are not! Most existing metadata is derived from each item's own text: it is thus impossible to perform full-text searches across languages boundaries. To this end, we could use English as the pivot language: translating (manually or using thesaurus/ontologies) the relevant metadata to English so that an English key words search would not leave apart big areas in the collections. Optical mathematical expression recognition coupled with formula searching could also be a promising path to discover articles on behalf of their scientific meaning rather than their linguistic incarnation. Every meaningful link can also be used as a way to discover material, regardless of its language: turning any citation into a link would be a neat starting point.

Mathematicians, scientists already have their portals to the mathematical literature Matching tools are a very powerful device for interoperability. When any item is contributed to the µDML, it should be linked to the reviewing databases, and from there to any relevant information that should be linked with it. It can also be internally linked to other µDML items, through subject similarity, citation, or whatever natural proximity measure will prove useful. The other way round, developing a matching tool to the µDML database would ease referencing to the items it registers for third parties (like publishers, eScience platforms, authors turning bibliographic references into actual links, etc.).

5.5 Going comprehensive

Small scale implementation of a variation on the µDML as discussed here seems entirely feasible now. We hope that this will happen soon. Of course, this doesn't obliterate the dream of a comprehensive DML, but this would be balanced by the actual launching of a partial DML service. Given the high satisfaction expressed by users of isolated projects such as NUMDAM, bridging at least two projects beyond their current boundaries would meet high expectations in the user base of the reference mathematical literature.

If a project based on the premises exposed above ever sees the light of day, it would be in a strong position to set up a multidisciplinary scientific advocacy board, that would invite further stakeholders to discuss policies, standards, and contribute content. It could act as a forum where scientists from all over the world, learned societies, librarians, publishers and service providers would have the opportunity to share their visions, and design a powerful environment, together with effective strategies and a balanced policy for preserving and accessing mathematical references over the long term.

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