The arXiv: 14 years of open access scientific communication

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Abstract

The arXiv was started in 1991 as a way for high-energy physicists to share preprints fairly and efficiently. Since then it has evolved into an archive of more than 330,000 articles in physics, mathematics and computer science. Within certain disciplines, the arXiv is now the primary means of scholarly communication and has changed the way that scientists work.

This paper charts the development and use of the arXiv e-print archive over the past 14 years in the context of changes in scholarly publishing. Lessons learned from this development include the importance of community and critical mass, and the difficulty of balancing openness with fairness and keeping submissions appropriate and relevant. I discuss how journal publishers have reacted to the arXiv, and ask what the arXiv reveals about the established system of journals and the importance of peer review. Finally, I consider the role the arXiv should play in the future scholarly communication landscape and ask how arXiv fits with emerging institutional repositories?

1 Introduction

The arXiv was started by Paul Ginsparg in 1991 at Los Alamos National Laboratory (LANL) as a way for high-energy theoretical physicists to share preprints fairly and efficiently [5]. The initial user-base was an email list of 160 addresses assembled from existing pre-print distribution lists for the hep-th subject area. It has since evolved into an archive of more than 330,000 articles in physics, mathematics and computer science. The arXiv now accepts ∼4,000 new articles each month, offers an alerting service, search facilities, and has 17 mirror sites around the world.

Figure 1 picks out some landmarks in the development of arXiv. Much of the history of arXiv is recorded in the logs of "What's New" pages [1, 2, 3]. The first phase was marked by rapid development of new facilities and expansion in subject area coverage. Implementation of automatic TeX processing software in 1995 meant that readers no longer had to download TeX source files and process or compile them to get a readable version of an article (a process akin to compiling a C++ or Java program; rather arcane to many word processor users). Instead, PostScript was available directly.

In 1996 the web submission interface was added. The facilities and scope of arXiv stabilized somewhat and arXiv offered most of the features that it does today. Submission rates and readership continued to increase steadily, and the mirror network was enlarged.

The year 2001 marked the start of the most recent phase for arXiv. Metadata was made available for harvesting via an OAI [9] interface and could thus be added to other services (such as the NASA ADS [10]). The move to Cornell spurred a process of institutionalization which has included the development of a new user registration and authentication system, formalization of procedures and policies, and even scheduled holidays.

The overall submission rate to arXiv has increased approximately linearly since 1991, as shown in figure 2. Starting around 1995 the growth in the submission rate to the high-energy physics categories (hep-th,

Aug 1991	Physics e-print archive started: `hep-th` archive with email interface.
1992	ftp interface added. `hep-ph` and `hep-lat` added locally; `alg-geom`, `astro-ph` and `cond-mat` added remotely.
Jul 1994	Web interface added.
Nov 1994	Data at some remote archives (using the same software) moved to main site, the remote sites become mirrors.
Jun 1995	Automatic PostScript generation from TEX source.
Apr 1996	PDF generation added.
Jun 1996	Web upload facility added.
from 1996	Worldwide mirror network grows.
Sep 1997	ATMP is first journal overlay on an e-print archive.
Jan 2001	OAI compliant coincident with the OAI protocol release.
Sep 2001	Administrative oversight transferred to Cornell.
Dec 2001	Cornell site becomes primary, LANL site now mirror and backup.
Jul 2003	email submission discontinued, new user registration.
Sep 2003	q-bio archive launched.
Dec 2003	holiday schedule announced for the first time.
Jan 2004	submitter endorsement system added.

Figure 1: Selected landmarks in the evolution of arXiv

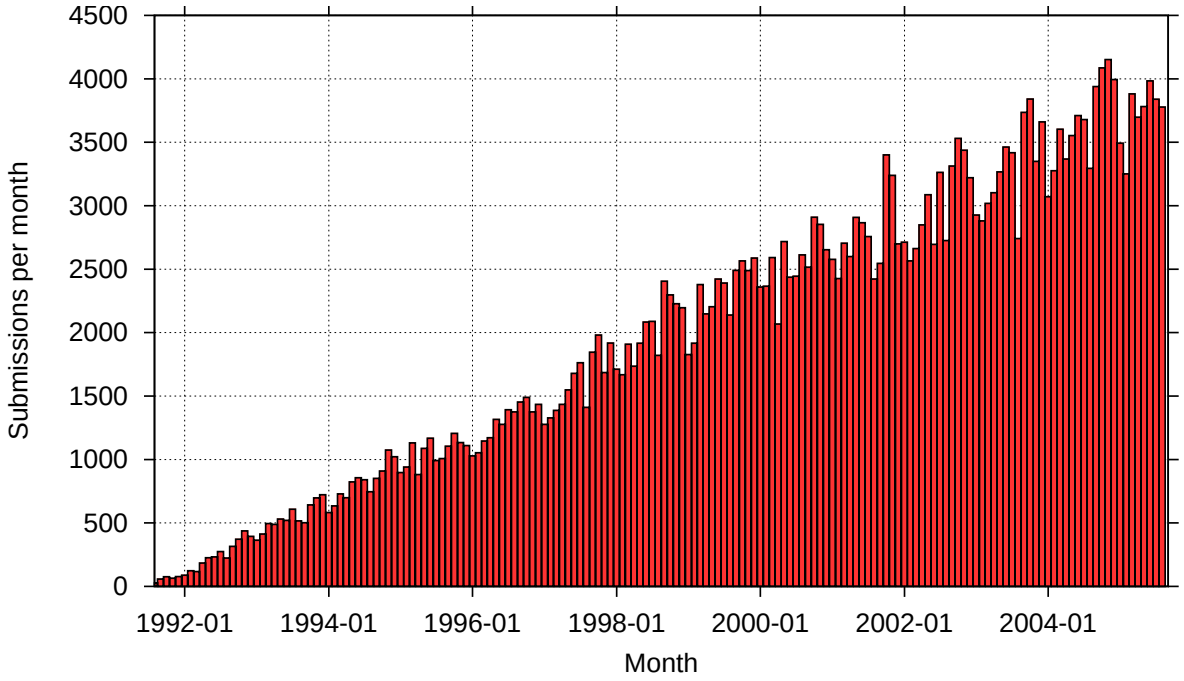

Figure 2: Monthly submission *rate* at arXiv.org. A up-to-date version of this graph is available from `http://arxiv.org/show_monthly_submissions`.

hep-lat, hep-ph, hep-ex) started to slow down. This did not mark any problem but instead a saturation in that almost all papers in these subject areas were being deposited on arXiv. This saturation is shown in figure 3.

While initially envisaged as a self-contained preprint redistribution service, arXiv continues to evolve into part of an integrated global communication system. The creation of the journal *Advances in Theoretical and Mathematical Physics* in 1997, as an overlay on arXiv, demonstrated how conventional peer-review can be implemented on top of an open access substrate. Such overlays continue to represent just a very small fraction of the literature but now include *Geometry and Topology*, *Geometry and Topology Monographs*, *Algebraic and Geometric Topology*, *Logical Methods in Computer Science*, *Theory and Practice of Logic Programming*, and all the journals of the Institute of Mathematical Statistics (IMS).

2 Community and critical mass

With some systems, it seems, one just has to "*build it an people will come*". Of course, it helps to have built the right thing in the first place and maybe to have some prominent advocates suggesting a visit. This was the case with arXiv. Kling and McKim [8] argued that physics community was ready and arXiv fit its practices well. They cite the different route chosen by PubMed as an example of a different resource being developed to meet different community needs. A corollary to the argument the arXiv was successful because of the particular user community is that this model might not be a good fit for other communities with different practices.

2.1 Creation of the q-bio archive

A new top-level classification, *Quantitative Biology* or q-bio for short, was created in September 2003 [7]. The creation of q-bio illustrates a number of elements of our strategy for expansion:

1) Logically, 'Biology' would have been a better classification to sit alongside 'Physics', 'Mathematics' and 'Computer Science'. Quantitative Biology would then be a natural sub-field of Biology. However,

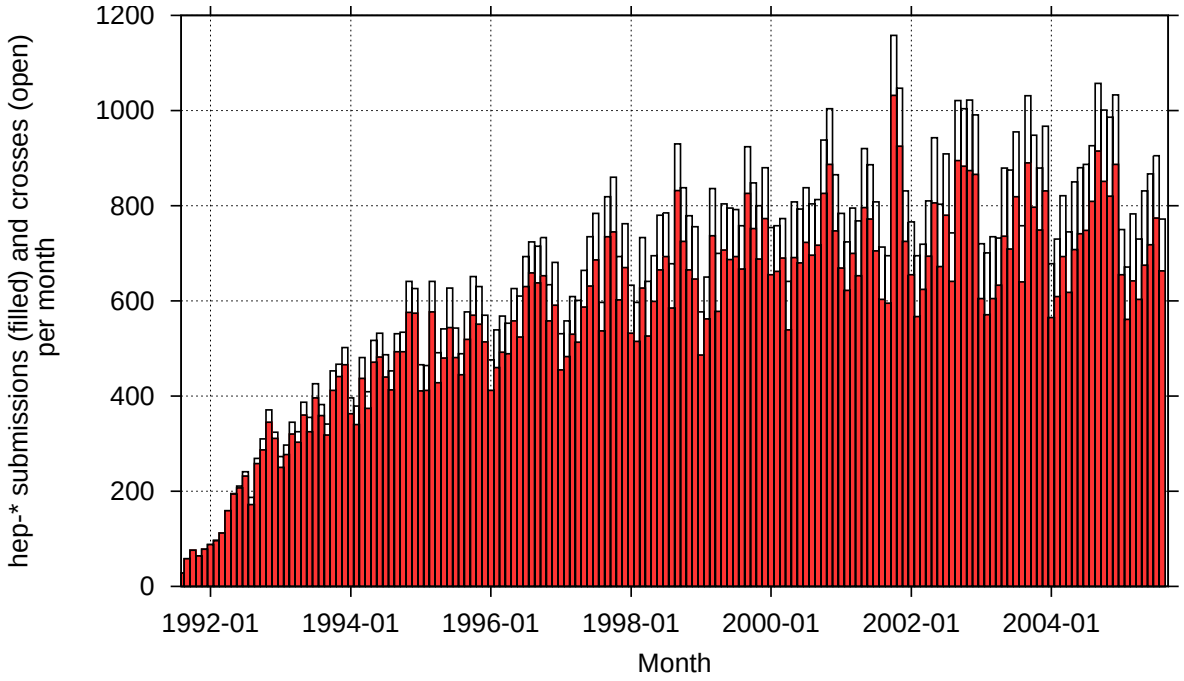

Figure 3: Monthly totals of new submissions to all the high-energy physics archives (hep-th, hep-lat, hep-ph and hep-ex) (filled bars) and cross-listings of papers from other archives (open bars). The submission rate started to flatten in 1995 and now shows just yearly fluctuations. This is an updated version of the graph available from `http://arxiv.org/Stats/hcamonthly.html`

there had been a number of requests for a separate subject area from key figures in the q-bio field, and they were already submitting papers to other parts of arXiv. There had not been similar request from others in the broader field of biology, so it was thought better to avoid a misleading Biology title without appropriate content, and to avoid creating additional subject areas that would likely be under-used and appear dead from the outset.

2) Those who had asked for a q-bio archive were charged with guiding its creation. This involved setting up a subject advisory board, deciding on sub-categories, and recruiting volunteer moderators for each sub-category.

3) The moderators for the q-bio identifier a number of existing papers that should be classified in each sub-category of q-bio . These example were used to train a machine learning system which was then used to find other papers that should be cross-listed to the new category [6]. These papers provided a seed for the category and all the authored were emailed with an explanation of the proposed cross-list and an invitation to use the new category. This provided a set of articles going back to 1992 that were cross-listed to the new category.

Is q-bio a success? The first and obvious answer is yes: there is steady growth in the submission rate and informal feedback is positive. A second answer might be more reserved as we see that there is no discontinuity in the characteristics submission rate graph associated with the creation of q-bio . It seems that q-bio is certainly successful in that it groups together submissions that were previously dispersed over other subject categories, but it has not perhaps attracted new users and faster than the underlying arXiv growth.

2.2 The price of popularity

Most practicing physicists occasionally receive emails or postcards from hobby scientists who believe they have unearthed errors in accepted theories or discovered new truths (relativity being a popular target and grand-unification a popular claim). These are often exercises in numerology or the incoherent

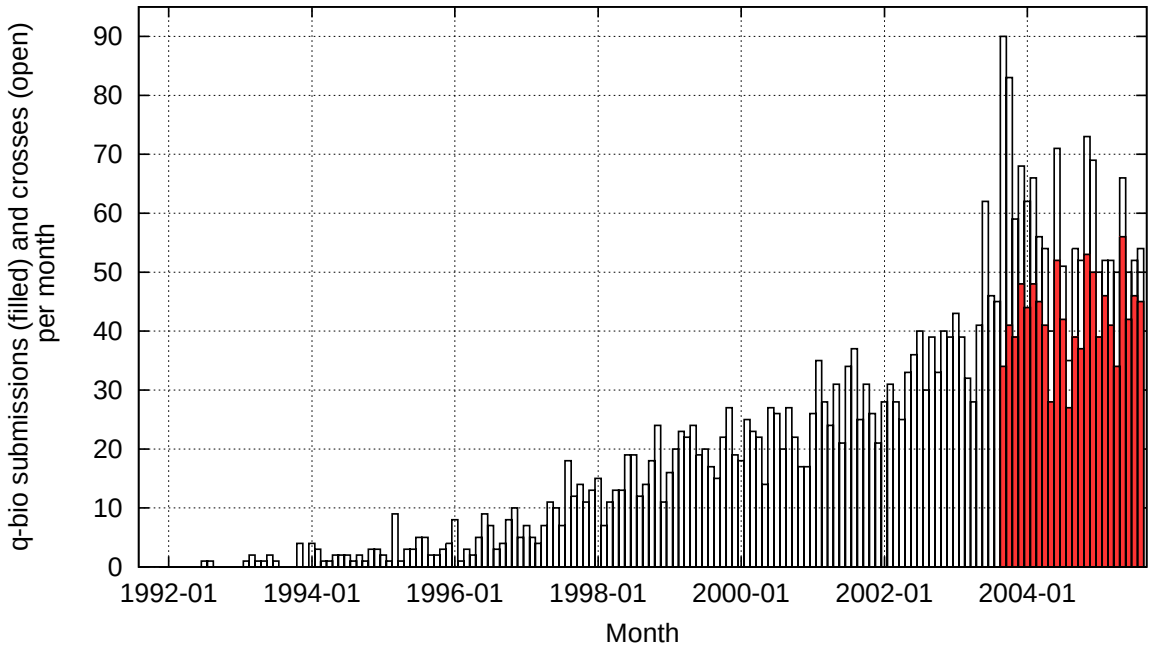

Figure 4: Monthly totals of new submissions to q-bio (filled bars) and cross-listings of papers from other archives (open bars). Ignoring the peak when the q-bio archive was started we see almost a straight line through September 2003 when the archive was started. This is an updated version of the graph available from `http://arxiv.org/Stats/remmonthly.html`

combination of the rights words in the wrong order. It seems that a key identifier of inappropriate submissions is that the authors work outside the research community with which they wish to communicate their ideas, or have their ideas associated with. It is as if arXiv provides well-focused targets for spam and this problem has increased with increasing publicity surrounding arXiv.

It is important to remember that arXiv exists to serve established research communities, not to provide channels for outsiders to contact them. The open dissemination of articles to all who are interested is a secondary feature. The first line of defense is an endoresement system whereby new submitters must be endorsed by two existing submitters in their subject area. A final screening is provided by volunteer moderators from each subject area who screen papers that would obviously not be of interest to the community. The starting point for appropriateness is that a paper should be "of refereeable quality", i.e. it would not be immediately rejected by a journal editor.

3 Changing use of arXiv, migration and preservation

Growth in the number of downloads from arXiv has been consistently faster than growth in the number of submissions. Figure 5 shows the number of downloads of abstract pages and each output format over time. The growth is not quite exponential though it has been close to a two-year doubling time for both abstract and full-text (now dominated by PDF) for the last few years.

3.1 Preferred download format

Figure 6 shows the fraction of downloads in each display format available from arXiv. We see three distinct phases: First, downloading the TeX source was most popular simply because there was no other option for papers submitted as TeX source rather than processed PostScript. PostScript generation was added in June 1995 and this immediately ushered in a second phase where PostScript downloads

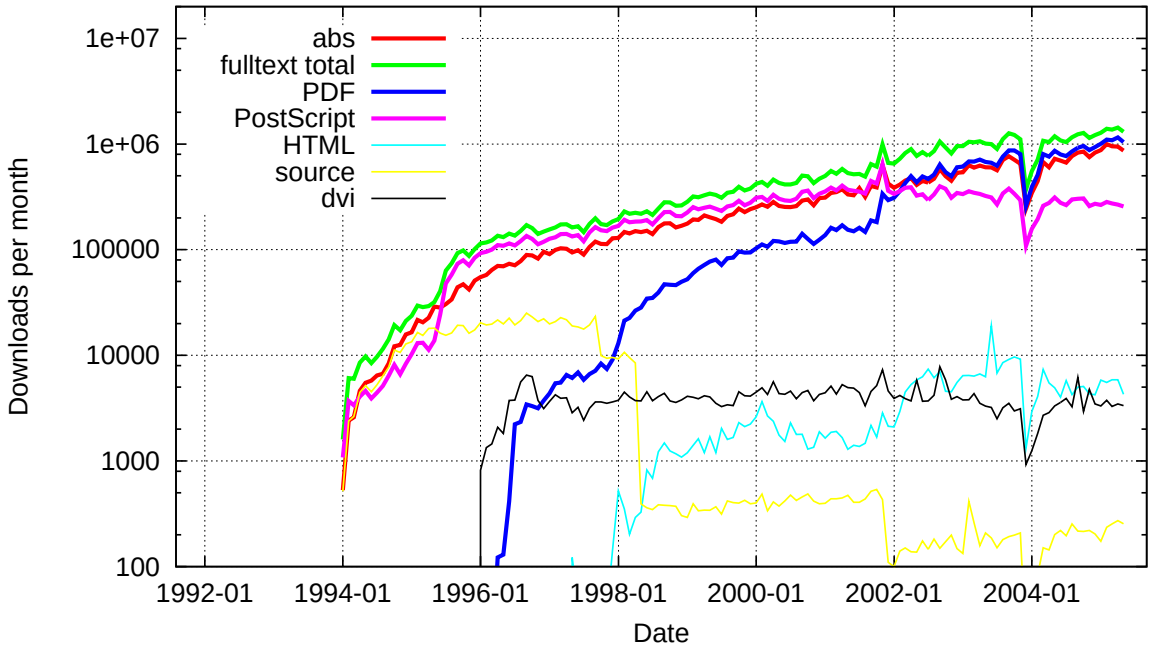

Figure 5: Monthly download totals since the launch of the arXiv web interface in 1994, shown on a logarithmic scale. This data has been screened to remove robot downloads from crawlers and from internal processes, and to remove duplicate downloads from the same IP address within a month.

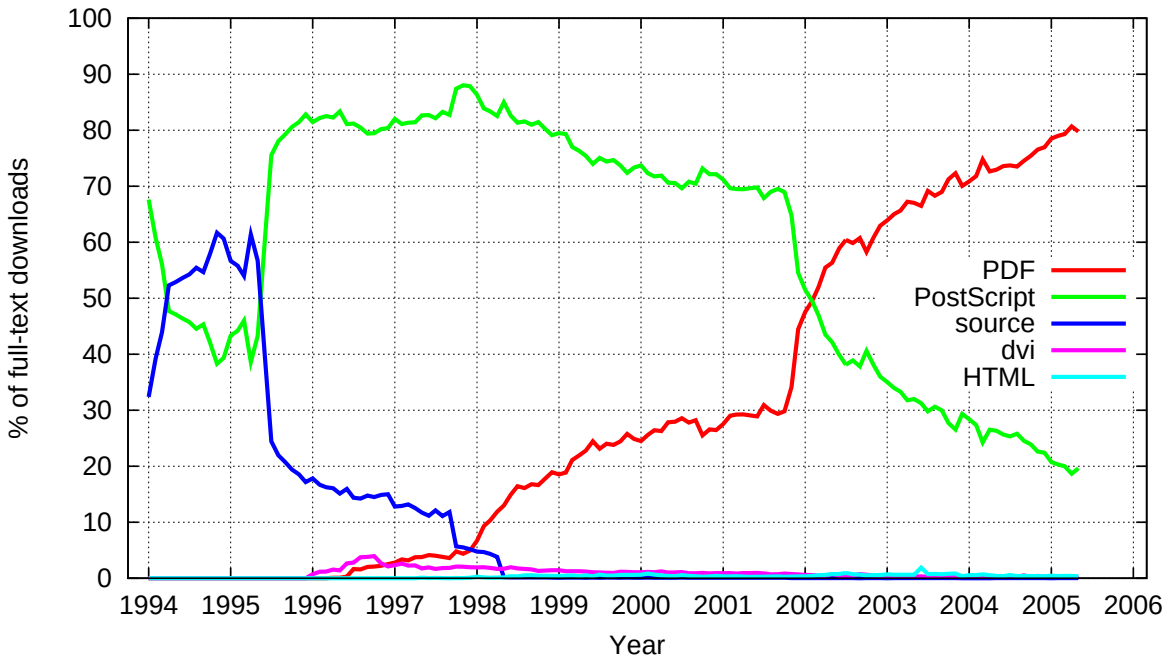

Figure 6: Graph showing change of preferred download format over time. PDF was first introduced by Adobe in 1993 (with the release of Adobe Acrobat 1.0) and from arXiv in 1996. In 2002 it replaced PostScript as the preferred download format and now accounts for 80% of downloads.

Site	Full-text downloads in June 2005	Abstract downloads in June 2005
(main site) arXiv.org	1027310	714162
lanl.arXiv.org	278572	151993
jp.arXiv.org	56302	27597
it.arXiv.org	50694	24622
de.arXiv.org	47393	30922
fr.arXiv.org	37038	18105
uk.arXiv.org	33702	21776
cn.arXiv.org	25297	10915
ru.arXiv.org	11784	8031
br.arXiv.org	10089	2034
tw.arXiv.org	8965	2864
il.arXiv.org	5461	3094
au.arXiv.org	5446	4464
kr.arXiv.org	4483	3494
aps.arXiv.org	4352	4363
es.arXiv.org	3241	1582
in.arXiv.org	3015	1888
za.arXiv.org	268	1153
Total	1613412	1033059

Figure 7: Numbers of full-text and abstract downloads from the main site (arXiv.org) and all mirror sites for June 2005. Mirror sites have country code prefixes except for "lanl" which is the LANL mirror and "aps" which is the APS mirror at Brookhaven. The total numbers of downloads have be counted as unique paper / IP address pairs to avoid over counting due to multiple downloads by the same user (plain counts are ∼30% higher). Considerable efforts have been made to remove robotic accesses which would otherwise inflate the counts.

dominated and source package download became gradually less popular. PDF generation was added in April 1996 but the popularity of PDF as a download format grew only very slowly and over many years. Finally, in 2002 there was a rapid swing to the and current phase where PDF downloads dominate.

Here we a common preservation scenario out twice over: what to do when formats become obsolete? The first case is rather trivial as users would likely have preferred to download PostScript all along and the source files were designed to produce PostScript output, however the facility wasn't available initially. The move to PDF is more interesting as this format wasn't known when early arXiv papers were submitted. The strategy employed was to process source files to produce PostScript much as usual (some differences in font use), and then to convert the PostScript to PDF on demand.

3.2 The mirror system

Mirrors account for about 37% of downloads (42% including repeats), the distribution of downloads in June 2005 are shown in figure 7. These data have been cleaned to remove mirroring and robot accesses as much as possible.

4 Rights, licenses and access

For a long time, arXiv operated without any explicit statements about rights. A non-exclusive license to distribute was assumed to have been granted by the act of submission. A few years ago, this was made explicit in the submission process, which now involves two elements of click-through as shown in figure 8. Without both boxes certifying submitter identity and agreements with terms checked, the submission will not be accepted.

A. Verify Your Contact Information

...explanation omitted...

First Name: Simeon
Last Name: Warner
Suffix: ('Jr.', 'II', etc; may be blank)
Affiliation: Cornell University
E-mail: simeon@cs.cornell.edu

☐ I certify that the above contact information is correct.

B. Legal Statement

- I grant arXiv.org a license to distribute this article.
- I certify that I have the right to grant this license.
- I understand that submissions cannot be completely removed once accepted.
- I understand that arXiv.org reserves the right to reclassify or reject any submission.

☐ I agree to the above terms.

Figure 8: License click-through during arXiv submission process

We plan to offer the option of simply granting arXiv a license to distribute, or saying that a Creative Commons license applies which also gives us the permissions we need. Clarke [4] argues that the "Attribution/NonCommercial/No Derivative Rights" (By-NC-ND) license is adequate for e-print use and would certainly give arXiv the necessary rights. However, one might want to encourage the use of the more permissive "Attribution" (By) license used by PLoS (for example).

5 arXiv and the conventional journal system

Writing in 1994, Ginsparg said "The rapid acceptance of electronic communication or research information in my own community of high-energy theoretical physics was facilitated by a pre-existing 'pre-print culture', in which the irrelevance of refereed journals to ongoing research has long been recognized." [5]. To read this statement as an assertion that journals are irrelevant is to miss a disconnect between the practice of physics, for which peer review is not considered very important (at least in the short term), and rewarding or professional progression for which the stamp of authority offered by journals is considered indispensable. Thus, physicists somewhat contradictorily argue that arXiv is essential for their work, and is how they communicate, and yet that the conventional journal system must remain as is.

In the early years of arXiv there was confusion and uncertainty about what the arXiv meant. Publishers had yet to move toward electronic distribution and some did not even understand how arXiv could produce professional quality output for almost no cost or effort. In 1996 the American Physical Society (APS) launched a similar e-print archive which had broader coverage than arXiv (then xxx.lanl.gov) and accepted a wider variety of formats [11]. It turned out that the APS archive was not widely used and ended up with some material that failed to meet the moderation standards of arXiv. It was discontinued in 1998 and the posted content is no longer available (was at http://publish.aps.org/eprint/). The APS were broadly supportive of arXiv during this time and since, including changing their copyright policy to explitly permit submission of author produced versions to e-print archives.

It was recognized early-on that arXiv was not an informal means of communication [5], even though it does not attempt to replicate the journal system. The format of articles is quite conventional and

inappropriate submissions are rejected. Furthermore, all submissions are stamped with the submission date and time thus providing a record that can be used to settle disputes about priority. Finally, it has been a principle of arXiv that submissions cannot be removed or altered once announced. New versions may be submitted which update, correct or withdraw an article, but the original is retained for all to see.

The arXiv submission policy aims to screen submissions that are not of "reviewable quality". Our experience with moderators has been that in the vast majority of cases it is trivial for a subject expert to determine whether a submission is acceptable or unacceptable. This ease is perhaps why physicists are happy to use pre-prints from arXiv.

6 Institutionalization

The arXiv is established as indispensable in some disciplines and of growing importance in others. The large number of submissions, almost 200 every working day, means that it is no longer feasible to run it with "a couple of postdocs" to both administer on a daily basis and develop it further. Since the move of arXiv to the Cornell University Library in summer 2001, efforts have been underway to transfer all daily operation and mainstream development efforts to library staff. This has necessitated a number of changes in operational and development strategies. The first was formalization of a number of previously ad-hoc procedures for daily operation Another has been improvement in tools and practices to separate less skilled administration actions from those needing intervention by someone with detail knowledge of the system internals.

Benefits of the move to the Cornell University Library include a long-term institutional commitment to preserve and maintain access to the collection, rationalization of policies that have been made both simpler and more uniform. There are, of course, costs associated with larger management overhead and less development agility.

Significant steps have been made toward fairer and more sustainable governance through greater liaison with the overall arXiv advisory board and with the separate advisory committees for each of the main subject areas. In particular, the separate advisory committees are used to recruit moderators for each subject area and the physics advisory committee has recently reached consensus on reorganization of the physics subject categories.

7 The future role of arXiv

Many authors have identified two roles fulfilled by scholarly publication: one being to communicate information necessary for continued research, and the other to provide certification necessary for professional rewarding and advancement. The arXiv has demonstrated a very efficient system for the former need, but has not addressed the latter.

One can think of the largely automated distribution system provided by arXiv as the "low hanging fruit" of the broader scholarly communication problem. Even the submission system for arXiv is extremely cheap, as most of the effort is offloaded to the author. Administration effort is less than 2 minutes per article on average (based on a single administrator being able to deal with problems relating to 250 submissions in a single work day; neglecting overhead of maintaining and developing the system). However, even this amount of time adds up to one full-time equivalent just for the daily administration.

Most of the expense of running arXiv is in handling new submissions. This has two positive results. First, the cost of maintaining the arXiv of old papers is negligible in the context of running the whole service so there is no incentive to reduce access or facilities for the archival collection. Second, if at some time new submissions were no longer accepted, it would not be expensive to maintain the archival collection alone.

Nascent institutional repositories may eventually replace arXiv. The distributed model is appealing

although experience suggests that it is much more difficult to implement. In 1995 arXiv was distributed over several sites each dealing with separate subject areas but these were gradually brought back under central control for management convenience and stability. It may be that an intermediate stage will be for arXiv to act as a slave subject-based publishing venue with institutional repositories serving as the primary archives, or vice-versa. We are already having these discussions with a few institutions where institutional repositories have been deployed.

There is a clear advantage in the funding model for institutional repositories in that if funded by the institution that runs them, puts material in them, and benefits from resulting publicity, then the ownership and benefit is clear. Contrast this with the current situation for arXiv where the Cornell University Library is putting significant funding into a resource where Cornell is only a minor benefactor. ArXiv is currently funded through the Cornell University Library and the NSF though other long term funding sources are being investigated.

8 Acknowledgements

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References

[1] What was new on the arxiv.org (xxx) e-print archives, 1991–1994. URL: `http://arxiv.org/new/91-94.html`. Downloaded 2005-09-07.

[2] What was new on the arxiv.org (xxx) e-print archives, 1994–1996. URL: `http://arxiv.org/new/94-96.html`. Downloaded 2005-09-07.

[3] What was new on the arxiv.org (xxx) e-print archives, 1996–2005. URL: `http://arxiv.org/new/`. Downloaded 2005-09-07.

[4] Roger Clarke. A proposal for an open content licence for research paper (Pr)ePrints. *First Monday*, 10, August 2005. URL: `http://firstmonday.org/issues/issue10_8/clarke/index.html`.

[5] Paul Ginsparg. First steps towards electronic research communication. *Computers in Physics*, 8(4):390–396, 1994. URL: `http://arxiv.org/blurb/blurb.ps.gz`.

[6] Paul Ginsparg, Paul Houle, Thorsten Joachims, and Jae-Hoon Sul. Mapping subsets of scholarly information, 2003. URL: `http://arxiv.org/blurb/sack03.pdf`.

[7] Terry Hwa and Michael Lässig. Announcement of new quantitative biology (q-bio) archive, September 2003. URL: `http://arxiv.org/new/q-bio_announce.html`.

[8] Rob Kling and Geoffrey McKim. Not just a matter of time: Field differences and the shaping of electronic media in supporting scientific communication. *Journal of the American Society for Information Science*, 51:1306–1320, 2000. URL: `http://arXiv.org/abs/cs.CY/9909008`.

[9] Carl Lagoze, Herbert Van de Sompel, Michael Nelson, and Simeon Warner. The Open Archives Initiative Protocol for Metadata Harvesting, version 2.0, June 2002. URL: `http://www.openarchives.org/OAI/2.0/openarchivesprotocol.htm`.

[10] The NASA Astrophysics Data System. URL: `http://adswww.harvard.edu/`.

[11] Gary Taubes. Electronic Publishing: APS Starts Electronic Preprint Service. 273:304, 1996. URL: `http://www.sciencemag.org/cgi/content/full/273/5273/304`.