Linking Literature and Data: Status Report and Future Efforts

Alberto Accomazzi

Harvard-Smithsonian Center for Astrophysics, 60 Garden Street, Cambridge, MA, 02138 USA

aaccomazzi@cfa.harvard.edu

ABSTRACT

In the current era of data-intensive science, it is increasingly important for researchers to be able to have access to published results, the supporting data, and the processes used to produce them. Six years ago, recognizing this need, the American Astronomical Society and the Astrophysics Data Centers Executive Committee (ADEC) sponsored an effort to facilitate the annotation and linking of datasets during the publishing process, with limited success. I will review the status of this effort and describe a new, more general one now being considered in the context of the Virtual Astronomical Observatory.

1. Introduction

Links between papers in ADS and data products hosted by astronomy archives have existed since 1995. These links have been created and curated by librarians and archivists as part of the data center’s effort to collect information about the scientific use of the data being hosted by the archive. The links provide more than just useful connections between bibliographic records and observations that allow users to access related material. They represent part of the scientific artifacts created during the research lifecycle of an astronomer, and as such are needed to fully document and describe the research activity itself (Accomazzi 2010).

One obvious benefit which comes from maintaining such links is the ease with which one can generate metrics about the scientific impact of the observations in the form of published papers or citations. Thus, in a highly competitive scientific discipline such as astronomy, maintaining the complete record of paper-data connections has become an accepted way to evaluate a project, mission, or even an entire research field (Grothkopf & Lagerstrom 2010, Trimble & Ceja 2010). The metadata collected during the creation of links maintained by ADS and its collaborators have so far been limited to some very basic information about the
location of the resources linked together. Typically these are simple mappings of ADS’s bibliographic identifiers (bibcodes) and URLs pointing to one or more particular data product(s) hosted by an archive. The ADS record will of course also have a link to the published paper itself, acting as a “bridge” between the manuscript and the data described therein. Figure 1 shows the connection between a paper and data products available from the Multimission Archive at Space Telescope (MAST) and the Chandra X-Ray Archive.

Fig. 1.— Links between an ADS record, the full-text manuscript hosted by a publisher, and data products available from MAST and Chandra

2. Development of Dataset Linking Infrastructure

In 2002, it became apparent that the methodology adopted to create, maintain and share these linkages could be improved. Thus, in 2003, the NASA Astrophysics Data Centers
Executive Council (ADEC) and the AAS journals issued guidelines aimed at improving the situation \cite{Eichhorn2004}. This new effort was aimed at addressing four separate issues in the management of these links: their curation, naming, resolution and persistence.

The creation of links to data products has been a time-consuming activity usually carried out by a librarian or archivist. \cite{Rots2004} describe the effort required to perform this activity, which typically consists of scanning the literature to identify which papers mention one or more data products from a particular archive, and then link those papers with the relevant datasets.

In 2004, in order to facilitate this activity, and in coordination with the ADEC proposal, the Astrophysical Journal introduced the capability for authors to properly tag the datasets analyzed in the paper. This introduced a mechanism to formally "cite" data in a way similar to how scientists cite other papers. According to this plan, citations to data products would be vetted by both editors and referees during the manuscript editorial process, and links would be created to the corresponding data products as part of the process which generates the online HTML version of the paper. The correlation between a paper and the datasets referenced therein would then be propagated back to the ADS and the participating data centers via metadata exchange.

The implementation of this linking proposal would not only benefit end-users, but would potentially provide significant savings in the curation efforts of archivists and librarians, who could now harvest these linkages directly from ADS, thus reducing the need for the manual scanning of the literature.

In order to properly cite the datasets in the literature, the ADEC and AAS adopted a standard way to uniquely identify data resources based on the IVOA Identifier standard \cite{Plante2006}. The proposed system of nomenclature \cite{Accomazzi2007} provided a standard for dataset identifiers which featured some important properties. Among them: uniqueness (one resource corresponds to a single identifier), and persistence (identifiers do not change even when data products are migrated to a different archive). The identifiers were designed to support the naming of resources with a broad range of granularity and included a “public” prefix identifying the archive or mission that generated the dataset as well as a “private” key identifying the data item within a specific collection.

In order to ensure the proper use and persistence of links to datasets, the ADEC charged the ADS with the task of setting up a verification and resolution service for dataset identifiers. In this role, the ADS would act as the registration authority on behalf of the community, creating the infrastructure necessary to enable the dataset linking. During copy-editing of a paper, the editors would use an automated tool provided by ADS to verify that a particular
dataset identifier is known and can be resolved to an online resource. Upon successful verification, the identifier would be incorporated into the paper with a link to a resolution service provided by ADS (rather than a simple link to the current URL for the resource). This model provides a level of redirection which can be used to properly track a dataset if and when it moves from one archive to another, and allows the resolver to provide options should multiple versions of a data product be available. A complete description of this implementation can be found in Accomazzi et al. (2007). Elements of this architecture are similar to the Digital Object Identifier standard used for the persistent linking of scholarly publications, which is discussed in section 4. However, this system was designed to be fully managed by the astronomical community requiring a minimal level of effort for institutional buy-in.

3. Current Status

Six years have passed since the introduction of the dataset linking infrastructure, so now is a good time to take stock of this effort. From a system design point of view, some of the features that made the implementation of this system attractive have, in retrospect, proven to be obstacles to its long-term success. Chief among all problems with the registration of dataset identifiers has been enforcing their persistence. Since data products ultimately reside within archives that participate in the ADEC but which are run independently of each other, the implementation and maintenance of services that provide access to the data is left to the archives themselves. Given that the thrust of this effort is completely voluntary, there is no contract or reward system which can be leveraged to enforce the long-term resolution of and access to a particular dataset. Experience shows that unless requirements for the preservation of these linking services become part of the archive operations, a simple system upgrade is enough to break valuable links to dataset resources. As an example, over 200 dataset identifiers which were published in a 2004 ApJ Supplement special issue on the Spitzer Space Telescope are no longer resolvable due to a change in the Spitzer Science Center interface.

Unfortunately the adoption and use of dataset identifiers in the literature has not been a success story. Citations to datasets began appearing in 2005 and increased in the following two years, peaking in 2007, before decreasing in 2008 and finally going down to zero in 2009 (see fig. 2). The reasons for this reversal are not entirely clear, but can probably be attributed to a variety of factors. First and foremost, even though the ADEC approved a policy encouraging archives and users to make an effort to more widely publish dataset identifiers, anecdotal evidence shows a low level of awareness from scientists of this possibility.
Researchers tend to be busy and, unless properly coached by editors and archivists, will easily overlook new demands or stipulations requiring additional work on their part. In addition, data archives don’t always make it obvious how a particular dataset (or data file) should be cited in the literature by the scientists who make use of the data in their research. Since astronomers have been accustomed to referring to the data they have used in terms of specific observations or regions of the sky, this general practice is still used. Rather than unambiguously identifying the data using dataset identifiers, astronomers describe how the data can be obtained. While this is a reasonable way for an author to convey the necessary information about the data being studied, it obviously defeats the goal of creating persistent, unambiguous, machine-readable links to the data products. Finally, it was hoped that after the initial adoption of the standard for dataset identifiers within the ADEC more data centers and more journals would follow suit, but this did not materialize. The critical mass
and community awareness necessary to make this common practice was never reached.

4. A Way Forward

Despite the lack of adoption from the community of the proposal described above, every scientist, librarian and archivist agrees that preserving data products and publishing links to data in the literature is a worthwhile effort. We believe that at this point in time we should even be more ambitious, and recognize that in fact for our discipline to flourish in the digital era all artifacts related to the research lifecycle need to be available online, and properly interlinked (Accomazzi 2010). Thus, the issue of creating links from the literature to data products can be recast in a wider scope – the preservation and interlinking of digital assets in astronomy. The use of the term “digital assets” in this context refers to artifacts used and generated during the research activity of an astronomer. This includes observing proposals, observations, archival data from surveys and catalogs, observing logs, tables and plots that are published in manuscripts. In short, we advocate capturing all the data and knowledge that has gone into the research activity itself, with the aim of providing a digital environment that can support the repeatability of the research described in a publication. While there are many possible implementations of a digital environment for data preservation, it is clear that any such effort must satisfy a set of principles. Below we identify some of the basic requirements that we believe will need to be addressed in the near future.

4.1. Management of Digital Assets

First, one should consider the issue of nomenclature and persistence of digital assets. Since we can expect that the data referred to in a paper will be hosted on a distributed set of digital repositories, naming and linking standards need to be clearly defined and adopted in order to create persistent links to such resources. The solution proposed by the ADEC was primarily designed to satisfy the requirements of uniqueness and persistence for data already available in well-established archives using community-developed standards. While this approach is technically sound and seemed at the outset to provide the best solution to the problem, new technologies and standards since developed by the digital library community now offer attractive alternatives that should be considered. For the creation and management of unique identifiers, the Handle System is a general purpose distributed information system for the minting and resolution of unique identifiers on the internet. The Digital Object Identifier (DOI) system is an application built upon the Handle system and is widely used by the digital publishing industry. Organizations making use of the DOI system agree to
a business model that requires the deposit and active curation of metadata for the digital assets registered in the system, and are subject to fines if found to be in breach of the DOI Foundation rules. This elevated level of commitment provides a certain level of assurance that the digital assets registered in the system will be properly maintained. In addition, the DOI foundation explicitly imposes requirements on its members to ensure the long-term survival of the system. For instance, should one of its members cease operations, the DOI resolution of its content would be transferred to other members of the foundation. When it comes to the preservation of data products, this type of long-term commitment has never been formalized or made explicit by most of the publishers, societies or even astronomical data centers (except for the case of the active NASA missions, whose digital assets are transferred to archival centers at the end of a mission). However, it is exactly the type of commitment we believe is essential for our community to make at this time.

4.2. Archival and Preservation

In order to enable the publication and broader re-use of scientific high-level data products, researchers should be required to upload such data to one or more trusted, community-curated, digital repositories. Not only does this requirement allow repeatability of experiment and analysis, but it promotes a level of transparency and trust that is an important component of the scientific discourse.

While much of the tabular data now published in scientific articles ends up being stored in services such as NED and Vizier, a significant amount of supplementary material does not make it into such archives. To be sure, authors are often encouraged to submit machine-readable versions of the data (or even computer code) as supplementary material submitted to the journal, but the uniformity, longevity, re-usability and discoverability of such material are at this point highly inconsistent and questionable. In addition, no explicit or common migration plan has so far been defined by publishers or learned societies, so future access and curation of these assets is not assured. We believe that it is essential to encourage the deposit of digital assets in a wide range of trusted repositories curated by the community in collaboration with the journals. The kind of material deposited in such repositories will supplement the products which are currently curated by projects such as NED and Vizier, and consist of anything which does not fit in the typical description of a data table or catalog. This may include published images, plots, observing notes, workflows, software, intermediate results, and large data collections. In order for these data products to be useful, it is essential for the user to deposit and for the repository to expose not just raw data but also its related metadata. This should include, at a minimum, a description of the datasets in the sample,
a set of applicable keywords, and some notes relating the data in question to the published paper(s) in which they were used.

The need to create a digital infrastructure in support of these activities is increasingly being recognized both in the US and in Europe by funding agencies such as NASA, the NSF, JISC and digital preservation programs are now being defined (Choudhury 2007). In particular, the NSF DataNet Data Conservancy program has established as one of its goals the support of scientific inquiry through the adoption of a comprehensive data curation strategy. Today there are a number of open-source digital repository systems available, some of which have already been deployed by universities and projects involved in preserving digital institutional assets (e.g. Fedora or DSpace). Other initiatives, such as the Dataverse Network (King 2007), provide a scientist-centered framework for storing data products associated with publications and encourage their citation through the use of unique, permanent dataset identifiers based on the Handle system.

5. Discussion

Even though there is general agreement that publishing and citing data is a noble goal and worthwhile effort, the experience of the ADEC data linking effort has shown that it takes sustained community engagement to turn a proposal into a successful activity. When many people and organizations are involved in providing crucial components of such a distributed system, the risk of multiple points of failure becomes significant and can ultimately spell the demise of even the best thought-out technical scenario. Rather than giving up on this worthwhile idea, we should take the failure of adoption as a learning opportunity to devise a more robust system that can not only provide links to existing datasets available from well-established archives, but also provide the capability of storing author-supplied data and metadata related to publications.

In the long run, it is likely that there will be an ecosystem of different repositories and technologies used for the preservation of research products. Some of them will be more focused on actively capturing and curating datasets, as is today done by projects such as Vizier and NED, and others which will provide an infrastructure which can be used by scientists and publishers to self-manage data products associated with published papers. The overarching goal of such systems should be to provide useful services to the astronomy community and guarantee that the data deposited in such repositories will be properly curated and preserved for the foreseeable future. This includes providing a migration path for obsolete data formats, curating and exposing metadata of digital assets in the repository, and providing discovery services to its content. This commitment comes at a cost, which should
be shared by the community as part of the effort which funds the infrastructure supporting astronomical research. In addition, it is essential that we promote and encourage policies that foster and facilitate the growth of the digital scholarly environment that the Virtual Observatory has been envisioning. The recent funding of digital preservation frameworks such as the Data Conservancy project suggests that the time has come for the VO to play a major role in the capture and preservation of the astronomy research lifecycle. We look forward for the members of the International Virtual Observatory Alliance to take a proactive role over the next decade in order to make this vision a reality.

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This preprint was prepared with the AAS LaTeX macros v5.2.