Creation and use of Citations in the ADS

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Abstract.

With over 20 million records, the ADS citation database is regularly used by researchers and librarians to measure the scientific impact of individuals, groups, and institutions. In addition to the traditional sources of citations, the ADS has recently added references extracted from the arXiv e-prints on a nightly basis. We review the procedures used to harvest and identify the reference data used in the creation of citations, the policies and procedures that we follow to avoid double-counting and to eliminate contributions which may not be scholarly in nature. Finally, we describe how users and institutions can easily obtain quantitative citation data from the ADS, both interactively and via web-based programming tools.

The ADS is available at [http://ads.harvard.edu](http://ads.harvard.edu)

1. Introduction

With the introduction of citation data in 1997, the Smithsonian/NASA Astrophysics Data System (ADS) abstract service started offering its users the option of finding out what papers are citing a particular work, and, similarly, what are the works referenced by it. As predicted, the addition of these data has proven to be very popular among our users, and as our coverage of citations has expanded from the core astronomy journals into the field of physics and e-prints, the use of the ADS citations has steadily increased.

In addition to the traditional source of citations provided by the Science Citation Index by the Institute for Scientific Information (ISI), the last few years have seen the advent of new sources of bibliographic services offering citation information, among them Google Scholar and Citebase. With so many different options available, it is natural for librarians and scientists to wonder if the ADS should be considered the ultimate source for bibliometric data in astronomy or if other sources should be consulted as well. This paper tries to give a nuanced answer to the question, discussing how the ADS maintains its citations and in which ways it differs from other bibliographic databases.

In the first part of this paper we describe in detail the sources of citation data which the ADS relies upon and the procedures we have in place to help us maintain our citation lists up-to-date and accurate, discussing the issues related to completeness and coverage. We then illustrate the many ways in which citations play an integral part of the ADS abstract service through a
2. Generating Citations in the ADS

Occasionally we are asked by our users why a certain citation appears to be missing from the ADS citations list. The answer to this question is best given by explaining how the ADS creates the list of citations to a particular paper. The procedure is the following:

1. Scan the full-text of paper A and find the reference section
2. Identify the individual reference strings and parse bibliographic tokens in them
3. Create a tentative bibcode B for each reference string based on the parsed tokens
4. Verify the existence of bibcode B in the ADS and compute similarity score between the ADS record and parsed reference
5. If the score is high enough, then we say that the reference has been resolved to the record corresponding to B and we save the pair (A, B) in the resolved reference table (“A cites B”), otherwise we go back to step 2
6. Create citations by inverting the reference table (“B is cited by A”)

The process described above has been implemented as a set of automated procedures that on a daily basis scan any new reference data entered into the ADS database and try to parse and resolve the data as best as they can. The procedures used to perform these tasks are described in Accomazzi et al. (1999) and Demleitner et al. (2004).

Based upon this approach, it follows that a particular citation from paper A to paper B will be properly attributed if all of the following are true:

1. Citing paper A is in the ADS bibliographic database
2. The ADS has fulltext or reference section of citing paper A available for analysis
3. The reference to paper B has been successfully parsed and identified
4. The cited paper B is in the ADS bibliographic database

Each bibliographic record for which the ADS has obtained a reference list will have a link to its list of references which have been identified as ADS records. Conversely, papers which have been identified as having been referenced in the literature will have a link to the papers citing them.

It is worth noticing that the list of references displayed by the ADS does not include any references which we were not able to successfully match to an
existing ADS record. This approach differs from the one followed by ISI and Citebase, which instead attempt to display the list of references as extracted from the fulltext with links to the individual records that have been successfully identified from the reference strings. While this approach may be regarded as more user friendly, the ADS decided not to follow it. One reason for this is that our agreements with the publishers providing us with the fulltext paper information often do not allow us to display the references published therein, but rather want us to point the user to the fulltext article available on their website. Another issue of concern is the usefulness of providing reference information that is not necessarily properly formatted or interpreted, as is often the case for the entries that cannot be resolved. This difference in handling the display of references to the user does not however affect the attributions of citations since in all cases citations can only be counted when the cited paper is successfully identified as an existing record.

3. Sources of Citation Data

The first source of citation data became available to the ADS in 1997 when the AAS purchased citation data for the core astronomy journals from ISI. These consisted of about 1.3 million citations which constituted the original citation data provided by the ADS. The list of citations from ISI was expanded and updated in 2000 and then again in 2003 to include more astronomy journals as well as some of the major physics journals, and it now includes more than 9 million citations for the period 1982-2002. In late 1999 we added over 1.2 million citations generated from processing digitized fulltext scans in our article archives using Optical Character Recognition (OCR) technology, an effort which is still ongoing. During that same year we also received the first set of electronic records from the University of Chicago Press which included reference data and which were integrated in the citation database. The addition of more electronic reference data from the other main publishers of astronomy journals in 2000 and from the APS journals in 2001 brought the total number of citations above 10 million. During the past five years more publishers have been collaborating with the ADS in the exchange of citation data, including IoP, Springer and EDP Sciences, bringing us to the current total of over 20 million resolved citations, generated by parsing 30 million references. A summary of the major contributors of reference data is available in Table 1.

As of March 2005, references from the arXiv e-prints have been integrated in the ADS. When we retrieve the metadata for the nightly update of arXiv e-prints, we also process the fulltext articles to extract the references contained in them. As Table 1 shows, this source of references has become an integral and important part of the ADS, supplementing the data provided by the publishers. However, it also presents us with new challenges, the biggest one being a lack of uniformity in the structure of the papers. Since each e-print is prepared for submission to one of several hundred different publications, and since there is no copy-editing involved, both contents and formatting of these papers may be hard to predict. As a result, there is always the possibility that our procedures may be unable to successfully extract references from the e-prints.
Table 1. Sources of Citation data in the ADS as of September 2006 and their coverage. Please note that there is some overlap in these numbers. The number of records listed (second column) corresponds to the references successfully identified as ADS records. The third column gives the success rate of the reference resolution process for the particular dataset.

| Source        | Records (millions) | Resolved | Date Range     |
|---------------|--------------------|----------|----------------|
| APS           | 10.26              | 61%      | 1893-current   |
| arXiv         | 7.50               | 61%      | 1992-current   |
| Blackwell     | 0.92               | 81%      | 1999-current   |
| EDP Sciences  | 0.81               | 86%      | 2001-current   |
| IoP           | 4.59               | 52%      | 1887-current   |
| ISI           | 9.83               | 72%      | 1982-2002      |
| OCR           | 3.13               | 82%      | 1950-2002      |
| Springer      | 0.43               | 58%      | 1997-current   |
| UCP           | 1.93               | 87%      | 1995-current   |

In addition to the technical challenges involved in obtaining references from e-prints, a natural concern about their inclusion is whether these references will be duplicated once the paper is published and the ADS receives the corresponding record from the publisher. In order to avoid the duplication of citations, we have been performing extensive matching between the e-prints and published articles. All e-prints for which we find a matching journal article with associated references will not contribute to the citation count of the cited papers. Whenever a (journal) article is published for which we have the preprint in our system, we will replace the preprint references with the references from the paper, if they are available. If they are not, we continue to use the references from the preprint but attribute them to the published paper.

Another concern that has been raised about the inclusion of references from e-prints has to do with the scholarly quality of works posted to the arXiv. As a precautionary measure against counting citations generated from e-prints that never make it into the published literature, we have instituted the policy of excluding the references from a preprint older than one year from the citation lists, unless the preprint has been published. Having adopted these safeguards, we feel that the integration of citations from e-prints and indeed the availability of e-print records in the ADS has had a major, positive effect on research, allowing our users to stay in touch with results from the latest research more efficiently, without compromising their use of and access to the refereed literature (Kurtz et al. 2003).

4. Citation Completeness

Due to the process involved in the creation of citations, and its inherently imperfect nature, we cannot guarantee even a certain degree of citation completeness,
and we do our best to assure that users are aware of this problem. As discussed in the previous two sections, the sources of citation incompleteness in the ADS may be summarized as follows:

- The ADS does not have the cited article in the database. This happens for instance for most papers appearing in mathematics, chemistry, and geophysics journals. If you are somebody who publishes in any of these fields, we simply will not know about those papers, much less about their citations.

- Our reference resolver program could not interpret the reference. This may be due to errors or incompleteness in the reference, unusual formatting of the reference or the paper itself, or simply limitations in our program’s abilities. Given the many citation styles used in the literature, and the great variety of formatting used by publishers supplying us with reference data, this is not a trivial matter to address, and often requires a fair amount of training and supervision.

- We do not have the reference list for the citing paper. This happens for older articles and for articles in journals and conference proceedings that do not supply us with reference lists. Although this often comes as a surprise to some of our users, the fact that we have a record for a particular paper does not mean that we also know what are the articles that it has referenced.

We are constantly adding to our database by extracting reference lists from scanned articles, new electronic articles, and trying to improve reference recognition capabilities, so this ongoing effort will cause the number of references and therefore citations to increase over time. We are also going back in time and adding back-records of older papers published in astronomy and physics, so that more of the reference data in our system will be successfully matched to these papers once they are entered in ADS. We periodically check our reference lists to see what publications are being cited in the core astronomy and physics journals and which we are not able to successfully match against existing ADS records. Based on this analysis, we can then quantitatively assess what are the most referenced scholarly sources which do not appear in ADS yet, and work towards creating new metadata for them. As an example, Albert Einstein’s famous 1905 papers were recently added to the ADS physics database after noticing the many unresolved citations they were receiving in the published literature.

Despite our best efforts, we are well aware that we cannot always achieve the degree of citation completeness and accuracy that some people may desire, particularly in light of the importance that citations play in today’s world of academia. As a result, we have been providing ways for our users to submit corrections to citations already in our database and supplement our own citation data with author- and librarian-provided bibliographic data. The result of this effort is that we are now able to review and integrate user-submitted citation information in a timely manner. More information on how to submit this data to the ADS is available from our web site.
5. Bibliometric Applications

With the inclusion of citations in our system, researchers and librarians have started using this data for a variety of bibliometric studies. Despite our warnings about the incompleteness of citation data in ADS (and indeed the wisdom of using citation data in the first place), the temptation to quantify the scientific output of a user or project has proved too great for many people to resist. As a result, we have provided services that allow our users to easily gain this information. In the following sections, we briefly illustrate some of the most popular and most requested ADS searches involving the use of citations, offering some advice and warnings on their usefulness. In all cases the first step is accessing one of the ADS abstract search interfaces, available at [http://adsabs.harvard.edu/adsabstracts.HTML](http://adsabs.harvard.edu/adsabstracts.HTML). A word of caution: the procedures outlined below apply to the capabilities available in the ADS as of September 2006. Being a system that is actively enhanced on a regular basis, readers should expect that some of the options described here may have changed by the time this paper is read.

5.1. Author Citations

Using the standard ADS abstract search query, one can easily find out the list of papers published by a particular author or group, or on a particular topic. With the introduction of citations, one can now further process these results so that the most cited ones are listed first. In this section we will show a few ways currently available in ADS for obtaining bibliometric information about a particular author or project. In the subsequent examples, we have assumed that a person is looking for citations to his or her own papers, but the procedures that we illustrate can be similarly applied to a list of people or to one of the bibliographic groups known to ADS and included in its abstract service pages.

**How many citations do I have?** Query the ADS for all publications by you, making sure that the number of returned records is adjusted so that they are all included in the resulting list. Then use the menu available on top of the resulting page to resort the results by citations, which will display the most cited papers at the top and will also give the total number of citations for the set of papers.

**How many of my citations are refereed?** Using the list obtained at the previous step, go to the bottom of the form, click on “Select all Records,” and then click on “Get refereed citation lists for selected articles.” The resulting page contains all the refereed papers that cite your papers, and the total number of the citations to your papers is given at the top of the page.

**How many citations have been made to my papers during the year X?** Perform a query for your papers, select all records, and enter the year in question as both the starting and ending year for the publication year range displayed in the menu at the bottom of the form. Send off the query by clicking on “Get citation lists for selected articles.” The total number of citations for the year in question is displayed at the top of the page.

**How do I exclude self-citations?** After performing the original author query, select all records, and then click on “Exclude self-citations” at the bottom of the result page and on “Get citations lists for selected articles.”
What is my h-index? Recall that a scientist has an h-index (or Hirsch number) of N if he or she has published N papers with at least N citations each. The number can be easily obtained by performing the first citation search illustrated above, and then going down the list of papers noting the citation count and rank for each of them until finding the one for which the rank is smaller or equal to the citation count. The rank of the paper in question is your N number. More information on applications of the h-index metric using the ADS can be found in Grothkopf & Stevens-Rayburn (2007).

5.2. Keyword-based Searches

Just as one can apply citation metrics to author queries, we can also use similar techniques on keyword-based searches. In addition to obtaining citation counts, we can also perform some additional follow-up queries of interest, as outlined below (a more complete discussion of these queries can be found in Kurtz et al. 2002). Let us assume that we are interested in a topic of interest X (say “the virtual observatory”); we start by querying ADS for papers on the subject, and we obtain a list of papers that are relevant to the subject.

What are the most cited papers on topic X? If we resort the list of papers returned by ADS on topic X by citation counts we can immediately see what the most cited papers are. However, one should be aware that citations accumulate during the lifetime of a paper, so that there is an age effect in the ranking. All things being equal, older papers will tend to have a greater number of citations than more recent ones (simply because they have had more time to accumulate citations), so one should keep this in mind when making comparisons.

What are the most useful papers on topic X? If we select all papers on our topic and then click on “Get reference lists for selected papers,” we obtain the list of papers most cited by the original list of records on our topic. These can be considered most useful to somebody who is interested in subject X, because a large number of papers on the subject cite them, and must therefore contain important information about it. Note that the papers on this list are not necessarily on topic X themselves. Usually these are articles describing surveys, instruments, techniques and theories that were used by the scientists researching topic X.

What are the most instructive papers on topic X? Having obtained a list of interesting, recent or useful papers on our topic of interest, we can now find the list of papers which cite a large number of these articles, and which therefore contain extensive coverage of topic X. These can be considered the most instructive papers on the topic. Often these are review articles on the subject, and represent a good starting point for somebody new to the field.

By combining these types of searches with selections on date ranges and/or bibliographic groups, one can easily narrow the scope of the search, for instance to consider only papers published in the last few years.

5.3. Keeping up with Updates

As discussed in the previous sections, scientists and librarians will notice their number of citations change over time, usually increasing as more publications reference their works. Similarly, as new e-prints and journal papers appear in the
literature, the rankings of papers on a particular topic will change. In response to scientists’ desire to stay current with research developments, the ADS has recently introduced the myADS personal notification service \cite{Kurtz2003, Henneken2006}. This service provides up-to-date customizable alerts to its subscribers whenever new bibliographic records of interest to them are added to the ADS databases. In particular, it allows a scientist to keep track of his/her citations, show recent papers published by a list of authors that he or she follows regularly, and provides a list of the most recent, most popular and most cited papers on his or her topics of interest. This service can be also useful to librarians or data providers who maintain a list of bibliographies related to one or more projects, since myADS can be configured through a series of queries to return any new papers related to the project. We strongly encourage active researchers and librarians to use this service in order to stay current with the latest developments in their research field.

5.4. Automated Access

Most of the queries that we have outlined above can be automated by making use of simple web clients available in the public domain. Programmatic access to these queries is facilitated by the fact that ADS offers the capability of generating output records in a few different highly-structured formats. Among them are three different XML formats, one of which ("XML Abstracts") includes a citation count for each paper returned by a query as well as a total citation count for the entire set of papers (for a citation query). Records for individual papers can similarly be downloaded as formatted XML documents, which makes additional manipulation of any fielded bibliographic item (e.g. author list or bibcode or citation count) a very easy task using any vanilla XML parser. Automated procedures that mimic the interactive session between a user and the ADS search engine can therefore be easily implemented using a sequence of query-retrieve-parse steps. For more information on the tools and formats currently available please see the ADS on-line help pages.

Another feature recently added to the ADS which facilitates the automatic parsing of bibliographic records is the availability of RSS feeds for any ADS query. At the bottom of the page containing results from an abstract query users will find a link to the RSS feed corresponding to the query results. By using the link with an RSS reader client or by parsing the content using a parsing program one can immediately see if a new record satisfying his or her query has been integrated in ADS. Please note that since the information transmitted in RSS feeds is quite limited, this approach would not be suitable for compiling citation counts (which are not included in the RSS streams). However, this approach could be used as the first step to discover any new bibliographic entries recently added on a particular subject or by a particular author, and then by retrieving the citations using follow-up queries. This can be very useful to people maintaining bibliographic lists of papers about a mission or instrument.

6. Conclusions

We are often asked both by individual users and by librarians what the coverage and completeness of citations are in the ADS. As we have discussed in
this paper, there is no simple answer to this question since it very much depends on the particular area of interest one looks at. Because the ADS has very good coverage of the astronomy and core physics journals and has ongoing collaborations with the main astronomy and physics publishers, we can generally say that in the field of astronomy and astrophysics the ADS provides a very good account of the citations for the published literature. The picture is not so clear when we start looking at papers in other fields of physics, since they may be referenced by articles in disciplines such as mathematics, chemistry, and computer science, which ADS does not cover well. It is therefore natural for people to ask how well citations in ADS compare with the competition. Our own analysis as well as independent studies comparing ADS and other sources (Stevens-Rayburn & Bouton 2003; Gómez & Merida-Martin 2007) have shown that citation coverage and depth have been improving in ADS over the past several years and that in most cases ADS gives the most complete citation results for researchers in astronomy. We believe that the recent addition of citation data from e-prints as well as our well-established relationship with editors and users in the astronomical community will continue to give us an edge over the other on-line abstracting services.

However, the use of citations in the ADS for bibliometric purposes is just one of its advantages. For the purpose of information discovery, the links between citing and cited articles are the primary purpose for maintaining citations in the ADS. The actual citation counts, while interesting, are a secondary by-product of the primary goal, which is to allow scientists to easily find and access those articles that will aid their research. In this regard, the citation lists, along with article readership information, provide us the necessary data for implementing the powerful follow-up queries used by the second-order operators and by the myADS notification service.

Acknowledgments. The ADS is funded by NASA Grant NNG06GG68G.

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