AIPS Memo 87

The NRAO AIPS Project — A Summary*

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The NRAO Astronomical Image Processing System (AIPS) is a software package for interactive (and, optionally, batch) calibration and editing of radio interferometric data and for the calibration, construction, display and analysis of astronomical images made from those data using Fourier synthesis methods. Design and development of the package began in Charlottesville, Virginia in 1978. It presently consists of over 800,000 lines of code, 80,000 lines of on-line documentation, and 400,000 lines of other documentation. It contains over 300 distinct applications "tasks," representing approximately 50 man-years of effort since 1978. The AIPS group in Charlottesville and Socorro has five full-time scientist/programmers, and several other computing and scientific staff with partial responsibility to the AIPS effort. The group is responsible for the code design and maintenance, for documentation aimed at users and programmers, and for exporting the code to about 200 non-NRAO sites that have requested copies of AIPS. It currently offers AIPS installation kits for a variety of UNIX systems, with updates available semi-annually.

In 1983, when AIPS was selected as the primary data reduction package for the Very Long Baseline Array (VLBA), the scope of the AIPS effort was expanded to embrace all stages of radio interferometric calibration, both continuum and spectral line. The AIPS package contains a full suite of calibration and editing functions for both VLA and VLBI data, including interactive and batch methods for editing visibility data. For VLBI, it reads data in MkII, MkIII and VLBA formats, performs global fringe-fitting by two alternative methods, offers special phase-referencing and polarization calibration, and performs geometric corrections, in addition to the standard calibrations done for connected-element interferometers. The calibration methods for both domains encourage the use of realistic models for the calibration sources and iterated models using self-calibration for the program sources.

AIPS has been the principal tool for display and analysis of both two- and three-dimensional radio images (*i.e.*, continuum "maps" and spectral-line "cubes") from the NRAO's Very Large Array (VLA) since early in 1981. It has also provided the main route for self-calibration and imaging of VLA continuum and spectral-line data. It contains facilities for display and editing of data in the aperture, or u-v, plane; for image construction by Fourier inversion; for deconvolution of the point source response by Clean and by maximum entropy methods; for image combination, filtering, and parameter estimation; and for a wide variety of TV and graphical displays. It records all user-generated operations and parameters that affect the quality of the derived images, as "history" files that are appended to the data sets and can be exported with them from AIPS in the IAU-standard FITS (Flexible Image Transport System) format. AIPS implements a simple command language which is used to run "tasks" (*i.e.*, separate programs) and to interact with text, graphics and image displays. A batch mode is also available. The package contains nearly 3.8 Mbytes of "help" text that provides on-line documentation for users. There is also a suite of printed manuals for users and for programmers wishing to code their own applications "tasks" within AIPS.

An important aspect of AIPS is its portability. It has been designed to run, with minimal modifications, in a wide variety of computing environments. This has been accomplished by the use of generic FORTRAN wherever possible and by the isolation of system-dependent code into well-defined groups of routines. AIPS tries to present as nearly the same interface to the user as possible when implemented in different computer architectures and under different operating systems. The NRAO has sought this level of hardware and operating system independence in AIPS for two main reasons. The first is to ensure a growth path by allowing

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AIPS to exploit computer manufacturers' advances in hardware and in compiler technology relatively quickly, without major recoding. (AIPS was developed in ModComp and Vax/VMS environments with Floating Point Systems array processors, but was migrated to vector pipeline machines in 1985. Its portability allowed it to take prompt advantage of the new generation of vector and vector/parallel optimizing compilers offered in 1986 by manufacturers such as Convex and Alliant. It was extended in simple ways in 1992 to take full advantage of the current, highly-networked workstation environment). The second is to service the needs of NRAO users in their home institutes, where available hardware and operating systems may differ substantially from NRAO's. By doing this, the NRAO supports data reduction at its users' own locations, where they can work without the deadlines and other constraints implicit in a brief visit to an NRAO telescope site. The exportability of AIPS is now well exploited in the astronomical community; the package is known to have been installed at some time on a large number of different computers, and is currently in active use for astronomical research at more than 140[1] sites worldwide. AIPS has been run on Cray and Fujitsu supercomputers, on Convex and Alliant "mini-supercomputers," on the full variety of Vaxen and MicroVaxen, and on a wide range of UNIX workstations including Apollo, Data General, Hewlett Packard, IBM, MassComp, Nord, Silicon Graphics, Stellar and SUN products. It is available for use on 80386 and 80486 personal computers under the public-domain Linux operating system. In late 1990[1], the total computer power used for AIPS was the equivalent of about 6.5 Cray X-MP processors running full-time.

Similarly, a wide range of digital TV devices and printer/plotters has been supported through AIPS's "virtual device interfaces". Support for such peripherals is contained in well-isolated subroutines coded and distributed by the AIPS group or by AIPS users elsewhere. Television-like interactive display in now provided directly on workstations using an AIPS television emulator and X-Windows. Hardware TV devices are no longer common, but those used at AIPS sites have included IIS Model 70 and 75, IVAS, AED, Apollo, Aydin, Comtal, DeAnza, Graphica, Graphics Strategies, Grinnell, Image Analytics, Jupiter, Lexidata, Ramtek, RCI Trapix, Sigma ARGS, Vaxstation/GPX and Vicom. Printer/plotters include Versatec, QMS/Talaris, Apple, Benson, CalComp, Canon, Digital Equipment, Facom, Hewlett-Packard, Imagen, C.Itoh, Printek, Printronix and Zeta products. Generic and color encapsulated PostScript is produced by AIPS for a wide variety of printers and film recorders. The standard interactive graphics interface in AIPS is the Tektronix 4012, now normally emulated on workstations using an AIPS program and X-Windows.

The principal users of AIPS are VLA, VLBA, and VLBI Network observers. A survey of AIPS sites carried out in late 1990[1] showed that 61% of all AIPS data processing worldwide was devoted to VLA data reduction. Outside the NRAO, AIPS is extensively used for other astronomical imaging applications, however. 56% of all AIPS processing done outside the U.S. involved data from instruments other than the VLA. The astronomical applications of AIPS that do not involve radio interferometry include the display and analysis of line and continuum data from large single-dish radio surveys, and the processing of image data at infrared, visible, ultraviolet and X-ray wavelengths. About 7% of all AIPS processing involved astronomical data at these shorter wavelengths, with 7% of the computers in the survey using AIPS more for such work than for radio and *another* 7% of the computers using AIPS exclusively for non-radio work.

Some AIPS use occurs outside observational astronomy, *e.g.*, in visualization of numerical simulations of fluid processes, and in medical imaging. The distinctive features of AIPS that have attracted users from outside the community of radio interferometrists are its ability to handle many relevant coordinate geometries precisely, its emphasis on display and analysis of the data in complementary Fourier domains, the NRAO's support for exporting the package to different computer architectures, and its extensive documentation.

As well as producing user- and programmer-oriented manuals for AIPS, the group publishes a newsletter that is sent to over 775 AIPS users outside the NRAO soon after each semi-annual "release" of new AIPS code. There is also a mechanism whereby users can report software bugs or suggestions to the AIPS programmers and receive written responses to them; this provides a formal route for user feedback to the AIPS programmers and for the programmers to document difficult points directly to individual users. Much of the AIPS documentation is now available to the "World-Wide Web" so that it may be examined over the Internet (start with "URL" `http://info.cv.nrao.edu/aips/aips-home.html`). The NRAO knows of over 230 AIPS "tasks," or programs, that have been coded within the package outside, and not distributed by, the observatory.

The AIPS group has developed a package of benchmarking and certification tests that process standard data

[1] "The 1990 AIPS Site Survey", AIPS Memo No. 70, Alan Bridle and Joanne Nance, April 1991

sets through the dozen most critical stages of interferometric data reduction, and compare the results with those obtained on the NRAO's own computers. This "DDT" package is used to verify the correctness of the results produced by AIPS installations at new user sites or on new types of computer, as well as to obtain comparative timing information for different computer architectures and configurations. It has been extensively used as a benchmarking package to guide computer procurements at the NRAO and elsewhere. Two other packages, "VLAC" and "VLAL", are less widely used to verify the continued correctness of calibration and spectral-line reductions.

In 1992, the NRAO joined a consortium of institutions seeking to replace all of the functionality of AIPS using modern coding techniques and languages. The "`aips++`" project is expected to provide the main software platform supporting radio-astronomical data processing in the latter half of the 1990's. Future development of the original ("Classic") AIPS will therefore be limited mostly to calibration of VLBI data, general code maintenance with minor enhancements, and improvements in the user documentation.

Further information on AIPS can be obtained by writing by electronic mail to `aipsmail@nrao.edu` or by paper mail to the AIPS Group, National Radio Astronomy Observatory, Edgemont Road, Charlottesville, VA 22903-2475, U.S.A.