1 Introduction

1.1 The NRAO *AIPS* Project — A Summary

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 1,861,000 lines of code, 225,000 lines of on-line documentation, and 458,000 lines of other documentation.[1] It contains over 612 distinct applications "tasks," representing very approximately 90 man-years of effort since 1978. The *AIPS* group, now solely in Socorro, has one full-time scientist/programmer, and a few other scientific staff with some low-level 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 hundreds [2] of non-NRAO sites that have requested copies of *AIPS*. It currently offers *AIPS* installation kits for a variety of UNIX systems (Linux and Mac OS/X), with updates available annually.[3]

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 (FITS IDI) 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 11.4 Mbytes of "help" text that provides on-line documentation for users. There is also a suite of printed manuals (available on-line) 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

[1] Counted on 15-March-2023 and omitting the GNU copyrights, PostScript and PDF files, and obsolete areas.

[2] The `15JAN96` release alone was shipped to 225 sites and installed on well over 800 computers. The `15APR99` release was shipped to 344 non-NRAO sites. In 2009, more than 2400 different IP addresses installed or updated copies of *AIPS*. In 2019, this number had dropped to 1155.

[3] The `TST` version, currently `31DEC24`, will be available continuously. It remains under development and sites may update their copies at will. Binary versions are available for Linux (32- and 64-bit) and Max OS/X (Intel and ARM) and text versions for these and other operating systems.

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 *AIPS* to exploit computer manufacturers' advances in hardware and in compiler technology relatively quickly, without major re-coding. *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 way more than 140[4] 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 and laptops including Apollo, Data General, Hewlett Packard, IBM, MassComp, Nord, Silicon Graphics, Stellar and SUN products. It is available for use on personal computers under the public-domain Linux operating system and, since 2003, On MacIntosh OS/X computers. 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 is 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. 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 semi-annually that is sent to subscribing libraries and is available on the Web. There is also a mechanism whereby users can report software bugs or suggestions to the *AIPS* programmers and receive written responses from them; this provides a formal route for user feedback to the *AIPS* programmers and for the

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

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.aips.nrao.edu/`). 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 sets through the dozen most critical stages of interferometric data reduction, and compare the results with those obtained on the NRAO's own computers. The "Y2K" 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, now named "`casa`," is expected to provide the main software platform supporting radio-astronomical data processing sometime in the future. Further 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 `daip@nrao.edu` or by paper mail to the AIPS Group, National Radio Astronomy Observatory, P. O. Box O, Socorro, NM, 87801-0387, U.S.A.

1.2 The *CookBook*

This *CookBook* is intended to help beginning users of the NRAO *A*stronomical *I*mage *P*rocessing *S*ystem (*AIPS*) by providing a recipe approach to the most basic *AIPS* operations. While it illustrates some aspects of *AIPS*, it does not pretend to be complete. However, it does include detailed instructions for running many important items of *AIPS* software. With these as a model, the user should be able to run other *AIPS* software aided by the `EXPLAIN`, `HELP` and `INPUTS` files and the complete index of software given in Chapter 13 of the *CookBook*. In this edition, some of the chapters have matured into something more like a users' manual, than a beginners' cookbook. These sections provide an overview of a few less basic, but nonetheless interesting, programs which often seem to be forgotten even by experienced *AIPS* users. To assist the beginning and infrequent user, appendices have been added to provide outlines of continuum, spectral-line, and high-frequency calibration procedures, primarily geared to users of the VLA, and a simplified outline of VLBA data reduction. A guide to reduction of data from the historic VLA appears in Appendix O. To assist in finding information in this now large document, an index has been added.

AIPS software is changing and growing continually. This edition of the *CookBook* describes the `31DEC24` (aka "*AIPS* for the Ages (Aged), version 25") release of *AIPS*. Some chapters have information only from earlier releases. When something only applies to fairly recent versions of *AIPS*, a comment to that effect is made. Features remain in later releases even if the particular comment does not say as much. There were many changes in *AIPS* software between the seventh (`15JAN94`) and the sixth (`15JUL90`) edition of the *CookBook*. The chapter on the *AIPS* calibration package for continuum, spectral-line, solar and VLBI data (Chapter 4) was revised in 2018 to describe calibration and editing of the Expanded VLA. Material applying to the old VLA was moved to Appendix O (old). The list of current *AIPS* tasks (Chapter 13) has been updated and reflects the extensive improvement and expansion of *AIPS* software. The chapters on imaging and improving images were merged as were the chapters on interactive and hard-copy displays. These mergers reflect in part the mergers of these operations. The chapter on spectral-line imaging (Chapter 8) has been revised with the assistance of Elias Brinks. Phil Diamond, John Conway, Athol Kemball, and Ketan Desai have rewritten the chapter on VLBI calibration and imaging (Chapter 9).

Appendix Z contains instructions and advice peculiar to the individual *AIPS* sites of the NRAO. This has been revised extensively to reflect the migration of much of the data reduction at NRAO sites away from VAXes and Convex computers to Sun and Linux workstations. The ninth edition has an Index which is current and updates concerning editing, calibration, imaging and single-dish processing in the `15APR98` and later versions of *AIPS*. This edition still contains, essentially unchanged, the helpful glossary of astronomical and computing terms written by Fred Schwab.

Paper copies of recent editions of the *CookBook* are no longer available from NRAO. However, much of the *AIPS* documentation, including the *CookBook*, is now available on the "World-Wide Web" so that it may be examined and retrieved over the Internet (start with "URL" `http://www.aips.nrao.edu`). This edition of the *CookBook* is issued in a ring-binder format with a chapter-based page numbering system. This allows us to update individual chapters without altering the pagination of others and to make each chapter available individually over the Internet. The documentation is also included with every copy of *AIPS* shipped.

Additional written documentation on *AIPS* is available in several forms. A programmers' reference manual called *Going AIPS* is available in two volumes. This was revised completely for the `15APR90` release due to the upgrading of the *AIPS* code to FORTRAN-77 and to reflect the extensive additions and improvements to the software. Unfortunately, it has not been revised since but it continues to be quite useful. The first volume is intended for applications programmers, while the second volume is needed by programmers developing *AIPS* for new peripheral devices or computers. *Going AIPS* may be obtained from the *AIPS* web site.

AIPS provides run-time documentation in the form of `HELP` and `EXPLAIN` files which may be viewed at the terminal or printed. (See § 3.8 for explicit instructions.) Should these not suffice, consult your local *AIPS* Manager and then, if needed, e-mail the *AIPS* programmer at `daip@nrao.edu`. Although individual *AIPS* programs have often been written, and are best understood, by a single programmer, the *AIPS* group as a whole assumes responsibility for all released software. Anyone in the group will attempt to help you or, at least, to identify another member of the group better able to help you.

Finally, users are encouraged to recommend new and better analysis and display tools and to help debug the existing software by entering "Gripes" (see § 11.1). Please note that examples of bugs that are documented by printouts of inputs, message logs, *etc.* are most useful to the programmers. Also note that written bug reports are *much* more effective than verbal reports. E-mail to `daip@nrao.edu` reaches everyone in the group.

1.3 Organization of the *CookBook*

1.3.1 Contents

Chapter 2 of the *CookBook* describes in general terms how to get started in *AIPS* — signing up, logging in, mounting tapes, *etc.* Appendix Z gives details of these operations specific to NRAO's *AIPS* sites. Your local *AIPS* Manager may be able to provide a version of this appendix appropriate to your system. Chapter 3 introduces the basic *AIPS* utilities. Chapter 4 leads you through the basics of reading in and calibrating your modern VLA *uv* data. Chapter 5 explains the basic operations required to make and improve images. Appendices A, B, and C provide simpler recipe-like approaches to calibration and imaging which beginning users may wish to try. Chapter 6 introduces the basic *AIPS* tools for making interactive and hard-copy displays of images and other data and Chapter 7 describes tools for analyzing them. Chapter 8 and Appendix B contain hints and further *AIPS* tools of particular interest, but not restricted, to spectral-line users and other observers who have images of more than 2 dimensions. Appendix O is designed for users of the historic VLA archive and for older VLBI formats. Similarly, Chapter 9 and Appendix C are aimed primarily at users of VLB interferometers. Chapter 10 deals with single-dish data reduction with *AIPS*. Chapter 11 describes how to help the *AIPS* programmers, to backup your data, and to exit from *AIPS*. It also suggests some cures for common hang-ups and miscellaneous "disasters" which seem to afflict AIPS users. No such list can be made comprehensive or sufficiently general to cover all the computer systems now running AIPS. You will need to consult with your local AIPS Manager or other users if you encounter an unlisted problem.

Chapter 12 is intended for the "mature" AIPS user who wishes to learn about data formats, procedures, `RUN` files, and various subtleties of `AIPS` syntax. We recommend that you read this after becoming familiar with the operations described in Chapters 3 through 7. Chapter 13 contains lists of all available routines broken down by categories. Appendix G presents Fred Schwab's Glossary of radio astronomy data processing terminology. Appendix F gives some useful recipes for estimating disk files sizes and for saving data and images on tape. Appendix V contains information about tasks used to maintain the VLA, including holography of dish surfaces. Appendix I contains the index.

1.3.2 Minimum match

In this *CookBook*, we use the minimum-matching capability of AIPS to abbreviate the instructions needed to run the programs. This speeds up your activity at the terminal while working in AIPS. However, the full names of some of the `AIPS` instructions may be easier to learn and to remember. They are given in Chapter 13.

1.3.3 Fonts and what they signify

Throughout this *CookBook*, RESPONSES TO BE TYPED BY THE USER APPEAR IN THE PRESENT FONT. Prompts provided by the operating or AIPS systems are left-justified on the same line, *e.g.*, system prompts `$` on VAXes or `%` on UNIX systems , `AIPS` prompt `>`. `THIS IS THE FONT USED FOR SAMPLE OUTPUTS FROM THE COMPUTER` and for program names such as `PRTUV`. A lower-case italic font, *such as this,* is used for numeric and character parameter values which must be supplied by the user. The symbol `AIPS` refers to the program which you will use to communicate with the computer. The symbol AIPS refers to the full system, made up of the `AIPS` program, numerous other programs which may be run from `AIPS`, and the hardware configuration. The symbol C_R means "hit the RETURN or Enter key on the terminal."

The symbol § means Section and refers to the various chapters and sub-chapters of this *CookBook*. Except in the values assigned to character string variables, AIPS is case insensitive. We use upper-case letters in this *CookBook* to differentiate AIPS symbols from ordinary words visually. This usage also allows us to generate html and pdf capable versions of the *CookBook* from the basic TEX files automatically.

1.4 General structure of AIPS

The diagram on the next page is an attempt to show the general structure of the AIPS software package. You may wish to refer to it as you read the remaining chapters. Input to AIPS is either interactive or batch via the main `AIPS` program. It uses the POPS language processor and symbol table to set "adverb" values and cause application "verbs" to be executed. Chief among these, the verb `GO` causes independent programs called "tasks" to run. Sequences of commands may be run in batch by `SUBMIT`ting them to a batch "checker" and running them using the batch version of `AIPS`. All programs access and modify disk data files, and interactive ones may access tapes and TV- and Tektronix-like display devices.

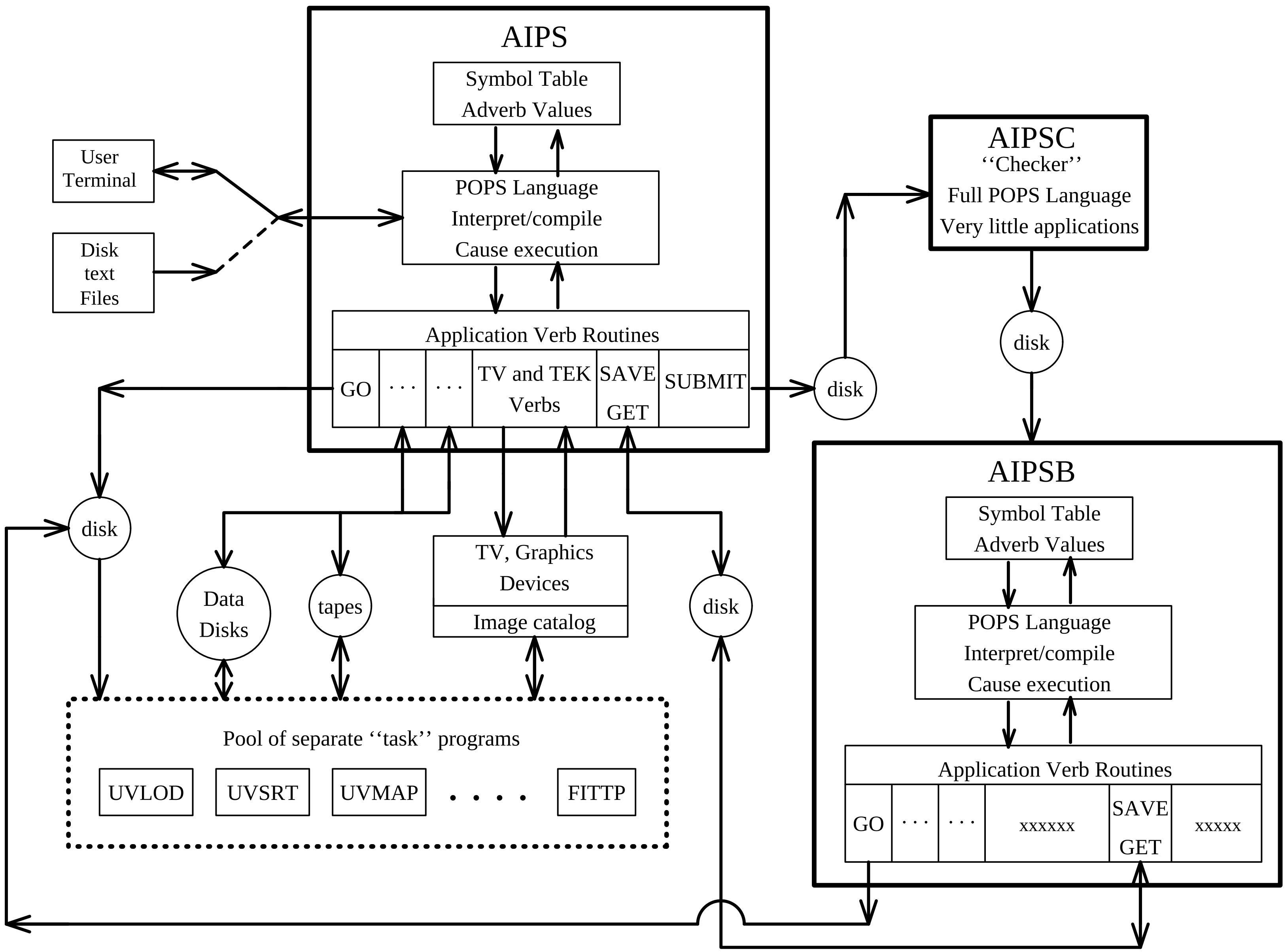

Figure 1.1: Basic AIPS flow diagram