An Approach Towards Scientific Specifications for AIPS++

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I. The Task

The astronomical community in general and the specifications group in particular have been given the task of writing specifications for AIPS++, a new processing and analysis package for radio astronomy. (I have purposefully not called AIPS++ an image processing package because I hope it will allow processing of much more than just images.) These specifications will be used by a consortium of programmers from observatories world wide who will begin writing code in early 1992 for testing by observers later that year. If AIPS++ is to last as long as its predecessor, AIPS, it must meet the needs of the science for more than a decade. Thus, as participants in the AIPS++ seminars, we must specify what is needed to advance science before those advances occur. This memo is meant to outline a process for determining those needs in a systematic fashion.

II. The Challenge

Our prime difficulty: we are supposed to know what we (and others!) will decide to do in the future. Two easy generalizations can be made:

1. We must have a flexible, easily expandable tool kit.
2. We must continue to have the current functionality of AIPS.

Writing specifications for point 2 is easy, point 1 is the challenge. Experience in the AIPS++ seminars has shown that it is much easier to specify what AIPS++ should not do than to specify what it should. The limits built into AIPS++ or any other package should not rule out progress in science.

The quality and speed of the scientist's thought should be the primary bottleneck to scientific progress. AIPS++ should be fast and flexible enough that this burden is placed squarely on the scientist as often as possible. Thus, we must specify what we want in programming tools, user interfaces, help facilities, manuals, modeling, and preparation for observing (with one or many telescopes) to accomplish problem-driven, multiwavelength projects. Fast algorithms on fast machines will not be enough. Speed can be used to free our thinking from the routine parts of science whenever an algorithm can be made reliable, but speed without flexibility is seldom worth the effort of developing a new processing package, except in tightly-defined programs demanding improved time resolution.

A large fraction of all research projects could be improved by more observing time, more antennas, larger telescopes, better instrumental sensitivity, more baselines, or a new waveband. AIPS++ should be capable of handling all of these advances when they occur but by itself cannot bring them about.

III. The Process of Science

To pass beyond the stage of glittering generalities examine the process of science in general (and astronomy in particular) to determine the areas in which AIPS++ can help the science to advance. The goal in science is the development, testing, and communication of new scientific ideas. An unrealistically rigid outline for meeting this goal follows.

1. Formulate an idea
2. Propose for observing and funding
3. Prepare an observing plan
4. Observe
5. Calibrate, map, Clean, diagnose errors
6. Visualize, analyze, compare with models
7. Communicate

Notes:

Feedback, connections, and iterations among steps are central to the process, a new idea may come during any step.

Steps 2 and 3 could be greatly helped by a telescope/data simulation program.

Step 7 is given minimal attention by most data reduction and image processing packages, yet it is the step which gives the payback to the scientist and the observatory. Publication quality graphics, poster- making utilities, and grammar checkers might be built in to the image processing package to help communication, including proposals.

Many current problems are solved by combining several types of data from different wavebands or different types of telescopes, often including model calculations or data from archives. Flexibility of data I/O will be important.

Astronomy is still largely an observational science. We learn about the sky by observing electromagnetic radiation (but in the future will want to observe particle radiation - neutrinoes - or include experimental data from spacecraft). This imposes a fundamental limit on what we can observe, which imposes a limit on how we can advance the science with observations.

The observable property of E-M radiation is intensity as a function of direction, time, polarization, and wavelength - $I(r,t,p,\nu)$. AIPS++ can help to advance the science by helping in the formulation of ideas, in the planning of observing, in real-time decisions at the telescope, in determining $I(r,t,p,\nu)$ from observed data (visibility functions or raw CCD frames), and in the analysis of the function I.

A. Advances from Improved Formulation of Ideas

Planning to have a good scientific idea is just about impossible, creating an environment in which ideas can be found has occasionally been achieved, but by people, not software. Optimal use of AIPS++ must go hand in hand with a good overall scientific environment. This includes ease of testing and rejecting bad ideas as well as having good ones. Easy, rapid visualization of ideas can be fostered by AIPS++.

B. Advances from Improved Planning of Observations

Optimal use of time and signal-to-noise ratio are the achievable goals here. The more complex the instrument the more we rely on rules of thumb. Help with planning interferometer observing would be of value, especially to newcomers.

C. Advances from Improved Decision Making During Observing

Real-time decisions at telescopes can make the difference between a successful observing run and an unsuccessful one. The main utilities of AIPS++ or a subset should be available on-line at major telescopes. A familiar environment running familiar algorithms would make the image processing routine and improve real-time decisions. Streamlined, preliminary algorithms could provide first-look capability at interferometers to be sure they are performing as expected, pointed at the correct object, and tuned to the correct passbands.

D. Advances from Improved Determination of I

Science is advanced most quickly if hardware and computing can advance together. Below are brief comments summarizing how AIPS++ and hardware might advance the science.

a. Improved Sensitivity to I

AIPS++ can help to improve sensitivity with new algorithms even if new receivers, dishes, and correlators are not available. Maps can have better signal-to-noise ratio via:

better deconvolution

better dynamic range

better subtraction of continuum or unwanted sources

straightforward use of 140-ft or GBT data

(How can GB spectral processor data be used?)

b. Improved I(r)

Higher spatial resolution from longer baselines or higher frequencies cannot be achieved with AIPS++ alone, but algorithms can help, especially if dynamic range is improved. Larger fields of view can be achieved by better algorithms to combine data from interferometers of different sizes (e.g. - VLA and DRAO) and by better mosaicing. Astrometry can be improved by new algorithms and flexibility in choosing coordinate systems. Establishing more astrometric reference objects in the radio would also be helpful.

c. Improved I(t)

Better time resolution, both long and short, can be improved with new algorithms and tasks allowing straightforward use of HTRP data. The science will take a leap forward when straightforward routines to overlay data from other wavebands (12-m, optical, GRO?) are available.

d. Improved I(ν)

AIPS++ alone cannot provide more channels or more sensitivity, but it can provide the astronomer with the opportunity to write tasks which allow better mosaics in frequency, better continuum subtraction, and more accurate handling of chromatic effects. Manuals and on-line help should be available to improve the scientist's understanding of what the (complex) spectral line tasks are doing to the data.

e. Improved I(p)

A significant contribution, within the reach of AIPS++, would be to make polarization tasks accessible and understandable to the average observer. Advances in determination of polarization and rotation measure are crucial to the understanding of cosmic B fields and the structure of pulsar emission regions.

E. Advances From Improved Image Analysis

In the rush to make progress goals can be forgotten. This occurs in astronomy when the image, rather than the science, becomes the goal. The history of optical astronomy and imaging science in general has shown that once image making has matured image analysis becomes more important to scientific progress. New data from the telescope, archival data, and the results of model calculations are all made into images for comparison and analysis. In this sense an image may have any number of dimensions, it is not limited to two. Tasks in AIPS++ can help to advance science by fostering comparison and analysis of images of arbitrary dimension. Providing the scientist with tools to build such analysis tasks would allow a fast start.

Progress in understanding new observations almost always means comparison with models. Model computations are usually made in coordinate systems which simplify theoretical progress, the observer must then extract images which can be compared with observations. AIPS++ can help to advance the science by simplifying the extraction.

IV. Conclusions: SCIENCE++

Given the goal of scientific advancement we must optimize the use of time: telescope time by improving the signal-to-noise ratio of the observations and the astronomer's time by removing the drudgery of science to allow more development and testing of ideas. Computers help, provided the software is reliable and adaptable, by allowing access to the microsecond domain. AIPS++ will make a double contribution when it is part of an optimal scientific environment, SCIENCE++, which unites the entire scientific process.

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