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An Initial Design for Major AIPS++ Objects

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Contents

1 Introduction

This document is intended to be a possible starting point in designing the object/class concepts for the AIPS++ software being developed by representatives of the AIPS++ consortium in Charlottesville, VA. The Jan. 21-24, 1992, course in advanced C++ and OOP design made it clear that an overall view of the major classes in a design is the starting point for any object-oriented software system. We hope to help this part of the design process by describing a tentative list and description of major and minor classes. We propose extensive discussion and evolution of these descriptions before different sub-groups of the consortium implementors focus on their areas of responsibility.

This document was never completed. It was still incomplete when the ideas and approach were rapidly replaced by the work and documentation of the Green Bank analysis and design in early February 1992. We are distributing this as is was because it provides context for the work that replaced it.

These objects/classes were derived from the astronomer's point of view. The astronomer studies the universe based upon known paradigms and the universe's observables, as governed by the radiative transfer through emitting, absorbing and scattering matter which determines the radiation on the celestial sphere. This radiation is then measured by instruments on observing platforms like the surface of the Earth or space vehicles. These measurements are altered to attempt to correct for instrumental, atmospheric, and other corruptions. These measurements are then used to make arguments about the nature of a part of the universe.

The underlying concept of this document is the attempt to use an English language-oriented, verbal syntax to make initial descriptions of classes and their important properties. Given the diverse set of users and programmers who must read and modify the design, we do not think that it's practical to require that the design be cast into a more formal form, such as predicate calculus. The syntax we plan to use is the standard discussed in the course, and used in some form in most discussions of object-oriented software development:

```
An   <X>  IsA   <Y>   that,
   HasA  <a list of parameters and components>
   Does  <a list of things>
   and Uses <a list of other objects/classes>
Comments: <supplementary information and things to consider>
```

The C++/OOP course showed that this is a useful starting point that can be understood by both astronomers and programmers without requiring a more detailed knowledge of object-oriented programming or the language of implementation. For this reason we believe that the

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initial design should evolve entirely in this form, leaving it to the programming experts to turn this into a graphical representation (such as PILOT) and ultimately into C++. It will probably, however, be necessary at a relatively early time to express parts of the design in mathematics; a good example of this is the clear relation between the mathematical description and class definition of a visibility observation in the Cornwell and Shone data structures paper.

In Appendix A we briefly describe the sense in which the IsA, HasA, Does, and Uses corresponds to some of the object-oriented analysis and design constructs.

It would be useful if the user specifications could be transformed into a form in which as many specifications as possible are described in these terms. Careful attention to using names defined in terms of other objects/classes should provide all the identification necessary to associate specification elements with the classes to be implemented.

Since this document is only a 0th order design, being put together in several days, we mainly try to describe major objects (classes) and their properties. Lesser constructs are included only to give some beginning ideas on how things might proceed.

Note that the positioning of the following sections is not always based on "IsA" or "HasA" relationships, but is used to group logical ideas together.

2 The Observable Universe

IsA collection of matter and radiation **that**

Has

- emission, absorption, and scattering processes determined by the physical properties of matter consisting of electrons, ions, atoms, molecules and solids
- the formal solution to the equation of radiative transfer

Does

- determination of the radiation field that reaches the
- "make" observable "objects" defined by their appearance in the form of radiation appearing on the celestial sphere
- infer unseen "objects" from their effects on observable objects, or other theorizing celestial sphere

Comments: A goal defining the observables that are most of what the astronomer must observe and analyze, and indicating what the theoretician or interpreter must basically compute in order to make comparisons of models and observations. Classes derived from these concepts will underly computational modeling of observables.

2.1 Measurements

2.1.1 A Field

IsA abstract class of data types **that**

Has

- coordinates for each piece of data
- tranformation properties appropriate to the data type

Does contain the description of data of the appropriate type as a function its coordinates
Comments: Applicable to an number of coordinate dimensions. Data types are elementary (real, integer, character, string) or physical (IQUV, brightness temperature, any measured or inferred quantity)

2.2 A Single Disk Sky Data Field

IsA field of measured total power **that**
Has

- detected, but uncalibrated total power units for each field coordinate
- associated seconday telescope data
- at least one coordinate of time
- optional frequency coordinate if processed by a spectrometer

Does contain uncalibrated single dish, total power measurements
Comments: Raw single dish data that requires calibration before acquiring full significance as measurements of sky surface brightness

2.2.1 A Single Disk Sky Image Field

IsA field of measured calibrated total power **that**
Has

- calibrated surface brightness measurements based on a fit to a model for uncalibrated field data for a source of known properties
- associated seconday telescope data
- at least one coordinate of time
- optional frequency coordinate if processed by a spectrometer

Does describe an image of the sky as convolved with antenna beam and frequency bandpass functions
Comments: Requires data processing of raw calibrator data to determine calibration parameters and application of these calbration parameters

2.2.2 A pixel

IsA single point subset of an image field of any dimensions **that**
Has units appropriate to the image type
Does represent the meaning, nature, etc., of image data
and Uses IQUV, complex, real, integer, etc., data types
Comments: The meaning of pixel data should normally be conserved upon "rotation" of the coordinate system in which these data are represented.

2.2.3 A Sky Image

IsA a field of ModeledSkyData
Comments: A fundamental class that, on one extreme, is the single pixel output of total power systems and on the other hand becomes the computer-processed image of multiple pointings of single dishes, arrays, etc. An image might be a pixel array (in N-dimensions), a photon list, set of scans that irregularly sample a part of the celestial sphere, some other measure of the radiation distribution on a part of the celestial sphere, or some other system- or user-defined data type which is useful to process and display with image handling tools.

2.2.4 Antenna Beam Pattern = Point Spread Function

IsA image of a point source as sampled by a single dish, **or**
IsA power distribution representation of the sensitivity pattern of an antenna-feed system **that**

Has two-dimensional angular distribution pattern with half-power-beam-width, null locations, and real differences between intended and real pointing positions that are major parameters affecting observations

Does

- weighting of instantaneous sampling of radiation on the celestial sphere are detected by a particular telescope-feed combination
- introduce image errors due to initially unknown differences between true and assumed pointing positions

and Uses antenna, and feed
Comments: Special case of the image class that may be used to correct images and which strongly limits observations of sources the size of the main antenna beam, or larger.

2.2.5 A Synthesized Beam Pattern = Point Spread Function

IsA image of an unresolved source for telescope array observations **that**

Has IQUV(α, δ) distribution largely described by central beam shape/size and sidelobe pattern

Does

- determine the instantaneous and averaging function with which observed radiation is sampled by arrays
- have theoretical properties for ideal instrumental conditions
- have real defects when there are real instrumental defects, atmospheric distortions, or time variations in sources

and Uses array geometry, observing platforms, observing situation, instrumental properties
Comments: Special and important case of the image class.

2.2.6 A Coherence Function Data Set

IsA collection of correlation multiplier data from one or more aperture synthesis arrays **that**

Has meaning of instances of two-dimensional transforms of IQUV($\alpha\delta, \nu$, t) on the celestial sphere as averaged and sampled by an array of telescopes and their associated electronics with delay with respect to an assumed phase reference position and correlation with specific spectral and averaging characteristics

Does

- give data on two-dimensional fourier transform sampling of radiation on the celestial sphere as weighted and selected by the antenna beam pattern and properties of the feed-to-correlator systems
- include effects of equipment malfunctions at both known and unknown times
- couple the sampling of the celestial sphere to the geometry and motions of telescope observing platforms
- not contain any (or good) information about radiation on the celestial sphere outside the antenna beam, or corresponding to fourier components outside (or inside) the sampled u-v plane

and Uses telescopes, observing platforms, telescope arrays

Comments: Fundamental class in which special correlation sampling of radiation on the celestial sphere produces measurements of fourier components with complicated dependence on instrumental, atmospheric, etc., circumstances of the observations.

3 An Astronomer

IsA scientist studying the universe **that**

Has ideas/models of sub-structures of the universe, and telescopes to gather information about these sub-structures

Does

- Conception and computation of models for the behavior of astronomical objects
- Preparation of proposals to use telescopes to gather specific data on astronomical objects for specific scientific projects
- Planning and control if the observing schedule and its parameters for telescopes obtaining data – sometimes using programs that prepare for, or guide, the observing and data collection process
- Analysis of data from telescopes in real-time, or thereafter, to determine the observable properties of "objects" in the observable universe that appear on the celestial sphere, by determining IQUV as a function of position (α, δ), frequency (ν), and time (t) in the form of images, spectra, spectral image cubes, time series sampling, or other useful forms of astronomical information
- Utilization of telescope data, and other information, from one or more sources and telescopes, to answer astronomical questions about structures and sub-structures of the universe

- Publication and other forms of communication of scientific results and ideas in the form of plots, pictures, and other display in the context of papers, books, and public presentations

and Uses astronomical paradigms, new ideas, measurements of the observable universe, telescopes, and telescope arrays
Comments: This should be basically a user description of things that relate to the purposes that AIPS++ should serve.

4 An Instrument

IsA a device that produces measurements of the physical universe **that**
Does

- attempts to measure one or more physical attributes of the universe
- records the measurements, possibly after applying some instrumental corrections, averaging, *etc.*
- produces a log of instrumental status

and Uses An observing schedule, source list
Comments: This is a very general concept of an instrument, meant to cover even non-radiation measurements, for example electron densities returned by a space probe.

4.1 A Telescope

IsA an instrument that instrumentally samples radiation from the celestial sphere and other nearby objects **that**
Has total power measurement capabilities in different frequency channels, a control system, an observing schedule, an operations staff, and data recording systems
Does

- sampling of radiation from the celestial sphere
- determination of some of the properties of observations made by the astronomer
- provide total power data for selected frequencies, integration times, and spectral channel output to either data recording systems or array-oriented data processing hardware

and Uses an antenna located on an observing platform, feeds, analog signal processing, timing systems, spectrometers, samplers, digitizers, and on-line data processing systems
Comments: This class should describe the functions of eye and all radio, optical, IR, UV, X-ray, etc. telescopes.

4.1.1 A Telescope Control and Data Handling System

IsA control and data processing system for an antenna and its electronic components **that**
Has instrument control information and total power/spectrometer data output
Does

- points antenna and controls settings of optics/feeds

- controls parameters of the electronics
- controls the observing process using
- potential for recording of total power, spectrometer, etc. data
- potential for passing total power data to array data handling systems
- timing and instrumental performance data recording systems

and Uses antenna, spectrometers, timing systems, and on-line computer systems
Comments: Needs to cover both single dish observing and more global use and use of antennas in arrays

4.1.2 An Antenna

IsA radiation collection and focusing device **that**
Has a collecting surface, optics, and location for feeds or detectors
Does

- collection and focusing of radiation on feeds or detectors
- determination of the principal regions from which radiation is received
- determination of some of the properties of observations made by the astronomer
- deliver focused radiation, with some efficiency and sensitivity pattern, to feeds, arrays of feeds, or focal plane arrays

and Uses a location on an observing platform
Comments: This class should describe the certain functions of the eye and all radio, optical, IR, UV, X-ray, etc. telescopes.

4.1.3 A Feed

IsA radiation collector and transformer **that**
Has reception solid angle, location on an antenna which is part of a telescope, and parameters for the reception and transformation of radiation
Does transformation of radiation into the form of waves propagating in a wave guide
and Uses one type of FeedDesign
Comments: Defines the coupling between optical elements of a antenna and signal in a waveguide, is the last element determining antenna pattern and polarization beam properties, causes selection of frequency bands, and is starting point of subsequent signal transmission.

4.1.4 A Front End

IsA RF to IF signal transformer **that**
Has frequency selection range, internal calibration system,
Does transformation of a waveguide signal to a voltage signal that can be represented by V(t)
and Uses telescopes, feeds, and other electronic systems
Comments: Should reflect all the properties of the electronic systems that affect data up to the point where samples the analog signals.

4.1.5 A Spectrometer

IsA signal transformer **that**

Has number of frequency channels, channel bandwidth, spectral sensitivity pattern.

Does

- transformation of voltage signal to frequency spectra as a function of time

and Uses a voltage signal V(t)

Comments: Applicable to single dishes and phased arrays doing total power spectroscopy via filter-banks or any other technique.

4.1.6 A Fourier-Transform Spectrometer

IsA spectrometer **that**

Has number of frequency channels, channel bandwidth, spectral sensitivity pattern.

Does

- Fourier transform of lags with respect to a particular time
- transformation of voltage signal to frequency spectra as a function of time

and Uses a voltage signal V(t)

Comments: Specialization of the more general spectrometer.

4.2 A Telescope Array

IsA collection of telescopes **that**

Has sets of telescope locations, control systems, data transmission systems, timing systems, possibly delay/phasing, and data recording or data input to a central summing or correlation system, for operation as a phase and/or correlation array

Does

- aperture synthesis observations of astronomical sources
- production of phased array total power signals

and Uses telescopes, observing platforms, and the atmosphere

Comments: Contains the properties of geometry and operation of multiple telescopes whose data are directly or indirectly combined for sum or correlation array operation with beam properties determined by array geometry and the atmosphere over the array.

4.2.1 An Array Control and Data Handling System

IsA data processing system for a number of telescopes that accomplishes the phasing of total power data for phased array data and the delay, sampling/digitization, correlation, averaging, and data recording of visibility data

Has

Does

- recording of total power, auto-correlation, and correlation data for a system of telescopes
- control the array observing process

- supply timing data and instrumental performance data

and Uses telescopes, timing systems, samplers, delay systems, correlators, and on-line computer systems
Comments: Needs to cover connected-array and VLBI systems. Needs more complexity than defined here and a clear definition of input and output components.

4.2.2 The Very Large Array (VLA)

IsA Radio Telescope Array **that**
Has

- 28 antennas with 25 m shaped parabolic reflector, rotating hyperbolic sub-reflector at prime focus, 90 cm dipoles on sub-reflector, 20, 6, 3.6, 2. and 1.3 cm feed in circular feed ring at cassegrain focus
- circularly polarized feeds and duplicate and 50 MHz IFs for each frequency
- location between Magdelena and Datil, in New Mexico, with array center at latitude 34°04′43.497″, longitude 107°37′3.819″ east, altitude 1800 m.
- antenna transporter system on twin railroad tracks with antenna stations for A (36 km), B (11 km), C (3.3 km), and D (1.0 km) configurations of 27 antennas each
- Cooled cryogenic receivers, mixers, etc. located in cabin "under" the reflector surface, connected to feeds by waveguide, and converting IF, timing, and monitor data to 18-22 GHz range for transmission in separate wave guide channels for each of nine antennas on each arm
- array control and data handling from building at near center of array with monitor, timing, and control information sent via waveguide to each antenna for 1 millisecond out of a cycle of 52 milliseconds, and A & B (RCP), C & C (LCP) 50 MHz IF data, timing data, and monitor data sent remaining 51 milliseconds
- correlation array operation with digital delays, 2-bit sampling, correlation of 52 millisecond averages (with Walsh function correction) normally summed to 3 1/3 second or longer average visibilities and recorded on tape by on-line computers
- network of Modcomp on-line control computers with computer console monitoring and control by array operators, visibility and associated data written on magnetic tape in VLA "archive format", "monitor data" written on magnetic tape independently
- Sun workstations etherneted to Modcomps for direct data access and nearly real-time date processing and display under development Jan.-July 1992

Does

- connected-element aperture synthesis in continuum and spectral line modes providing coherence function data sets and associated information
- phased array operation with use of 1 to 27 antennas for VLBI; high time resolution processing (HTRP) with special purpose polarization and averaging modules together with PC control and fast data sampling; and 3.6 cm telemetry reception from space craft

and Uses telescope array, array control and data handling system
Comments: The particular properties of this array, and all other radio telescope arrays should be described here with complete parallelism matching the definition of the Telescope Array class.

5 Organizational

5.1 An Astronomical Source

IsA astronomer-defined region of radio emission on the celestial sphere **that**
Has IQUV(α, δ, ν,t) characteristics that one measures with telescopes telescopes and arrays, and an astronomer-defined angular geometry
Does Display of its IQUV(α, δ, ν,t) properties on the celestial sphere
and Uses radiative transfer to celestial sphere, and through the atmosphere
Comments: Sources in catalogs, transient and other types of source variability/motion, and other complications, should all be covered in any definition of a source class. While a fundamental entity for study, the meaning of "source" is both in the minds-eye of the astronomer and heavily affected by a telescope's or telescope array's spatial, frequency, and time sampling capabilities.

5.2 A Calibrator

IsA astronomical source **that**
Has known properties in terms of IQUV distribution on the celestial sphere and time stability
Does play role of an observed source that produces data with predictable characteristics that can be used to determine instrumental calibration parameters
and Uses radiative transfer to the celestial sphere, and through the atmosphere
Comments: Calibrators will often be associated with a particular instrument or class of instruments.

5.3 An Observational Database

IsA collection of measurements **that**
Has observing schedule, source lists and qualifiers, measurement data, instrumental data, calibrators
Does

- organizes the data by time, source name, measurement value and other criteria
- organizes the instrumental data
- enables data to be edited, and for calibration information to be applied to the raw data
- mechanisms for other databases to be concatenated, and for subsets of the database to be split off
- records a history of changes that are made to a database, and allows for some changes to be undone

and Uses instruments
Comments: This is an organizational structure that allows the astronomer access to all the measurement and instrumentals data from single or multiple observing sessions.

5.4 An Archive

IsA collection of observational databases **that**

Has measurements, information on instrumental parameters

Does

- allow the astronomer to search for particular observations that might be of interest
- enable the astronomer to make and test statistical queries against the data contained in the archive

and Uses data collected from one or more instruments

Comments: This might be a complete archive of instrumental data, or a summary archive.

6 Positions

6.1 An Observing Platform

IsA position as a function of time **that**

Has a position in space and time

Does determination of the capabilities of on-board telescopes to make observations at specific times for specific portions of the celestial sphere

and Uses telescopes

Comments: A basic abstraction should should cover the properties of telescope-bearing objects like the earth, airplanes, balloons, Earth-orbit space craft, solar system-orbit spacecraft, and eventually the moon and more remote telescope platforms.

6.1.1 The Earth's Surface

IsA observing platform **that**

Has latitude, longitude, and altitude parameters that determine locations on the Earth that define an Earth-based sidereal time and coordinate system, and the portions

Does determine position and observable sky for telescopes

and Uses the Earth with its properties of rotation, nutation, motion through the solar system, etc.

Comments: Simple in concept, but should contain all the elements of geodesy that affect ground-based telescopes

6.1.2 A Space Vehicle

IsA platform **that**

Has location and other properties determined by its position in space (controlled by astronauts and/or ground-based control), and data acquisition, transmission, and recording facilities

Does transportation telescopes for observations, local data recording, and/or transmission of data to ground-based data acquisition systems

and Uses an orbit

Comments: Contains all the positional and operational capabilities of space telescopes, particularly orbiting VLBI telescopes.

6.2 A Coordinate System

IsA mathematical description of position with respect to some reference frame **that**

Has geocentric, heliocentric, galactocentric, antenna-centered, array centered, etc., types of intrinsically triple coordinates

Does

- specifies locations of physical objects and sources on the sky with respect to a reference frame
- allows conversions between coordinate systems, generally with a well-defined rotation matrix
- used for specification of antenna and array observing positions on the sky, and specification of pixel locations in an image
- used for specification of telescope locations in arrays

and Uses an astronomer or instrument selected default system

Comments: Many of coordinate systems are angular and confined to a surface (the celestial sphere). Some instruments have natural coordinate systems, all are defined by geodetic coordinate systems.

7 Radiation Propagation

7.1 The Celestial Sphere

IsA an apparent emitting surface for radiation **that**

Has definition in terms of a apparent two-dimensional coordinate system (α, δ) with respect to a location on an observing platform

Does determination of the apparent angular geometry of the observable universe

and Uses the radiative transfer properties of the universe and an observing platform

Comments: The focal point of the geometry of the observing process that couples telescope location to the observational coordinate system. For far-field measurements, will need a representation for near-field.

7.2 The Earth's Atmosphere

IsA special structure of absorbing, emitting, and scattering matter **that**

Has radiative transfer properties and changing structure

Does

- Determination of ground-based observing windows for radiation
- Introduction of changes in radiation observed by telescopes that affect the apparent resolution and imaging properties of telescopes and arrays of telescopes
- Is a environment that can be studied by telescopes through observations of sources with known properties

and Uses atmospheric structure, frequency, location on the Earth's surface and a time

Comments: Can be based on a model, observations, or both.

8 A Data Analysis System

IsA combination of computer hardware and software for processing data from telescopes and optionally comparing these data and their products with theoretical models and results from other telescopes **that**

Has flexible data input and output, and a powerful, flexible, easily programmable, and user-oriented software system

Does

- serve the data processing needs of the Astronomer class
- provide data analysis capabilities at telescopes or telescope arrays whenever feasible
- support the operation, de-bugging, and maintenance of telescopes and arrays of telescopes
- support remote telescope observing and data analysis
- provide data reduction facilities for users at their diverse universities, institutes, etc.

and Uses telescope data handling systems, array telescope data handling systems, computers, software tools, and the ideas of astronomers

Comments: Describes general data analysis needs

8.0.1 AIPS++

IsA data analysis system **that**

Has user interface, tools, tasks, displays, etc.

Does what consortium members, and users want

and Uses telescope, telescope array data, software libraries, and compatible computer hardware

Comments: Describes the specific functionality of AIPS++ with respect to data sources, users, and its role in the software for consortium members and users.

9 Appendix A

For those interested in the translation of the **IsA, HasA, Does, and Uses** syntax to the definition of classes and related constructs, it is worth cross-referencing these to terminology used by other authors.

The initial idea for this syntax came from the course (and course notes) presented to us by Tom Murphy for Semaphore Training. In this course he used an abbreviated form of the graphical language described by Ackroyd and Daum (1991) that matched well with the this terminology. However, an even closer corespondence is found with the analysis and graphical notation of Coad and Yourdon (1991). In the Coad-Yourdon system the basic triad is Class-Attributes-Services, which is essentially the same as the Class-HasA-Does syntax we are using, but the latter is more naturally suitable to English language "sentences".

In order to have more complete information we have added the Uses construct, making a quartet of **Class-HasA-Does-and Uses**, so there is a way to indicate that the object/class being discussed makes use of the properties of other objects/classes.

Finally, we add **Comments** so extra information that does not initially fit into this syntax can be supplied. Particularly because these definitions will evolve, we want people to concentrate more on what the objects/classes represent than on whether all the details of the words and syntax are "right". Eventually they need to be agreed upon, but at these early stages of the project discussions of content are more important.

Figures 1 and 2 use the Coad-Yourdon diagrammatic scheme to related some of the "classes" discussed in this document.

10 References

Ackroyd, M. and Daum, D. 1991, *Journal of Object-Oriented Programming*, **3**(5), 18-28.
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