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VLA COMPUTER MEMORANDUM #130

THE DATA ARCHIVING AND DISTRIBUTION SYSTEM INITIALLY PLANNED FOR THE VLA

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INTRODUCTION

The data archiving and distribution system for the VLA will strongly affect the way VLA users will work with their data. Although it will be some years before this system will get to the point where changes are very difficult, the initial plans for this system that are currently being implemented in the asynchronous computer software are of interest to potential users.

This memo summarizes a number of considerations concerning the planned archiving and distribution system. It also describes the "standard" map parameters and the factors that may be altered at the request of the user. In addition, the characteristics of the interface to post-observing processing are summarized.

THE INTERFACE BETWEEN SYNCHRONOUS AND ASYNCHRONOUS SYSTEMS

The synchronous computer system which controls the array, collects the data, and performs the data corrections and calibrations that are possible on a real-time basis has three forms of data output that can be viewed as input to the asynchronous computer system. The first is the collection of visibility, visibility-related, and monitor data written on a fixed-head disk once every data "sampling" time. The second is a copy of the same visibility and visibility-related data written on magnetic tape for archiving purposes. The third is the selected monitor data written on to magnetic tape to provide a log of system behavior.

The visibility and visibility-related data written on the fixed head disk will be taken from the fixed head disk by a program running in the asynchronous computer and translated into a data base format for all subsequent processing that takes place in this computer.

The visibility and visibility-related data written on tape by the synchronous computer system will serve as the sole archive of data maintained in time-baseline format. There will be no equivalent duplicated in the asynchronuous computer archiving system. This is being done both to minimize needed storage and to make the data accessed from the archive for any pre-synthesis processing as un-touched as possible.

The monitor data written on the fixed head disk will be translated into a special data base designed to allow VLA operators and engineers to access and display past performance of the array. This is intended to allow flexible access to the monitor data not necessarily kept on the monitor log tapes together with the capability to access and display monitor data "saved" in both systems using interactive graphics displays. It is planned to have a number of Tektronix 4012 storage tube terminals linked to the asynchronous computer for use by VLA engineers, technicians, and operators.

THE ASYNCHRONOUS COMPUTER DATA BASE

Nearly all programs in the asynchronous data reduction system are designed to input to or recieve data from a data base which is maintained in non-sequential data files. The visibility data in the data base is put and maintained there only when it is needed. The times this is done are either during observing or during post-observing processing. Hence it should be viewed as a temporary storage format, in the DEC-10, designed for easy access by user computational tasks. The data base is defined by a formal description of how data with specific names and descriptions map into specific blocks and words. The user will be aware of the data base only in terms of name and parameter descriptions that he provides to CANDID - the language by which he (or default standard programs) controls data processing tasks. Knowledge of key words, the names or values they may have, and the syntax for expressing these are all the programs need as input.

SEQUENTIAL ARCHIVING SYSTEM

There are two forms of archival data produced by the asynchronous computer system, one basically dealing with visibility data, and one dealing with maps made from visibility data. They differ only in their specific content.

The sequential archive will be produced only by programs that access the asynchronous data base. Initially planned to be written on standard 9 track, 1600 bpi magnetic tapes, this sequential archive will have as simple as possible a format, largely defined in terms of what would be readable from I/O control by FORTRAN programs. Each sequential archive tape will contain a complete description of tape contents and format.

The sequential archiving of visibility data will consist mainly of completely sorted, calibrated visibility data in u-v-w order. Thus it will appear as a simple table of (u,v,w,Vreal,Vimag) data. Aside from the history and selection criteria described in the data preface for each tape, no time-baseline information is maintained with this sequential archive.

The sequential archiving of maps will consist of IQUV maps produced with data selection and map parameters chosen as "standard" by the asynchronous system or specifically chosen by the user. It is expected that a large number of VLA users will not have the familiarity with aperture synthesis mapping needed to ask for the mapping parameters exactly suited to their scientific program. For this reason a considerable amount of care should go into choosing the "standard" map parameters. A discussion of this question will occupy a large part of the rest of this memo.

A special non-standard form of sequential archive of calibrated visibility data will be produced for the users who request it. This will contain visibility data archived in time-baseline format. The production and use of data in this format will be strongly discouraged except for cases where essential to the observing program.

CALIBRATION OF VISIBILITY DATA

We are proceeding under the basic assumption that all data calibration will be carried out in the synchronous and asynchronous computer systems. The user who wishes to be involved with the calibration or re-calibration of his data must plan to do so only in the asynchronous computer system at the site, either at the time of his observing run or at subsequent re-calibration sessions.

Re-calibration done outside the time span of an observing run will begin with the data archived by the synchronous computer system.

In the special cases where a sequential archive of calibrated visibility data has been produced on tape for the user, he may choose to begin the re-calibration from this data.

The calibration carried out by the synchronous computer system is defined in terms of what can be programmed to be done in real time on the basis of current knowledge of the instrument. The early years of the VLA will hopefully see an evolution from an initial state where much of the correcting and calibrating is necessarily done in the asynchronous computer to a final state where most of this is done in real time.

At the present time it is impossible to estimate the extent to which the resources of the asynchronous computer system will be tied up with pre-synthesis processing. This depends entirely upon the reliability of the basic VLA hardware and the extent to which programmable algorithms for editing, correcting, and calibrating are developable. Depending upon these factors, the resources of the asynchronous computer will be more or less available for mapping and map analysis and display.

THE VLA DATA DISTRIBUTION SYSTEM

In addition to any graphic representations of visibility and map results obtained during an observing run with the VLA, the user will leave the site with a number of 9 track, 1600 bpi magnetic tapes. The contents of these tapes are defined as that sub-set of the data archived in the asynchronous archiving system that is desired by the user. In fact, this is the primary reason for the specification that the sequentially archived visibility and map data be "FORTRAN-readable".

It is assumed that the data tapes leaving the site will be used at other computer systems. The user will have the choice of receiving his tapes in ASCII, BCD, or EBCDIC format. Each tape will be prefaced by a complete description of the past history and contents of the tape, including all the selection criteria and parameters describing the data. It is tentatively planned to make the first file on the tape a long character string which, when read, will give a complete FORTRAN program that will successfully read the remaining contents of the tape.

POST-OBSERVING PROCESSING

It is assumed that some form of post-observing processing capability will be provided at NRAO facilities. The extent to which some of this can be provided at the VLA site is largely unpredictable until the array is in full operation and the operational needs of the VLA are decided upon.

It will be some years before we know the extent to which asynchronous computer system resources will be available for mapping and the related map analysis and display. For this reason, aside from planning interim usage of currently available equipment, we feel it would be wisest to plan the nature and kind of post-observing processing without regard to where hardware still to be purchased is located. The decision of where to carry out what proportion of what type of data processing is best deferred until we have some modicum of VLA operational experience.

Because of the need for VLA staff to be able to do anything necessary to understand the usage of the array, we are proceeding on the assumption the every type of post-observing data processing routine will eventually be developed in the asynchronous computer system. The extent to which non-VLA staff will be able to routinely use this software is a question that cannot be decided at the present time.

However, one segment of the asynchronous data processing system is the graphics system. This will be mainly used as a map display system with initially limited but expandable map analysis capability. Currently this system consists of a PDP 11/40, linked to the DEC-10, which the user controls to display results on three possible output media: a COMTAL raster scan CRT (color and black and white) with 256X256 resolution and 256 gray scale levels or 64 colors; a DEC GT44 refresh line graphics system; and a high resolution electro-static printer plotter with publication quality line plotting capability and crude gray scale capability.

This system runs independently of the DEC-10 except when it requests that the DEC-10 carry out some major computational task for it. Therefore, independent of the nature of the data processing load on the DEC-10, the graphics system will always be available to the user to display and carry out limited map analysis.

Depending upon future decisions, this system could be up-graded in capability to increase the range of map analysis tasks available to the user.

VLA MAPPING PARAMETERS

Let us now discuss the parameters of the asynchronous computer software which is being programmed to do synthesis mapping. This is a subject of great importance in future planning because of the large sizes of some of the VLA maps. It is also appropriate for a discussion of the VLA data distribution system because the primary output of this system for most users will be synthesis maps.

Our primary approach to the specification of synthesis mapping is in terms of the number of points per synthesized beam-width, hereafter refered to as NPPSBW. Because this approach has not been standard in the past, let us discuss the relationship between this parameter and the other parameters that may be used to specify the properties of a synthesis map.

Let θ = angular resolution of an aperture

λ = observing wavelength,

and D = diameter of the aperture.

Since

$$\theta = \lambda / D \tag{1}$$

then

$$\theta_{antenna} = \lambda_{cm} / 2500 \tag{2}$$

for VLA antennas and

$$\theta_{syn,beam} = \lambda_{cm} / B_{max} \tag{3}$$

for a maximum synthesized aperture in cm. Therefore we can derive a simple relationship giving the number of synthesized beam widths per antenna beam width using

Because of the fact that the standard mapping algorithm will involve the FFT which requires the NFOV to be 2 to some power, the computational NFOV, hereafter refered to as CNFOV, corresponding to this will be:

	CNFOV	
Config.	Standard Case	Full Data Case
A	2048	4096
B	512	1024
C	256	512
D	64	128

Working with these restrictions on CNFOV and u-v coverage, one can then choose one more FFT mapping parameter. This parameter is either the actual field of view, hereafter refered to as FOV, on the sky, which one wishes to map, or the NPPSBW.

It should be noted that none of the above considerations involve sampling or, in fact, any specific formula for antenna aperture or synthesized aperture. One only assumes that BOTH antenna beam width and aperture beam width are defined by the same formula.

One cannot derive the FOV from CNFOV and NPPSBW, or NPPSBW from CNFOV and FOV without making specific assumptions about sampling or the type of beam width.

We assume that all algorithms based upon an FFT will involve gridding corresponding to sampling both u and v at the one-dimensional Nyquist sampling rate. Considering the u and v cases to be equivalent,

$$du = dv = 1/(FOV\ nu) \qquad (5)$$

where FOV is the diameter of the field to be mapped in radians and nu is the observing frequency.

Using u_{max} to describe the radius of the synthesized aperture used in mapping, the diameter of the synthesized aperture is $2u_{max}$. The numerical field of view, NFOV, is then given by

$$\theta_{antenna} / \theta_{syn.beam} = 40\, B_{max}\ (km)\ . \qquad (4)$$

In discussing the u-v coverage used in synthesis mapping, we will consider two simplified cases. The standard case will be assumed to be that where B_{max} corresponds to the arm length; therefore only a circular central portion of the actual u-v coverage is used in the map. The other case will be where B_{max} corresponds the largest separation of antennas.

For the standard case, the four VLA configurations give:

Config.	B_{max} (km)	$\theta_{antenna}/\theta_{syn.beam}$
A	21	820
B	6.4	256
C	1.95	78
D	0.59	24

while for the case where all available u-v data define the synthesized aperture:

Config.	B_{max} (km)	$\theta_{antenna}/\theta_{syn.beam}$
A	35	1400
B	11	440
C	3.4	136
D	1.0	40

Therefore, if we ask for the NPPSBW to be exactly 2, the numerical field of view, hereafter refered to as NFOV, is given by

Config.	NFOV Standard Case	NFOV Full Data Case
A	1600	2800
B	512	880
C	156	272
D	47	80

$$NFOV = 2 u_{max} / du \qquad (6)$$

which now allows us to relate NFOV and FOV through the relation between du and FOV. Therefore,

$$NFOV = 2 u_{max} nu FOV \qquad (7)$$

Noting that $u_{max} = B_{max}/c$, and taking $FOV = \lambda_{cm}/2500$ corresponding to an antenna aperture, this reduces to

$$NFOV = 80 B_{max} (km) \qquad (8)$$

which is equivalent to eqn.(1) expressed in terms of two points per synthesized beam-width. We conclude that the assumption of u-v plane gridding at the Nyquist rate for maps made over one antenna resolution width results in two grid points per synthesized beam in the synthesis map.

Note that if we had used

$$FOV = 1.22 \lambda/D, \qquad (9)$$

the usual formula for a circular aperture, we would have obtained a different numerical factor in the formula (eqn. 8) relating NFOV and B_{max}. We conclude that the use of the one-dimensional Nyquist sampling rate to determine du together with thinking of the antenna beam as a two dimensional circular aperture, can lead to an extra factor of 1.22. Examining the origin of this, it comes down to using different formula for the resolution width of an aperture in the antenna and synthesized aperture cases.

Let us now use the following standard formulas,

$$du = dv = 1 / (FOV nu) \qquad (10)$$

and

$$NFOV = 2 u_{max} FOV nu \qquad (11)$$

to continue our discussion of the relationships between CNFOV, FOV, and NPPSBW.

It should be emphasized that it is the power of two limitation of the computational numerical field of view, CNFOV, that gives values of NPPSBW that differ from 2. Given an arbitrary NFOV and an arbitrary CFNOV,

$$NPPSBW = 2\ CNFOV/NFOV, \qquad (12)$$

and using equation (2) for the FOV and eqns, (10)-(11),

$$NPPSBW = 0.025\ CNFOV/B_{max} \quad (km) \qquad (13)$$

We will now discuss two of the most logical algorithms for arriving at mapping parameters, We will call these two algorithms CASE A and CASE B,

************* CASE A ***************

The observer specifies $CNFOV = 2^n$ and FOV in radians, Then

$$du = dv = 1/(FOV\ nu) \qquad (10)$$

and

$$NPPSBW = 2\ CNFOV/NFOV = CNFOV/(u_{max}\ FOV\ nu)\ , \qquad (14)$$

Taking the values of CNFOV for the various configurations discussed earlier, one obtains for the "standard" case where B_{max} = maximum arm length, and for the full data case where B_{max} = maximum antenna separation:

Config,	Standard Case		Full Data Case	
	CNFOV	NPPSBW	CNFOV	NPPSBW
A	2048	2,56	4096	2,93
B	512	2,0	1024	2,33
C	256	3,28	512	3,76
D	64	2,72	128	3,2

**************** CASE B ********************

Alternatively, the observer could specify $CNFOV = 2^n$, NPPSBW, and either the standard or full data case to get maps with fields of view given by

$$FOV = \lambda \; CNFOV \; / \; (NPPSBW \; B_{max}) \qquad (15)$$

so that for NPPSBW = 2,

Config.	Standard Case		Full Data Case	
	CNFOV	FOV/λ	CNFOV	FOV/λ
A	2048	1.76'	4096	2.01'
B	512	1.38'	1024	1.60'
C	256	2.26'	512	2.58'
D	64	1.87'	128	2.20'

Keeping in mind that that the HPBW for the VLA antennas is roughly 1.7' λ, the above table indicates that in most cases the field out to the HPBW or more is mapped.

We conclude that CASE B is probably preferable to CASE A for a "standard" map product because the relation between the size of a point source and the basic cell size in the map is then independent of any parameter specification.

Summarizing what seem to be the best choices for "standard" map parameters, any of which can be altered by an observer's choice, we will take

B_{max} = maximum arm length

NPPSBW = 2

so the "standard" maps for the four regular configurations will be:

"Standard" Maps

Config.	CNFOV	FOV/λ
A	2048	1.76'
B	512	1.38'
C	256	2.26'
D	64	1.87'

The fact that certain map parameters will be viewed as standard will not alter that fact that the observer may request and receive output maps with different parameters. For example, by asking for twice the standard NFOV he can synthesize essentially twice the HPBW if he is worried about sources aliasing into his maps. By doubling both CNFOV and the NPPSBW he can obtain maps with improved capability to fit or subtract point sources.

However, to avoid over-loading the asynchronous system un-necessarily, it is hoped that ONLY MAPS INTENDED FOR TAPE DISTRIBUTION will exceed the "standard" sizes. Most of the maps being prepared, displayed, and analyzed will then be limited to the standard sizes.

SUMMARY

The output of the asynchronous computer system that the user will take away from the site will be FORTRAN-readable, sequential, 9 track magnetic tapes. Normally this will mean a tape of calibrated, ordered (u,v,w,Visibility) data for his sources and a tape containing maps with either the standard parameters or parameters chosen by himself. In special cases a tape of (time,baseline, Visibility) data may also be supplied.

The only form in which data in (time, baseline) format will be archived on the site is initially planned to be the data tapes written as part of the output of the synchronous computer system. This initial plan may be modified upon the basis of experience.

There will be two archives maintained by the asynchronous computer system. One will be a sequential archive of sorted, calibrated visibility data identical to that provided to the user to take away from the site. The other will be a sequential archive of the maps identical to that provided to the user leaving the site. This is based upon a desire to make the archiving and distribution system essentially the same so that non-contiguous observing runs can be easily merged together as needed.

The amount of re-mapping and post-observing analysis that will be possible in the asynchronous computer system will remain unknown for at least a couple of years. However, an independent map display system with limited map analysis capability does exist in the system. Therefore, independent of the nature of the computational load on the DEC-10, this capability will always be available to users.

Most of the archiving and distribution programs are still to be implemented so changes are possible if desirable. Suggestions and opinions from others about this planned system would be very helpful.