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INTERACTIVE GRAPHICS ON THE VLA PIPELINE

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The main objective of the VLA Pipeline System is to provide the mapping throughput necessary to operate the VLA at full efficiency, including the full spectral line capacity designed into the hardware. The most important factor governing its throughput is obviously the computer capacity as measured in I/O bandwidth and in compute cycles. The major concern in the design of the pipeline has been to provide this capacity, however this alone is not enough to make the pipeline successful. If the pipeline is to have its full impact on the amount and the quality of science done with the VLA it also has to be one of the astronomers tools. It will have to be able to cope with less than perfect data. It must have the flexibility to perform the kind of mapping functions desired by the astronomer based on his assessment of the data and his objectives. Finally it must enable him to select a subset of data to take away for further analysis. This subset should contain all the relevant information but be sufficiently reduced in volume to take away on a reasonable number of magnetic tapes. For example a spectral line observer should be able to see the full field observed in all of the channels observed with all significant instrumental errors removed before he has to make the (unfortunately) necessary decision to reduce the database until it only contains the object of interest. If the VLA cannot meet objectives such as these we severely limit our chance of making new discoveries and we will be removing a critical segment of the research path in which the astronomer should participate.

To meet these objectives we have some additional requirements on the pipeline. The only way for an astronomer to inspect all the database is by visual 2D (or 3D) display. The only way in which he can respond fast enough to change mapping strategy without plugging up the pipeline is to provide interactive links between these displays and the pipeline functions. The following proposal indicates the kind of functionality and sketches some possible solutions. These solutions will have to be further developed in context of the rest of the pipeline in order that they do not comprise the main objective of obtaining the necessary throughput.

1. MAP PLANE

(a) Map display.

We must be able to inspect all the maps being produced by the pipeline. The I^2S display system already ordered, especially in conjunction with the Escoffier image storage box can do this.

(b) Windowing.

The astronomer must be able to select a subset of his data for output on tape and further post processing, after visual inspection of all of his data. This reduction in the size of the database is necessary to reduce the amount of output and the further processing requirements to manageable levels. The reduction in size of the data base can be achieved in a number of ways:

(i) Limit the spatial area to the object (or objects) of interest. This is easily done by two dimensional windows using the display and interaction device.

(ii) Limit the number of frequency channels to the minimum containing useful information. This could be done by displaying and windowing data sorted into space-frequency planes, however this may place an unacceptable drain on the capacity of the display system. The more practical method would use the Escoffier image storage device and a cinematographic display. Separate display of individual channels is not acceptable since features near the noise level which would not be recognized in individual maps are easily recognized by their continuity in adjacent channels. Once the channels which contain signal have been recognized the remaining channels can be combined to form the continuum.

(iii) Optimize the resolution and number of points per beam. This includes the making of new maps with different resolution, smoothing in velocity channels, and the more complex operations such as defining a set of channels outside the line to make a smaller number of broader band continuum channels for final output.

(iv) Discard the UV plane data. This will only be possible if data quality can be judged to be acceptable at this stage of the processing since some instrumental information is lost in the mapping process. High quality data display software and hardware are necessary to make this decision.

(c) Map Analysis

Although it is not the intention to do substantial amounts of data analysis in the map plane a few functions are needed to enable the astronomer to make efficient use of the pipeline. These would include: the statistical analysis of a specified region in a map (mean, rms and amplitude distribution functions), simple point source estimation programs to determine the parameters necessary for a point source subtraction from the ungridded data, and perhaps some simple map combination algorithms.

(d) Hard Copy

Hard copy of the maps in addition to the magnetic tape output are important for working on. We have a number of possibilities:

(i) Grey scale copies of the image display. This can be obtained using the gray scale copier now on order. This copier works directly from the monitor output, is fully interactive and requires no software development or host capacity.

(ii) High quality images can be written by the Dicomed image recorder. This has the advantage of high capacity and good quality; for example 64 512^2 images can be recorded in pseudo-color on one film sheet with no loss in resolution. The demand for this type of output is not presently known. It might be very useful for astronomers to carry away all their data in one pocket and to be able to look at it with a microfiche reader, instead of having a stack of eight high density tapes and using a fairly large post processing system to look at it!

(iii) Line graphics, for example contour maps from the Versatec. Although these are a very inadequate way to convey a lot of information about the image they are essential to provide quantitative information about smaller regions in the image.

(iv) A video tape recorder may find limited use.

2. VISIBILITY PLANE

(a) Visibility display.

Effective editing and control of data processing require rapid display of the visibility data. Since there is about as much of this as map data we have another formidable display problem. While lineprinter type outputs (eg LISTER) are very useful for some special purposes I consider them as a totally inadequate solution to this problem. Display of visibility data presents at least two additional problems. The data is complex and at least two different coordinate systems are necessary; the instrumental (baseline, time, frequency) coordinates, and the sky related (U,V,W) spatial frequency system. The display of complex quantities can be tackled by independent display of amplitude and phase (or sin and cos) but this is particularly poor for low signal to noise regions since the phase may become a random number for small amplitudes and yet the data quality will still be excellent. An intensity-hue algorithm has been developed for the I^2S display in which independent control of transfer functions for intensity and hue are implemented. This would make it possible to interactively adjust the transfer function to map the important range of amplitude into intensity and the important range of phase into hue. Vector-graphic displays can also play an important role here although they may have inadequate capacity for conveniently displaying the entire visibility plane. Useful vevtor-graphic displays could range from interactive 3D displays to simple two dimensional plots on the Versatec. The nature of the visibility plane axes presents further problems. Some patterns are only contiguous, and hence easily recognized, in the baseline time display while other systematic sky based structures will only appear in the UV coordinate display. Both are needed.

(b) Diagnostic use of map and UV plane Fourier transform pairs. I hope the average quality of data will be sufficient to justify going directly to a map, so that if no significant errors are seen no editing will be needed. After all it is only significant errors in the <u>map</u> plane that really matter. When errors are apparent the user should be able to inspect the Fourier transform of a section of his map as a diagnostic probe. For example consider a map with low level stripes: a region showing strong errors can be isolated, the obvious sources in the map excluded (or a suitable clean residual map used), and a Fourier transform taken to find the cause of the stripes. If the original visibility data were used for this the field sources could obscure the error. This Fourier transform of the map should be readily displayable and a fairly straight-forward algorithm developed to interpret the error (which will now be confined to well defined region in the visibility plane) in terms of the correlator and the time.

(c) Baseline-time display

In some cases it will be important to inspect the visibility data in the baseline-time domain. Raw data in this form is not readily accessible in the pipeline but the Brouw mapping package has options to take the sorted visibilities and to grid them back into a baseline-time format with the same structure as a map. Since this has the map format it is readily accessible by the display system. In such a display correlator errors could appear as horizontal stripes and temporal fluctuations (for example interference) as vertical stripes. With this display the interpretation in terms of correlators and time would be obvious and could be determined using the cursor and interaction device.

(d) Calibration and Monitor Data Display

As an aid to the initial calibration visual inspection of calibrated visibilities and the monitor data base may be useful. Display of the antenna-based gain solutions would also be important. Although the baseline-time gridded calibrator data displayed by an image system could be used, vector-graphic displays are clearly more suitable for these functions. Initially this could be provided by using the Versatec plotter with improved plotting algorithms. For example we could easily plot all antenna-based solutions on one Versatec page. It is unclear to me to what extent these displays should be incorporated into the pipeline since their relevant data bases are available in the DEC10. I will return to this point later.

3. CONTROL

(a) Function

As a result of inspection of the data the user may need to vary the parameters and sequence of tasks in the pipeline. For example a map display should be used to obtain the clean windows and the map statistics used to determine suitable levels to stop the iteration process. Mapping resolution, field of view and point source subtraction parameters will be set in response to map inspection with the display system. The required information to make these decisions is best obtained at the display station. It then has to be made available to control the pipeline.

(b) Data Editing

Information about data errors will be easily found using the pipeline displays. This information also has to be made available for use by the mapping (and perhaps calibration) programs. For example after inspection of the baseline-time visibility data it may become obvious that all baselines are effected by interference in a well-defined time range. The astronomer should be able to interactively specify this indow and the system should generate the necessary flag files for use in the next run of the mapping program.

(c) Tape Output

The astronomer should have a chance to see the final product before committing it to the tape on which all his further analysis will depend. Consequently it is logical to put the main FITS tape writing functions at the display stage. The astronomer should be able to use windows obtained interactively from the display to set the parameters for the map writing program.

4. ARCHITECTURE

How do we meet the preceding objectives, and provide a good user environment, with the hardware and software structures being developed? The main difficulty I have in visualizing this involves the role of the DEC10 relative to the pipeline minicomputers. To clarify the following discussion I have made the following assumptions about the architecture.

(i) I assume in the production system that all data will go to the pipeline and that a copy of the calibration data and at least a description of the source data base will go to the DEC10.

(ii) The most obvious user access to the pipeline is via the DEC10, simply because it has the capacity and the number of terminals required to handle the many users who will be running their data through the pipeline.

(iii) The DEC10 will be used to obtain the antenna-based calibration using essentially the present software.

(iv) The displays will have to be on the PDP's, both for interfacing convenience and to avoid impossible I/O demands between the pipeline and the DEC10. Hence display based user interaction must occur on the PDP's.

(v) Initiation of tape writing and tape monitoring are most conveniently done on the PDP with the tape unit.

(vi) Monitor data bases are only accessible from the DEC10.

(vii) The users' environment should involve as few different computers as possible.

(viii) The reliability of the system will be increased if we can decrease the total number of computers involved in any transaction.

If all these assumptions are correct the conflicting requirements become clear and I do not see a perfect solution. The following proposal passes the control of the pipeline from either the DEC10 or the PDP's.

(a) Hardware

Figure 1 sketches a possible configuration and table 1 describes the hardware which is additional to that currently being developed in the pipeline. The display system is based on the PDP11/44 (the upgraded 11/40). It should drive the I^2S (eventually two?), the Versatec plotter, the tape unit, and have inputs from at least one terminal and a user interaction device. The image storage unit is interfaced directly to the I^2S (see Escoffier's memo) and the gray scale copier is interfaced directly to the I^2S monitor. The preferred user interaction device is a control panel currently under design. This will also interface directly to the I^2S. In order to avoid serious additional I/O and storage requirements the 11/44 display system should have read-only access to a dual port disk on GRIDDER. Files with control and editing information will be passed between the PDP's and the DEC10 using the DECNET links.

(b) Software

(i) Location

The I^2S, the image storage device, the Versatec driver, and FITS software all reside in the 11/44 display. Some non-interactive software, or at least the user interface to this software, could be put in the DEC10. This could include: Versatec plotting programs, and line- printer listing programs.

(ii) Control

Control files generated interactively in the 11/44 display would include: mapping parameters, database selection parameters, self-calibration models, clean windows, etc. Most of the software needed to initiate these pipeline jobs already exists in the DEC10 and communicates to the pipeline via the MAPCON system. Although it would be possible for the 11/44 display system to communicate this information back to the DEC10 for incorporation in the jobs submitted from the DEC10 to the pipeline this is a cumbersome procedure and would be less reliable since at least three computers would have to be operating. The alternative is to duplicate in the 11/44 the software necessary to submit jobs to the pipeline via MAPCON. This user interface could be made almost identical to the DEC10 software by making a PDP11 version of the command scanner. Additional features should be added to the command scanner to make use of the interactive graphic devices.

Figure 2 is a functional sketch showing how the astronomer would be able to control the data reduction. The insert in the top right of each box indicates whether that program runs from the DEC10 the PDP or both.

(iii) Editing

Editing files will be made by the display system. A minimum requirement is to produce a file which includes the current level of index record flagging (ie antenna-based flags per scan). This could either be sent to the DEC10 to be included in the DEC10 side flagging files (a SAVE file for use by FLAGER would do), or sent directly to GRIDDER to be logically OR'd with the normal flag file. An additional correlator based flagging file should be developed. Brouw's mapping programs already have the relevant hooks. To keep this file down to a manageable size it could be restricted to scan level flagging without serious loss of flexibility.

(iv) Interactive Control of the Pipeline

With the speed of the pipeline mapping functions, especially in the continuum case, it would be convenient if the pipeline jobs could be controlled from the computer with the display. However this would involve a much more significant development of control software in the pipeline, and would constitute a change in the philosophy of the whole system. I propose that such a development is not pursued at present and that before embarking on this kind of change we rethink the pipeline goals and the relationship of the DEC10 to the other minis as part of our longer range plan.

TABEL 1 PIPELINE DISPLAY HARDWARE

DEVICE	TYPE	DESCRIPTION
Image display	I^2S-70E	2 512 x 512 image planes, graphic overlay, and cursor
Grey scale copier	Honeywell VGR/4000	Grey scale hard copies from the video image signal
Image storage	NRAO	Storage for 128 512 x 512 maps with film loop playback capability.
Control panel	NRAO	Potentiometers and switches to control the display tables in the I^2S.
Dot Matrix Printer	Versatec	Hard copies of line graphics.
Image recorder	DICOMED	64 512 x 512 color images onto film.