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IMAGE CONSTRUCTION AT NRAO

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In this document I will propose that NRAO set up a small research group to study problems of image construction in radio astronomy. By image construction I mean the conversion of observed data into images of the radio sky with parameters position, frequency, and time; therefore such work is logically distinct from image processing by which I mean the display and analysis of images.

NRAO should be interested in image construction methods because of their impact in wide range of applications. Some examples are:

1. The CLEAN algorithm has improved the dynamic range of most synthesis arrays. In the case of the VLA, the dynamic range of a CLEANed snapshot map (~20dB) is comparable to or exceeds the dynamic range for a full track required in the original specification for the VLA.

2. Selfcalibration has improved the dynamic range of VLA maps by 10-20 dB. In VLBI mapping was impossible prior to hybrid mapping.

   The success of CLEAN and selfcalibration is such that the design of interferometer arrays is affected.
3. Other techniques, similar to selfcalibration, have allowed WSRT to produce a map of 3C84 at a dynamic range of ~45dB (peak/noise).

4. Very accurate beam deconvolution has produced maps from the Effelsberg single disk telescope with dynamic range ~40dB.

5. "Basket weaving" has alleviated the baseline drift problem in single dish mapping.

6. Multiple beams in single disks have helped overcome atmospheric effects.

7. In VLBI fringe-rate mapping allows the mapping of point sources spread over a large field of view.

8. MEM has been used to combine single disk data taken in scans at different position angles.

Besides these new developments in radio astronomy many new techniques have arisen in other wavelength bands. For example, the Maximum Entropy method of image construction is ubiquitous in X-ray imaging.

Purely from our experience in radio astronomy we can see that image construction techniques have greatly expanded the capabilities of our telescopes. In this respect they are just as important as, say, low noise receivers or broadband correlators. However one major difference between the hardware and the software is that the latter is often poorly engineered and understood. Indeed, as the following partial list of the shortcomings of CLEAN and selfcalibration should indicate, our understanding of software is often unacceptably limited:

CLEAN
- no known noise analysis
- no uniqueness criteria
- algorithm and user dependent answers
- can produce spurious features even although it is always stabilized by convolution with a clean beam
- answers do not fit the data from which they were derived
- inefficient for extended emission

Selfcalibration
- no known noise analysis (depends upon noise analysis for CLEAN)
- uniqueness not understood
- algorithm and user dependent answers
- relative effectiveness for one and two dimensional arrays not known
- can get spurious sources for low S/N.

This list of deficiencies should amply illustrate the point that the performance of these two image construction methods would not meet any reasonable specification. These criticisms are not merely academic but have a serious impact upon the interpretation of any CLEANed or selfcalibrated map as would be produced by any array. Following this last concern further, I note the following subjects:

- Can we use better deconvolution algorithms than CLEAN? If so, how much super resolution is reliable?

- Can we interpolate short spacings reliably? See Rots' proposal.

- What distribution of spacings in an array is desirable? For example, how can we best discriminate between the possible VLBA configurations. Some people have proposed answers but, in my opinion, no reasonable approach has been put forward. Any answer should be linked to the behaviour of CLEAN and selfcalibration.

- What is the best way of synthesizing u, v plane coverage with a broadband interferometer? Again, the answer depends upon image construction algorithms.

- Can we develop reliable, robust algorithms for removing interference from data? This is critical for low frequency broadband arays. Any algorithm should use a prior knowledge of source structure.

- Can we use models for the atmosphere in selfcalibration to help cope with non-isoplanatism or low signal to noise?

In connection with the analysis of data taken by present or proposed NRAO single disks I put forward the following examples of areas of research:

- Is beam deconvolution useful? Are the NRAO dishes stable enough? What is the best algorithm?

- Can we combine inhomogeneous single dish data sets e.g. different scan angles?

- A large variety of reasonably well-understood spectral estimators exist. Are these useful in spectral line work? The assumptions implicit in some estimators (eg. AR modelling) are valid in certain astrophysical situations.

- Should we use multiple beaming?

- What are the best methods of baseline removal?

I believe that I have demonstrated above that the present and future use of NRAO telescopes depends heavily upon image construction methods. Consequently, concentrated research in this area is essential for the efficient use of both present and proposed NRAO telescopes. Finally, I note that in this whole area cross-fertilization with other disciplines such as medical imaging should be very fruitful.

TC/bmg