NOTE 219 – AIPS++ Mosaicing development plan

Tim Cornwell

Draft 1997 April 30

Contents

1 Purpose

This document describes a phased plan to realize the Mosaicing specifications as described by Holdaway *et al.* (AIP++ Specification memo 120) (hereafter HSCR). The concentration here is on the grouping of work to be done. For any necessary clarification of the definition of the work, see HSCR.

2 Current status

`sky` currently (April 1998) provides simple mosaicing capabilities. Specifically, the program can correct for VLA and WSRT primary beams in either a linear mosaic or via a clean-based algorithm. In the clean-based algorithm, the minor cycles are performed using an average PSF, and major cycles using the fully correct PSF (including any time-variation). Both these capabilities result from an initiative to demonstrate that the synthesis framework is capable of supporting mosaicing data reduction.

A significant design decision in `sky` is that all deconvolution is performed inside `sky`. This is contrary to the model used in Miriad mosaicing, whereby the dirty image, PSFs and primary beams are written out and processed separately in another program. The rationale for the choice not to do this in *sky* is that the ancillary information (arising from the MeasurementSet) that must be carried along may be quite complicated (internally the VisibilityIterator class is used to encapsulate this information).

Other points relevant to HSCR:

- The SkyEquation formalism naturally decomposes primary beams into antenna-based terms, as desired in HSCR.

- Tracking of *e.g.* solar system objects is available via the Measures system.

- The calibration object, `cal`, knows nothing about mosaicing: all prediction of model visibilities is done by `sky`. Visibility-plane calibration is thus independent of whether or not the data are mosaiced. This means that the forms of visibility-plane calibration envisaged by HSCR should be straightforward to implement. The exception may be derivation of a relative calibration between single dish and interferometric data.

- The one key capability yet to be developed fully and demonstrated in the synthesis framework is the solution for image plane-based calibration effects such as non-isoplanicity or pointing errors.

- Optimization of performance and disk space usage will continue to require special attention. One strategy advocated by Sault, Staveley-Smith and Brouw is to grid at a fixed wavelength (thus implying frequency-scaled uv and sky position coordinate systems). This would reduce the disk space needed for scratch images such as the transfer functions at the cost of causing problems elsewhere with a non-physical coordinate system.

- The advent of image regions will also help performance since currently the entire model image is transformed even if the primary beam covers only a fraction of the image.

3 Phase I: Improve sky

To build on the current capabilities of `sky`, we need to do the following:

- Rework the existing PBSkyJones class hierachy to allow the types of PB models described in HSCR. In this phase, we will only allow PBs with known form. Solveable primary beams will come later.
- Optimize the use of FFTs in the Gridded transform (class GridFT) to avoid FFTing regions outside the primary beam model.
- Post-deconvolution primary beam correction, both single field and multiple field.
- Provide different deconvolution methods:
  - inverse and Wiener filtering (including production of the effective uv coverage *i.e.* the FT of the average PSF).
  - SDI-CLEAN
  - MEM using Cornwell-Evans algorithm (as modified by Sault)
- ComponentModel processing should be optimized and extended to include a number of effects such as time and bandwidth smearing.
- Wide-field imaging and mosaicing should be decoupled. A wide-field image will be constructed from a number of facets cleaned simultaneously. The SkyEquation mechanism will automatically apply the correct primary beam correction to each one. Sault, Staveley-Smith and Brouw show that the correction to place different facets on the same ultimate tangent plane can be performed by the appropriate rotation of the uv data during the gridding and degridding steps. This should be put into place in UVWMachine, and then `sky` changed to make the appropriate facet images. The missing ingredient is a simple facility to insert the facets into a final large image.

A suitable concluding milestone for this phase would be to able to make mosaics from a very large spectral-line mosaic dataset from WSRT. Another milestone would be to correct known assymetries in the primary beam model *e.g.* the VLA primary beam squint when observing circular polarization on the Sun.

4 Phase II: Develop Single Dish OTF imaging in sky

Single Dish On-The-Fly data reduction can be accomplished using the SkyEquation formalism but to acheive satisfactory performance when imaging only OTF data, some changes may be required. In particular, a different version of SkyEquation::gradientsChiSquared is probably necessary since a Fourier transform is not required. In the case of mixed single dish and interferometric data, the current gridded transform machine should be adequate.

An important dependency is that MeasurementSet V2 is needed in order to hold OTF data in a reasonably compact form.

A concluding milestone would be to construct an OTF image from 12m spectral data.

5 Phase III: Simulation capability

Once the changes above have been made, we can move on to develop a simulation capability using the tools refined in the previous work. Specifically, the SkyEquation can be used to provide transforms of models, and the refined PBSkyJones can be used to implement various primary beams in the mosaicing.

I suggest that the simulator be a separate object, with an interface similar in spirit to that of `sky` *i.e.* tending towards atomic, low-level operations rather than high-level operations.

VisJones classes for simulating additive noise and gain errors now exist and are used in the current simulator. Some work is needed on an interface for defining observing patterns (such as mosaicing sequences).

Part of the simulation tools should be devoted towards examining the three measures of accuracy of reconstruction described by Cornwell, Holdaway and Uson (1992):

Dynamic range : Peak on-source brightness divided by rms off-source rumble.

Fidelity : Median of on-source brightness divided by error in reconstruction.

Visibility SNR curve : Radial average of visibility divided by rms error in reconstruction.

A concluding milestone would be to simulate a simple mosaiced observation from one of the consortium telescopes, and make an image using sky, and evaluate the imaging performance. As a check on performance, the simulation should be done for separate time-variable pointing errors per antenna.

6 Phase IV: Mosaicing tools

There is a need for a number of basic tools for aiding mosaicing.

- Summary of a mosaic observation, both textual and graphical.
  - Display pointing centers graphically. Possibly overlay with *e.g.* spectra, or visibility curves.
  - For any given point in an image, display which pointings (field-ids) are relevant (and with what weight).
- Selection tools, textual and graphical.
  - Based on field-id, *etc.*
  - Based on proximity to a given point on the sky
  - Based on data criteria *e.g.* peak visibility
- Weighting tools to control the weighting of various parts of the mosaic.
  - tools to show effect of weighting on sensitivity and beam shape
  - relative weighting of interferometric (*i.e.* sensitivity-based or sidelobe-minimizing
  - relative weighting of SD and interferometric data

7 Phase V: Advanced mosaicing tools

Development of advanced mosaicing tools will require the simulation capabilities and tools developed in phases III and IV.

- On-the-Fly interferometric imaging. The computational load seems to be immense but the formalism should handle this adequately.
- Adaptive weighting of data during the deconvolution process.

- Calibration determination between SD and interferometers by, for example, regression in the overlap region of the uv plane. Bob Sault has done work in this area that we should emulate.

- Self-calibration for Primary beam parameters such as scaling of the PB (*e.g.* probably adequate for WSRT UHF feeds?), and pointing offsets. This is simpler for componentmodels and should be done that way first. Note that if done correctly, non-isoplanatic imaging should be a special case. By using bright sources at known positions, one can determine antenna- and sky position-dependent gain terms (phases in the non-isoplanatic case) on the bright objects, and then take these phases into account when forming an image of the residuals. In this way, a corrected image of the entire field can be formed. The next step is to extend this to the emission modelled by images (not just the componentmodels).

8 Scheduling

The phasing is not strict. Phase I and II can proceed concurrently. Phases II, IV can be interchanged. Phase V obviously must come last.

I'd estimate phases I-IV are several FTE-months of effort each. Phase V is probably substantially longer, maybe 6 months. Hence the entire effort is probably 18-24 FTE-months. Phase II should be done by someone familiar with OTF data, phase III requires a moderate but not sophisticated understanding of interferometry, and the other phases require someone with a deep understanding.