Imaging Pipeline Software

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Math705 Research Project

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Abstract

An imaging pipeline for Image Synthesis is designed to take data either gathered by radio interferometry telescopes, or generated to simulate those telescopes, and form an image of an area of the sky. This software will be similar to that which will be used for the Square Kilometer Array, a project that AUT is involved in, where the same processes will have to take place.

This project will follow a Design Science methodology where software will be the generated artefact used to experimentally investigate image synthesis. The project will start with the gathering of knowledge on the techniques used in an imaging pipeline. It will also involve gaining knowledge on solutions to complications such as concurrency control and the mapping of visibilities to a grid. Then the project will involve implementing the techniques in the form of a Java program and then will be tested using visibility input data available in the High Performance Computing Research Laboratory. The software will be testing against other pipelines and changes will be made to try to improve its performance.

The output from the developed software, using visibility data as input, will be an image of the sky. The images produced by the pipeline will be analyzed to compare it against the known sky images for the data sets to validate whether the techniques are implemented properly and potentially look at its performance.

It is expected that an imaging pipeline will be developed with the capability for image synthesis. Also expected to gain knowledge in the three main steps involved in the pipeline, namely gridding, (inverse) Fourier transform, and deconvolution, as well as some techniques for algorithm optimization.

Keywords:

Acknowledgements

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1. Introduction

## 1.1 Aperture Synthesis

The resolution of radio telescopes can be increased by using pairs of telescopes (baselines) and taking the product of the received signals. This resolution can be changed by increases the separation of the baseline, rather then increasing the size of the individual telescopes. This method popularized by the work of (Ryle & Hewish, 1960) states that using these baselines it produces “exactly the same result as that obtained by using the complete large aperture”. This technique allowed for cheaper production of much larger apertures and the eventual development of the techniques used now.

These techniques gather Fourier domain data in the form of a visibility, however the way in which they are sampled is non-uniform, so we must place it on a rectangular grid. This process is known as gridding and the methods used now are based on the work by (Brouw, 1975). These visibilities V(u,v) fall upon the plane in which the baselines are setup, for a wider coverage of this place more baselines can be added and could also be moved around.

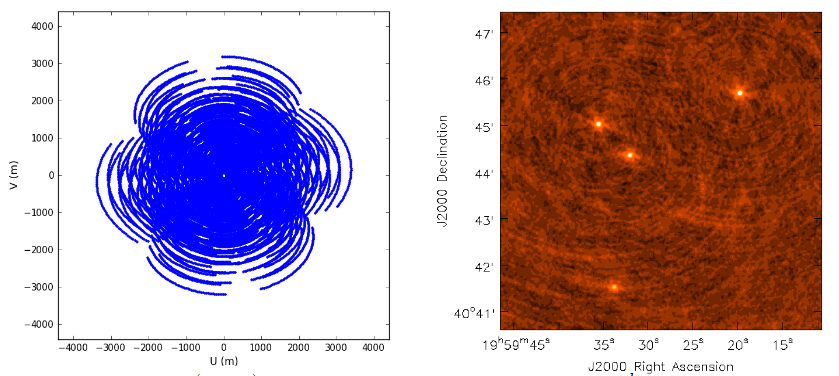
With more modern telescopes being developed, moving them around became a substantial task and instead the rotation of the earth can be used to move these points around the plane. An image of these points on the V(u,v) plane can be seen on the left of Figure 1.

Figure 1. V(u,v) plane showing data points. (Rau, 2012) Retrieved from Australian Telescope National Facility, from https://www.atnf.csiro.au/research/radio- school/2012/lectures/tue/RVU\_ImagingDeconvolution.pdf

## 1.2 Fast Fourier Transform (FFT)

A Fourier Transform is a process for signal-processing and analysis. (Brigham, 1988) states that the extent of the use the process is as follows “biomedical engineering, imaging, analysis of stock market data, spectroscopy, metallurgical analysis, nonlinear systems analysis, mechanical analysis, geophysical analysis, simulation, music synthesis”. It is widely regarded as one of the most important algorithms based on its impact in so many areas. Simply put a Fourier Transform is used to show different parts of a continuous signal, however for Interferometry an Inverse FFT (iFFT) is used as we are combining the amplitude and phase of the signal to form an image. For the performance of the pipeline an inverse Fast Fourier Transform will be used. Using such a method is based upon the work of (Hogg, MacDonald, Conway, & Wade, 1969). The algorithm used was first discovered by Gauss and later rediscovered by (Cooley & Tukey, 1965) which also notes that “Wherever possible the use of N = r^m with r = 2 or 4 offers important advantages” which impacts the design of the pipeline.

## 1.3 Gridding

Early techniques for places the visibility data on a grid involved placing the visibilities upon the closest grid point that aligns with the plane on which they were gathered and either adding then all together or averaging them out. Early methods where used by (Hogg, MacDonald, Conway, & Wade, 1969). However, this led to artifacts forming and therefore a limited application for the process. An alternative method was first used by (Brouw, 1975) and would take a weighted value based the distance between local grid point and the point of the visibility. This technique was improved upon by (O'Sullivan, 1985) with his gridding algorithm that was “computationally efficient” and resulted in “arbitrarily small artifact levels”.

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## 1.4 Deconvolution

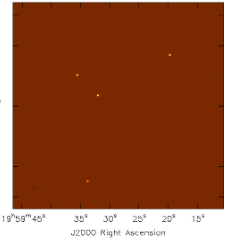
Once an image is formed from the Fourier Transform is it called a ‘dirty image’, as seen in Figure 1, this is due to the effects of having limited sampling of the V(u,v) plane. The process of Deconvolution can be used to ‘CLEAN’ the image. One example of this from (Cornwell & Bridle, 1996) is an iterative process that assumes that the real image can be made up of “small number of point sources in an otherwise empty field of view”. This ends up with the real sky image. An example of this can be seen in Figure 2, where the ‘dirty image’ from Figure 1 has been ‘CLEAN’ed.

Figure 2. Real image after it has been iteratively ‘CLEAN’ed. (Rau, 2012) Retrieved from Australian Telescope National Facility, from https://www.atnf.csiro.au/research/radio- school/2012/lectures/tue/RVU\_ImagingDeconvolution.pdf

2. Methods

3. Results

4. Discussion of Results

5. Conclusion

**References**

Brigham, R. O. (1988). *The Fast Fourier Transform and its Applications.* Prentice-Hall.

Brouw, W. N. (1975). Aperture Synthesis. In C. De Jager, & H. Nieuwenhuijzen, *Image Processing Techinques in Astronomy* (pp. 301-307). Dordrecht: Springer.

Cooley, J., & Tukey, J. (1965). An algorithm for the machine calculation of complex Fourier series. *Mathematics of Computation*, 297-301.

Cornwell, T., & Bridle, A. (1996). *Deconvolution Tutorial*. Retrieved from National Radio: https://www.cv.nrao.edu/~abridle/deconvol/deconvol.html

Hogg, D. E., MacDonald, G. H., Conway, R. G., & Wade, C. M. (1969). Synthesis of Brightness Distribution in Radio Sources. *Astronomical Journal*, 1206-1213.

O'Sullivan, J. D. (1985). A Fast Sinc Function Gridding Algorithm for Fourier Inversion in Computer Tomography. *IEEE Transactions on Medical Imaging*, 200-207.

Rau, U. (2012, Sept 24). *Imaging and Deconvolution.* Retrieved from Australia Telescope National Facility: https://www.atnf.csiro.au/research/radio-school/2012/lectures/tue/RVU\_ImagingDeconvolution.pdf

Ryle, M., & Hewish, A. (1960). The synthesis of large radio telescopes. *Monthly Notices of the Royal Astronomical Society, Vol. 120*, 220-230.

Appendix

1[Add footnotes, if any, on their own page following references. For APA formatting requirements, it’s easy to just type your own footnote references and notes. To format a footnote reference, select the number and then, on the Home tab, in the Styles gallery, click Footnote Reference. The body of a footnote, such as this example, uses the Normal text style. (Note: If you delete this sample footnote, don’t forget to delete its in-text reference as well. That’s at the end of the sample Heading 2 paragraph on the first page of body content in this template.)]