An Overview of the SKA Science Analysis Pipeline

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Abstract. When completed the Square Kilometre Array (SKA) will feature an unprecedented rate of image generation. While previous generations of telescopes have relied on human expertise to extract scientifically interesting information from the images, the sheer data volume of the data will now make this impractical. Additionally, the rate at which data are accrued will not allow traditional imaging products to be stored indefinitely for later inspection meaning there is a strong imperative to discard uninteresting data in pseudo-real time. Here we outline components of the SKA science analysis pipeline being developed to produce a series of data products including continuum images, spectral cubes and Faraday depth spectra. We discuss a scheme to automatically extract value from these products and discard scientifically uninteresting data. This pipeline is thus expected to give both an increase in scientific productivity, and offers the possibility of reduced data archive size producing a considerable saving.

1. Introduction

The volume of data to be generated by a fully operational Square Kilometre Array (SKA) is staggering. In round figures, the current estimate is that the SKA will deliver a petabyte of image data per day. It is quite clear that this data volume is unmanageable with traditional techniques and that as much analysis as possible will need to be automated.

The science data processor (SDP) of the SKA includes a science analysis pipeline, which will extract and characterise all scientifically interesting sources within an observation. The pipeline will present astronomers with complete catalogues of point, extended and spectral sources and their properties.

2. Science Analysis Pipeline Overview

The science analysis pipeline is conceived as operating in two phases, source detection and source characterisation. The source detection phase seeks to exhaustively identify areas of interest amongst the surrounding background in the first phase. Existing source detection algorithms will play a part in this extraction (Whiting 2012; Hancock et al. 2012), but will need to be enhanced (Dehghan et al. 2016) and augmented by extended source detectors (Frean et al. 2014; Butler-Yeoman et al. 2016).
The source characterisation stage will then extract appropriate science data products for each detected source. The science products include information such as spectral index and polarization properties of the sources.

A simplified overview of the source finding and characterisation within the SDP is shown in figure 1. A initial portion operating at a relatively high cadence delivers information about the locations of bright point sources to the sky model used within the pipeline’s calibration and imaging sections. Images and preliminary source information are then passed into the main data analysis block for further analysis. Where necessary, there may be provision for users to extract raw images from a buffer at this stage, even if the SKA does not archive the full raw images.

2.1. High cadence point source finder

Some initial source finding must be conducted for use in the calibration and imaging portions of the SKA pipeline. The location and shape information of bright point sources must be determined in real time and fed back to the pipeline’s sky model.

The source characterisation requirements of the imaging pipeline are somewhat more relaxed than needed for science purposes, which allows the source finding algorithms in this portion of the pipeline to trade accuracy for speed. Nevertheless, the information obtained here is useful as a seed to the later data processing, as it provides some initial estimates of source properties that can be refined as necessary.

2.2. Science analysis pipeline

At the completion of an observation data enters the main portion of the data analysis pipeline. Sources are then located and characterised. While some of the operations required are likely to be computationally expensive, the relatively infrequency with which they are run (typically every few hours) means that this will not be a dominant computational driver for the SDP design. Indeed, much of the processing need not happen synchronously with observations, but could be conducted at any time before the input buffer is overwritten by incoming data from subsequent observations.

The first task of the science analysis system is to identify and locate sources. This is most likely to be performed by a series of three specialised source finders targeted at point sources, extended sources (Butler-Yeoman et al. 2016) and sparse spectral features respectively. These source finders must be more conservative than existing source finders, so that valuable data will not be missed.

The lower portion of the architectural diagram in figure 1 shows a nominal set of processes that are used to extract useful data from a particular observation. In practice a particular experiment might not require some portions of the processing, but the intent is that the full characterisation tree would typically be used.

Execution of some elements of the data extraction pipeline will be conditional on earlier results. For example, full polarization characterisation is only necessary for polarised sources. Similarly, full spectral profiling of sources will be necessary only when spectral index fitting fails to adequately capture the source behaviour.

3. Discussion

At least for the foreseeable future, routine storage of the full data set emerging from the SKA’s imaging pipeline would require heroic storage capacity, having equally un-
realistic budget implications. Indeed, full data storage would render operation of an SKA data archive the dominant operating cost for the instrument. However, the real time availability of science data products makes possible considerable savings in data storage. Rather than the commonly assumed practice of archiving all images, one could instead consider storing only regions where sources were located, while areas of background could be discarded. For even greater efficiency point sources could be completely characterised and then discarded from the archive. As astronomical images typically contain many pixels (or voxels) that contain no useful information, the potential savings are considerable. Though the choices of trade-off made have potentially large impact on the reduction of data volume, savings of a factor of 10 seem straightforward and 100 likely for most observations. Even higher savings appear possible in special circumstances such as for spectral line observations.

One could regard selective data retention as a form of scientifically-aware, lossy data compression. Excision of observed data is currently not a common operation in radio astronomy, as telescope operating costs are considerably more expensive than the concomitant data storage. This situation reverses in the case of the SKA where reobservation will be cheaper than storage.

A careful consideration of whether project resources are better spent on data collection or data storage appears vital for maximising scientific return from the instrument. The instinctive desire to store more data comes at the price of other telescope capabilities. Some segments of the astronomical community are planning programmes that will have particular demand for data storage. As data storage costs are expected to decrease with time, it is likely that large savings can be made by phasing of experimental ambition of storage intensive projects over time. Science requiring modest storage...
could be favoured in the early years of the SKA, while the demanding projects become ever more tractable as storage costs drop.

The extent to which these ideas will be employed by the early SKA are as yet unclear. This paper therefore does not represent the formal position of the SKA project, but simply outlines possible principles of operation for the science analysis pipeline as conceived by the science analysis pipeline team of the SKA's Science Data Processor (SDP) consortium.

4. Unanswered questions

Specifications for some data products are as yet poorly developed. Should the SKA move to a science product only storage model, then this becomes a critical issue. It appears that there has been little engagement of the scientific community with this matter, to a large extent because of a general expectation that the SKA will operate similarly to the telescopes of previous generations. Given the likely operating mode for the SKA it is vital that the required data products be identified. The scientific community must therefore carefully consider the trade-offs when determining requirements.

A second source of uncertainty arises from the unclear boundary between the SDP and the SKA's data archive. At present the long-term data archive sits outside the SKA's construction cost cap, and as such details of its operation remain underdeveloped. Portions of the processing described in this paper could conceivably be deployed onto the archive or onto regional science and engineering centres.

5. Conclusion

The science analysis pipeline of the SKA seeks to automatically find and characterise sources within the fields observed by the telescope. It is unlikely that the SKA project will be furnished with an exhaustive archive, as is possible for the current generation of radio telescopes. However, some intelligent winnowing of the incoming data is possible by identifying regions of scientific interest. Storage of just these regions reduces the storage requirements of an SKA archive considerably.

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