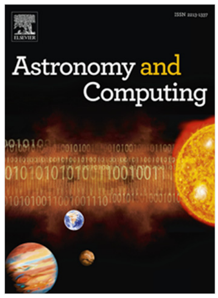
Accepted Manuscript



Multi-GPU maximum entropy image synthesis for radio astronomy

M. Cárcamo, P.E. Román, S. Casassus, V. Moral, F.R. Rannou

PII: S2213-1337(17)30009-4
DOI: https://doi.org/10.1016/j.ascom.2017.11.003
Reference: ASCOM 207

To appear in: *Astronomy and Computing*

Received date : 26 January 2017
Accepted date : 25 November 2017

Please cite this article as: Cárcamo M., Román P.E., Casassus S., Moral V., Rannou F.R., Multi-GPU maximum entropy image synthesis for radio astronomy. *Astronomy and Computing* (2017), https://doi.org/10.1016/j.ascom.2017.11.003

Multi-GPU maximum entropy image synthesis for radio astronomy

M. Cárcamo[a], P.E. Román[a,b], S. Casassus[c], V. Moral[c], F.R. Rannou[a]

[a]*Departamento de Ingeniería Informática, Universidad de Santiago de Chile, Av. Ecuador 3659, Santiago, Chile*
[b]*Center for Mathematical Modeling, Universidad de Chile, Av. Blanco Encalada 2120 Piso 7, Santiago, Chile*
[c]*Astronomy Department, Universidad de Chile, Camino El Observatorio 1515, Las Condes, Santiago, Chile*

Abstract

The maximum entropy method (MEM) is a well known deconvolution technique in radio-interferometry. This method solves a non-linear optimization problem with an entropy regularization term. Other heuristics such as CLEAN are faster but highly user dependent. Nevertheless, MEM has the following advantages: it is unsupervised, it has a statistical basis, it has a better resolution and better image quality under certain conditions. This work presents a high performance GPU version of non-gridding MEM, which is tested using real and simulated data. We propose a single-GPU and a multi-GPU implementation for single and multi-spectral data, respectively. We also make use of the Peer-to-Peer and Unified Virtual Addressing features of newer GPUs which allows to exploit transparently and efficiently multiple GPUs. Several ALMA data sets are used to demonstrate the effectiveness in imaging and to evaluate GPU performance. The results show that a speedup from 1000 to 5000 times faster than a sequential version can be achieved, depending on data and image size. This allows to reconstruct the HD142527 CO(6-5) short baseline data set in 2.1 minutes, instead of 2.5 days that takes a sequential version on CPU.

Keywords: Maximum entropy, GPU, ALMA, Inverse problem, Radio interferometry, Image synthesis

1. Introduction

Current operating radio astronomy observatories (e.g. ALMA, VLA, ATCA) consist of a number of antennas capable of collecting radio signals from specific sources. Each antenna's signal is correlated with every other signal to produce samples of the sky image $I(x, y)$, but on the Fourier domain (Candan et al., 2000). These samples $V(u, v)$ are called visibilities and comprise a sparse and irregularly sampled set of complex numbers in the (u, v) plane. A typical ALMA sampling data set contains from 10^4 to more than 10^9 sparse samples in one or more frequency channels.

In the case where $V(u, v)$ is completely sampled, Equation 1 states the simple linear relationship between image and data:

$$V(u, v) = \int_{\mathbb{R}^2} A(x, y) I(x, y) e^{-2\pi i(ux+vy)} dx dy \qquad (1)$$

Thus the image can be recovered by Fourier inversion of the interferometric signal (Clark, 1999). In this equation, kernel $A(x, y)$ is called the primary beam (PB) and corresponds to the solid angle reception pattern of the individual antennas and it is modelled as a Gaussian function. If the antennas are dissimilar, it is the geometric mean of the patterns of the individual antennas making up each individual baseline (Taylor et al., 1999).

In the real scenario of collecting noisy and irregularly sampled data, this problem is not well defined (Marechal and Wallach, 2009; Chen, 2011). To approximate the inverse problem of recovering the image from a sparse and irregularly sampled Fourier data a process called Image Synthesis (Thompson et al., 2008) or Fourier Synthesis (Marechal and Wallach, 2009) is used. Current interferometers are able to collect a large number of (observed) samples in order to fill as much as possible the Fourier domain. As an example, Figure 1 shows the ALMA 400 meter short baseline sampling for Cycle 2 observation of the HD142527 plotoplanetary disc. Additionally, the interferometer is able to estimate data variance σ_k^2 per visibility as a function of the antenna thermal noise (Thompson et al., 2008).

Many algorithms have been proposed for solving the image synthesis problem and the standard procedure is the CLEAN heuristic (Hogbom, 1974). This algorithm is based on the dirty image/beam representation of the problem (Appendix A), which results in a deconvolution problem (Taylor et al., 1999). CLEAN has been interpreted as a matching pursuit heuristic (Lannes et al., 1997), which is a pure greedy-type algorithm (Temlyakov, 2008). Image reconstruction in CLEAN is performed in the image space using the convolution relationship, and it is therefore quite efficiently implemented using FFTs. This algorithm is also supervised. The user could indicate iteratively in which region of the image the algorithm should focus. However, statistical interpretation of resulting images and remaining

Email address: miguel.carcamo@usach.cl (M. Cárcamo)