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Learning how to clean deep and fast, with R2D2: Residual-to-Residual DNN series for high-Dynamic range imaging in radio astronomy

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Image reconstruction from Fourier data by Radio Interferometry (RI) in astronomy requires solving an ill-posed inverse problem. Modern telescopes target high-resolution high-dynamic range imaging of complex structures with faint and diffuse emission, making the data and images of interest very large. We propose a new approach for large-scale high-dynamic range RI imaging, dubbed R2D2.

Deep Neural Networks (DNNs) trained end-to-end can solve linear inverse imaging problems almost instantaneously, but standard architectures cannot ensure consistency of the recovered image with the observed data. While unfolded architectures restore necessary robustness to variations of the measurement setting, embedding large-scale measurement operators such as those associated with modern RI observation in DNNs is impractical. Alternative Plug-and-Play (PnP) approaches such as AIRI [1, 2], where regularisation DNN denoisers are blind to the measurement setting, circumvent that challenge, and have proven effective in providing acceleration over advanced sparsity-promoting optimisation methods such as SARA [3, 4]. AIRI was in fact demonstrated to nearly close the computational gap between SARA and CLEAN, while providing a paradigm shift in reconstruction quality thanks to its DNN-based regularisation approach [2]. However, the highly iterative nature of all these competing algorithms still hinders their scalability to extreme data sizes.

R2D2 is a new approach aiming to address the ultimate scalability challenge faced by RI imaging algorithms in the Square Kilometre Array (SKA) era. Its reconstructed image is built as a series of a few residual images progressively increasing the dynamic range, and estimated iteratively as outputs of DNNs taking the residual dirty image of the previous iteration as input. The algorithm can be interpreted as a learned version of traditional matching pursuit approaches, such as CLEAN, which iteratively identify model components from residual dirty images. Preliminary validation of R2D2 was performed for monochromatic RI imaging (at a small scale and in simulation) in comparison with CLEAN, SARA, AIRI, and to an end-to-end approach resulting from cutting the R2D2 series to its first term. Simulation results suggest that a series of only four terms (*i.e.* four passes through the data) delivers an imaging resolution and dynamic range competitive with AIRI and SARA at a fraction of the cost, superseding CLEAN both in precision and computational cost, and largely improving the imaging quality over an end-to-end DNN, whilst only being four times slower. R2D2 opens the door to real-time precision RI imaging with the current and forthcoming generation of telescopes. This abstract summarises ongoing work, building from [5].

References

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