Urvashi Rao Venkata

National Radio Astronomy Observatory,
1003 Lopezville Road, Socorro, NM 87801
(Off) 1-575-835-7372, (Cell) 1-575-418-5567
Email : *rurvashi@aoc.nrao.edu*

Career Objective

Algorithm research and software development for image reconstruction, signal calibration and image/data analysis, applied to synthetic-aperture imaging instruments.

Research Interests and Skills

- Application of numerical optimization techniques to inverse problems in image reconstruction.
- Algorithms for the detection and removal of electromagnetic interference.
- Algorithms for calibration of radio-frequency receivers.
- Analysis and interpretation of measured data and reconstructed images in radio interferometry.
- Interactive visualization of large datasets.
- Parallel and high-performance computing.

Technical Skills

- Programming languages : C, C++, Python
- Environments : Unix/Linux
- Data Analysis Packages : Matlab/Octave, Scipy/Numpy, CASA, ASKAPSOFT
- Libraries : GNU Scientific Library, Numerical Recipes, Bayesys, KeLP, MPI, Python/C API

Education

Ph.D. Physics Aug 2004 - Mar 2010
New Mexico Institute of Mining and Technology, Socorro, NM, USA
- GPA: 3.96/4.0
- Dissertation: *"Parameterized Deconvolution for Wide-Band Radio Synthesis Imaging"*

M.S. Computer Science (Scientific Computing) Sep 2002 - Jun 2004
University of California, San Diego, CA, USA
- GPA: 3.89/4.0
- Thesis: *"A performance model and load balancer for a Parallel Monte-Carlo Cellular Microphysiology Simulator"*

M.Sc.(Hons.) Physics Aug 1997 - Jun 2002
Birla Institute of Technology and Science, Pilani, India
- GPA: 8.65/10.0

B.E.(Hons.) Computer Science Aug 1997 - Jun 2002
Birla Institute of Technology and Science, Pilani, India
- GPA: 8.65/10.0

Research Experience

- **Pre-doctoral Student**, National Radio Astronomy Observatory (NRAO) [Jan 2008 - present]
  Affiliated Student, Australia Telescope National Facility (ATNF) [Jun 2006 - present]
  Research Assistant, Dept. of Physics, NMIMT [Aug 2004 - present]

  Ph.D. Dissertation : **Parameterized deconvolution for wide-band radio synthesis imaging**
  Advisors : Timothy J. Cornwell, Frazer N. Owen, Jean A. Eilek

  - Developed a multi-scale multi-frequency deconvolution algorithm for wide-field imaging in radio interferometry, designed for data taken using broad-band receivers in which the incident radiation, telescope transfer function and antenna fields-of-view are all frequency dependent.
    Main results :
    - The ability to extract more image data products (describing spatial and spectral structure) than earlier possible from a wide-band observation, and over a wider field-of-view.
    - A formal mathematical analysis of the imaging process led to ideas for demonstrable improvements in two independent algorithms for multi-scale and multi-frequency imaging.
  - Implemented the algorithm in two data analysis packages used by the NRAO and the ATNF.
  - First author on a refereed paper (Proc.IEEE) describing established and recently developed radio synthesis imaging algorithms and the relations between them, in a common mathematical framework.

- **Graduate Intern**, National Radio Astronomy Observatory [Jul 2004 - Aug 2004]

  Project : **Multi-Frequency Synthesis Imaging for the EVLA**
  Advisor : Timothy J. Cornwell

  - Studied and evaluated existing multi-frequency synthesis imaging techniques in the context of broad-band radio-interferometric imaging with the Expanded Very Large Array telescope and identified areas where algorithmic improvements were required.
  - Developed a hybrid scheme for wide-band imaging and listed the conditions under which this computationally simple method will suffice to extract the required astrophysical information.

- **Research Assistant** [Sep 2003 - Mar 2004]
  Dept. of Computer Science & Engineering, UC San Diego [Sep 2002 - Mar 2003]

  M.S. Thesis : **A performance model and load balancer for a parallel Monte-Carlo cellular microphysiology simulator.**
  Advisor : Scott B. Baden

  - Developed a load balancer for a parallel 3D cell microphysiology simulator. It used an empirically derived performance model to predict spatial and temporal workload distributions within a 3D computational volume, and a dynamic domain decomposition based on a 3D Hilbert space-filling curve to preserve locality and minimize communication.
  - Achieved load-balance for 95% of the runtime, and a speedup of two over a regular static domain decomposition, but this improvement was not sufficient to offset the increased communication costs.

- **Graduate Intern**, National Radio Astronomy Observatory [Jul 2003 - Sep 2003]

  Project : **Monte-Carlo Methods for Bayesian Image Reconstruction in Radio Astronomy**
  Advisor : Timothy J. Cornwell

  - Used the Bayesian interpretation of image reconstruction to develop a Markov-Chain Monte-Carlo based algorithm to find the most probable set of 2D Gaussians for a multi-scale representation of an image formed using an interferometer.
  - Obtained uncertainty estimates for each fitted parameter arising from the measurement noise, the non-uniqueness of the imaging solution, and the non-orthogonality of the image basis functions.

- **Research Intern**, National Centre for Radio Astrophysics (NCRA), TIFR, Pune [Jan 2002 - Jun 2002]

  Project 1 : **Automatic RFI Identification and Flagging**
  Advisor : A. Pramesh Rao

  - Developed a pattern recognition algorithm to automate the identification and removal of data affected by radio-frequency interference from measurements taken with an imaging interferometer.
  - Implemented this algorithm as part of the offline data analysis software packages at two radio observatories, the NCRA (2002) and the NRAO (2008).

  Project 2 : **Numerical Solutions of Complex Antenna Gains and Polarization Leakage**
  Advisor : Rajaram Nityananda

  - Studied the mathematical description of the process of calibrating a radio interferometer for the case of full-polarization measurements using a set of crossed dipole feeds.
  - Implemented and compared numerical solvers based on least-squares methods and eigen decompositions of a correlation matrix, to extract instrumental gains for all feeds, using measured data.

- **Summer Student**, National Centre for Radio Astrophysics,TIFR,Pune [Jun 2001 - Jul 2001]

  Project : **Comparative Study of Algebraic Deconvolution Algorithms**
  Advisor : Rajaram Nityananda

  - Studied the measurement and imaging process of a radio interferometer in terms of a system of linear equations that need to be solved in order to form an image.
  - Compared 1-D implementations of algebraic image reconstruction methods based on singular-value decompositions and non-negative least squares, and studied the effect of a windowing constraint.

- **Other projects**, BITS, Pilani [before Jun 2002]

  Theoretical study and software implementation of existing algorithms for Computed Axial Tomography, Wavelet image decomposition and compression, and Fragile Watermarking for digital image security.

Work Experience

- **Programmer**, National Radio Astronomy Observatory [Jul 2004 - Jul 2007]
  Supervisor : Joseph P. McMullin

  - Designed and implemented an interactive plotting tool for the display of radio-interferometry data, allowing for the generation, storage and access of user-defined masks to tag data for removal.
    Main features :
    - Flexible data access based on a database query language, rules for data re-use and efficient metadata access, the ability to use customized derivative classes for alternate data access mechanisms.
    - Rendering via the Python Matplotlib package and standard C-Python APIs, custom GUI features added to the Tk backend of Matplotlib, user interaction via the plotter GUI and the Python command-line usable interchangeably within the same session.
    - A C++ framework based on the Singleton design pattern to allow multiple instances of customized derivatives generated at runtime by the user to work together.
  - Conducted a user-survey to get a list of required features for a mask generation tool, and implemented a subset of these requests while porting an existing code module to a newer system.

- **Teaching Assistant** [Apr 2004 - Jun 2004]
  Dept. of Computer Science & Engineering, UC San Diego [Apr 2003 - Jun 2003]
  Supervisor : Scott B. Baden
  Course : Introduction to High Performance and Parallel Computing
  Responsibilities : Discussion sessions, office hours, grading of written and programming homework

Publications

- *"Advances in Calibration and Imaging Techniques in Radio Interferometry"*, **Urvashi R.**, S.Bhatnagar, M.A.Voronkov, T.J.Cornwell, Proceedings of the IEEE, Vol.97, No.8, p-1472, August 2009
- *"Monte-Carlo Image analysis in Radio Interferometry"*, **Urvashi R.V.**, T.J.Cornwell, Astronomical Data Analysis Software and Systems XIV ASP Conference Series, Vol. 347, p-168 2004
- *"A performance model and load balancer for a Parallel Monte-Carlo Cellular Microphysiology Simulator"*, **Urvashi R.V.**, M.S. Thesis, University of California, San Diego, June 2004.
- *"Solving for Polarization Leakage in Radio Interferometers Using Unpolarized Sources"*,Bhatnagar S., **Urvashi R.V.**, Nityananda R., Astronomical Data Analysis Software and Systems XII ASP Conference Series, Vol. 295, p-469 2003.

Memos and Technical Reports

- *"Casapy Flag tool and casa::Flagger"*, **Urvashi R.**, CASA Programmers Note, 23 August 2007
- *"Design of casa::TablePlot for Casapy"*, **Urvashi R.**, CASA Programmers Note, 18 August 2007
- *"Multi Frequency Synthesis Imaging for the EVLA : An initial investigation"*, **Urvashi R.V.**, T.J.Cornwell, S.T.Myers, EVLA Memo 101, April 2006
- *"Monte Carlo Methods for Bayesian Image Reconstruction and Analysis in Radio Astronomy"*, **Urvashi R.V.**, T.J.Cornwell, EVLA Memo 102, February 2006
- *"Automatic RFI identification and flagging"*, **Urvashi R.V.**, A. Pramesh Rao, NCRA Technical Report No. R00202, October 1 2003

Selected Talks and Presentations

- *"Wide-Field Wide-Band Imaging in Radio Interferometry"*, Talk at the ATNF Student Symposium, 16 June 2009, Sydney, AU (via audio link from Socorro)
- *"Remote Sensing, Image Making and Radio Telescopes "*, Colloquium at the New Mexico Tech Physics Department, 09 Apr 2009, Socorro, USA
- *"Wide-Field Wide-Band Imaging with the EVLA - initial results"*, Talk at the Fourth SKA Calibration and Imaging Workshop, 31 March 2009, Socorro, USA
- *"Multi Frequency Synthesis Imaging with Wideband EVLA data"*, Lunch Talk at the EVLA Advisory Committee Meeting, 19-20 March 2009, Socorro, USA
- *"Multi-Frequency Synthesis Imaging with Multi-Scale Deconvolution (EVLA, e-MERLIN)"*, Talk at the Workshop on Imaging and Calibration Algorithms for EVLA, eMERLIN and ALMA, 02 December 2008, Oxford, UK (via video link from Socorro)
- *"Multi-Frequency Synthesis Imaging with Wide-Band (E)VLA data"*, Talk at the 24th Annual New Mexico Symposium, 24 October 2008, Socorro, USA
- *"Multi-Frequency Synthesis Imaging with Multi-Scale Deconvolution"*, Invited Talk at the XXIX URSI General Assembly, 15 August 2008, Chicago, USA

- *"Wide-Band Imaging - Algorithms and Errors"*, Talk at the Third SKA Calibration and Imaging Workshop, 09 April 2008, Perth, AU
- *"Multi-Frequency Synthesis Imaging with Multi-Scale deconvolution"*, Talk at the Second SKA Calibration and Imaging Workshop, 05 December 2006, Cape Town, South Africa
- *"Wide Bandwidth Imaging: Challenges and prospects for the EVLA and beyond"* ,Talk at the URSI National Radio Science Meeting, 06 January 2006, Boulder, USA

Technical Schools Attended

- Ninth Synthesis Imaging Summer School, NRAO, Socorro, June 2004
- Introductory Astrophysics Summer School, Inter-University Centre for Astronomy and Astrophysics (IUCAA), Pune, India May 2000 - Jun 2000

Academic Awards and Fellowships

- NRAO Pre-Doctoral Research Fellowship Jan 2008 - Dec 2009
- Award for Overall Best Outgoing Student, Dept of Physics, BITS, Pilani May 2001

Relevant Coursework

• Electromagnetics(I,II), Quantum Mechanics(I,II), Astrophysics(III,IV), Advanced Radio Astronomy, Statistical Mechanics, Advanced Dynamics	Dept. of Physics, NMIMT
• Numerical Mathematics(I,II,III), Scientific Computation(I,II), Numerical Optimization(II,III)	Dept. of Mathematics, UCSD
• Algorithm Design and Analysis, Operating Systems, Principles of Computer Architecture, Parallel Computation, Principles of Distributed Computing	Dept. of Computer Science & Engineering, UCSD
• Computational Physics, Multimedia Systems, Computer Graphics, Geographical Information Systems, Numerical Analysis, Operations Research	BITS-Pilani

Extra-curricular

- Web lectures as part of the BITS-Embryo project, aimed at introducing undergraduate students at the Birla Institute of Technology and Science, India, to current research and technology trends in various disciplines. (1) *"Remote Sensing At Its Extreme - the interdisciplinary nature of observational radio astronomy"*, BITS-Pilani, Nov 2007 and (2)*"Remote Sensing and Image Making"*, BITS-Goa, Jan 2009.
- An introductory lecture about the working of a radio interferometer, for a group of 16 high-school students who visited the NRAO, Socorro,NM in April 2009.
- Tour guide for the Very Large Array at open-house events in 2005, 2008.
- Coordinator, Physics Department, APOGEE 2000. Organized the Physics section of an all-India science and technology festival held annually at BITS-Pilani.
- Astronomy Club Secretary, BITS-Pilani, 1999-2000. Conducted interactive observation sessions and gave informal Astronomy lectures.

References

Available on request.

Dissertation Abstracts

Ph.D. Dissertation : *"Parameterized Deconvolution for Wide-Band Radio Synthesis Imaging"*, Department of Physics, New Mexico Institute of Mining and Technology, Socorro, NM, USA, (2010,in prep).

The technique of aperture synthesis imaging was first developed at radio wavelengths to make an image of the spatial distribution of electromagnetic radiation emanating from a distant object. An imaging interferometer is an indirect imaging device that uses measurements from a set of connected antenna elements to measure the spatial Fourier transform of the sky brightness distribution. Image reconstruction in aperture synthesis is an inverse problem for which least-squares optimization techniques are regularly used. Measurements are inherently noisy and spatial frequency sampling is always incomplete, making this reconstruction a non-linear process with non-unique solutions. Further, the physical measurement of the incident electromagnetic radiation using antennas and radio receivers introduces artifacts that need to be modeled and removed from the measured data. The desired dynamic range on reconstructed images is of the order of a million to one. To achieve this, instruments need to be highly sensitive, and one step currently being taken by many radio interferometers worldwide is to install broad-band receivers to increase the overall sensitivity. Doing so, affects the image reconstruction process in three ways (1) the spatial frequency coverage and angular resolution change with frequency (2) the antenna power pattern and field-of-view changes with frequency (3) the incident radiation has spectral structure. These effects along with many others must be simultaneously accounted for during calibration and image reconstruction.

This dissertation project involved a study of existing methods to deal with wide-band effects during image reconstruction, and to delevop and implement an algorithm that fixed all three. Technically, this work involved formal derivations of the imaging process, understanding the approximations used by existing methods, listing the steps required for a more accurate algorithm, implementing it within existing data analysis packages, and testing the algorithm's performance on simulated and real data.

Main results :

- This work resulted in a multi-frequency synthesis imaging algorithm that parameterizes a 2D image using a multi-scale basis and the spectrum per pixel as a polynomial. The data products are a set of coefficient images describing this polynomial for each pixel.
- For the study of broad-band emission from astrophysical sources, the coefficient images are interpreted in terms of parameters of a power law, giving images of (a) continuum emission, (b) spectral index (c) spectral curvature. (Previous algorithms did not measure spectral curvature or use a multi-scale basis and were shown to be insufficient for new wide-band instruments and extended emission.)
- This algorithm demonstrated that it is often possible to reconstruct both spatial and spectral structure of the incident radiation, even when the sampling at any single observing frequency is insufficient to accurately reconstruct the spatial structure at that frequency. This is useful for instruments with sparse sampling patterns, and for the spatio-spectral imaging of time-variable sources using aperture synthesis.
- The frequency dependence of the antenna power pattern was folded into the wide-band imaging process to achieve accurate spectral reconstructions across wide fields-of-view. (Previously, wide-field imaging was restricted to a single-frequency, and any uncorrected frequency-dependence of the antenna power pattern resulted in artificial spectral structure in the reconstructed image.)
- An analysis of the existing multi-scale and multi-frequency deconvolution algorithms in a formal numerical optimization framework led to ideas for demonstrable improvements in both the algorithms.

The multi-scale multi-frequency imaging algorithm has been implemented in two data analysis packages :
(a) Common Astronomy Software Applications used by the National Radio Astronomy Observatory.
(b) Australian SKA Pathfinder software being developed at the Australia Telescope National Facility.

M.S. Thesis: *"A performance model and load balancer for a Parallel Monte-Carlo Cellular Microphysiology Simulator"*, Department of Computer Science and Engineering, University of California, San Diego, June 2004.

MCell is a cellular microphysiology simulator that uses Monte-Carlo methods to simulate the behaviour of a large number of reactive molecules as they diffuse through space in a 3D computational domain. MCell-K is a scalable parallel implementation of MCell that was initially implemented with a static regular partitioning of the 3D volume to distribute the workload. Load imbalance was found to be a major bottleneck of the system, with the maximally loaded processor carrying at least twice the average load.

For my masters thesis project I designed and implemented an adaptive load balancer for MCell-K. It used an empirically derived performance model to predict spatial and temporal workload distributions, and employed a domain decomposition based on a Hilbert space-filling curve to preserve locality and minimize communication across processors. This load balancer needed to be designed while MCell-K was being refactored, and was therefore implemented on the serial version of MCell and tested by running it in a simulated parallel environment. Performance metrics were based on estimates of communication costs and time measurements for each simulated node. Load balance was achieved for 95% of the total runtime, and the average runtime performance with dynamic partitioning was a factor of two better than with a static regular partitioning. However, this improvement was insufficient to counter the increased communication cost and attempts at finding a trade-off did not yield a workable solution.