OSKAR Introduction

1 What is OSKAR?

The OSKAR package consists of a number of open source applications for the simulation of astronomical radio interferometers. OSKAR 2.x has been designed primarily to produce simulated data from telescopes that use aperture arrays, as envisaged for the SKA.

2 Features

Below is a summary of the current features of the OSKAR package.

- **Simulation capability:**
  - Evaluation of a polarised Radio Interferometer Measurement Equation, accelerated using NVIDIA GPU(s).
  - Extensible framework using Jones matrix formalism.
  - Optimised for simulation using very large source catalogues.
  - Capable of simulating interferometers constructed from large aperture arrays.
  - Sky models:
    - Input catalogues of point and/or elliptical Gaussian sources.
    - Built-in sky model generators for random power-law, random broken-power-law, and gridded source distributions.
  - Station beam response:
    - Direct evaluation of aperture array station beams (E Jones) from arbitrary telescope configurations (using either single level or hierarchical beam forming schemes). Options include:
      - Independent specification of pointing direction for each station or tile.
      - Apodisation weighting.
      - Antenna element position and dipole orientation errors.
      - Systematic and random element phase and gain errors.
    - Inclusion of (embedded) antenna element patterns specified by an analytical dipole response or a numerically defined pattern, as a function of element type and frequency.
    - Inclusion of parallactic angle rotation.
  - Interferometric response allows for:
    - Time and bandwidth smearing.
    - Uncorrelated system noise.
    - Filtering as a function of baseline UV distance.
- **An application to simulate interferometer data**
  - Configurable using INI format settings files.
  - Export to CASA Measurement Set format.
- **An application to simulate aperture array beam patterns**
  - Configurable using INI format settings files.
  - Export to FITS image format.
- **A simple graphical user interface application for setting up and running simulations.**
- **A number of utility applications to provide support for scripting of simulations.**
- **Supported and tested on Linux and macOS.**

3 Getting Started

The following documents are available:

- Installation Guide
  Describes how to build and install OSKAR.
- Example
  Describes how to run an example simulation and test that your version of OSKAR is working as intended.
- Theory of Operation
  Describes the theory of operation of OSKAR, its implementation of the measurement equation and its treatment of polarisation. Please read this document to verify that OSKAR works as you expect.
- Apps
  Describes the available OSKAR applications.
- Sky Model
  Describes the format of the OSKAR sky model files.
- Telescope Model
  Describes the format of the OSKAR telescope model files and directories.
- Pointing File
  Describes the format of OSKAR pointing files.
- Settings Files
  Describes the settings used by OSKAR and the format of the OSKAR settings files.
- Binary File Format
  Describes the format of binary files written by OSKAR applications (for reference only).

4 FAQ

This section attempts to address some frequently asked questions about OSKAR. If you have a question that is not answered here, please send it to `oskar@oerc.ox.ac.uk` and we will do our best to respond.

1. **Which operating systems/platforms are supported?**
   OSKAR has been tested to compile and run correctly on various recent Linux distributions, and recent versions of macOS and Windows. If you encounter a problem with OSKAR, please report it to `oskar@oerc.ox.ac.uk`.
2. **Does OSKAR require an NVIDIA GPU to work?**
   No, but simulations will probably run faster if an NVIDIA GPU is available. Other GPUs are not currently supported.
3. **Which GPU model should I use to run OSKAR simulations?**
   OSKAR should be able to run on an NVIDIA GPU with compute capability of 2.0 or higher. We recommend using a dedicated compute card which has decent double precision floating point performance, as consumer gaming models only work well in single precision (the exception being the Kepler NVIDIA Titans). Recent OSKAR simulations have been running successfully using NVIDIA's K20 and K40 compute cards in HPC clusters.
4. **I have multiple NVIDIA GPUs in my computer. Can OSKAR make use of all of them to run faster?**
   Yes, normally, as the CUDA device(s) to use can be specified at run-time, and work is shared between them by splitting up the sky model and the time samples within a visibility block. However, see also the answer to the next question to check if using multiple GPUs in this way will be worthwhile for you.

5. **Why does OSKAR run at virtually the same speed regardless of whether I use a sky model containing 10 sources or 100 sources?**
OSKAR was designed to run simulations efficiently for aperture-array-based telescopes using large sky models containing many thousands of sources across the whole sky. This is done by assigning a GPU thread for every source. However, as modern GPUs have thousands of processing cores, there must be enough work to do to keep the GPU occupied in this way. If your sky model contains only 100 sources, you may be using only a few percent of the available hardware, so performance will be relatively poor when using small sky models like this. It will probably be faster to use CPU cores only for sky models containing fewer than 32 sources.

6. **Is OpenCL supported?**
No. However, depending on demand, support for OpenCL could potentially be added in a future release.

7. **Are pre-built binary packages of OSKAR available?**
Binary installer packages are now available for macOS and Windows systems. On Linux, OSKAR still needs to be compiled from source.

8. **I found a bug!**
Please let us know by sending an email to `oskar@oerc.ox.ac.uk`.

9. **I found a bug, but I managed to fix it!**
Wonderful! Please send us your patch by sending an email to `oskar@oerc.ox.ac.uk`. We'll test it and integrate it back into the master branch.

10. **Please could you add this feature?**
Please get in touch - we will certainly consider new features but can't guarantee that we can implement all of them.

5 Roadmap

We hope to add the following capabilities to OSKAR at some point. In no particular order:

- Allow use of analytical and numerical dish patterns.
- Swap X and Y dipoles to match IAU polarisation axes on the sky.
- Allow full 3D specification of individual element feed angles.
- Allow full Stokes beam patterns.
- Include a usable ionospheric model.

6 License

OSKAR is made available under the 3-clause BSD License, as follows:

7 Acknowledgements

OSKAR has been developed using hardware donated by NVIDIA UK.

OSKAR uses the following tools and libraries:

- The NVIDIA CUDA toolkit: `https://developer.nvidia.com/cuda-zone`
- The FFTPACK 5 FFT library: `https://www2.cisl.ucar.edu/resources/legacy/fft5`
- The LAPACK linear algebra library: `http://www.netlib.org/lapack/`
- The DIERCKX spline fitting library: `http://netlib.org/dierckx/`
- The Qt GUI framework: `https://www.qt.io/`
- The casacore Measurement Set library: `https://github.com/casacore/casacore/`
- The CFITSIO FITS file library: `https://heasarc.gsfc.nasa.gov/fitsio/`
- The Random123 random number generator: `https://www.deshawresearch.com/resources_random123.html`
- The ezOptionParser command line parser: `http://ezoptionparser.sourceforge.net/`
- The Tiny Template Library: `http://tinytl.sourceforge.net/`
- The RapidXML XML parser: `http://rapidxml.sourceforge.net/`
- The CMake build system: `http://www.cmake.org/`
- The Google Test framework: `https://github.com/google/googletest/`

- Python: https://www.python.org/

This research has made use of SAOImage DS9, developed by Smithsonian Astrophysical Observatory. SAOImage DS9 can be obtained from http://ds9.si.edu.

8 Third-party Licenses

Third-party licenses are reproduced in this section in order to allow binary distributions of OSKAR.

8.1 The NVIDIA CUDA toolkit

The End-User License Agreement (EULA) that covers use of the NVIDIA CUDA toolkit is available at the following URL:

https://docs.nvidia.com/cuda/eula/

OSKAR may link to the CUDA Runtime Library and CUDA FFT Library. The CUDA Runtime Library and CUDA FFT Library are copyrighted by and are property of NVIDIA Corporation.

As per the terms in Attachment A of the NVIDIA EULA, binary package installers may redistribute copies of the CUDA Runtime Library and CUDA FFT Library.

8.2 The FFTPACK 5 FFT library

FFTPACK is a product of the Computational and Information Systems Laboratory at the National Center for Atmospheric Research (NCAR).

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Developed by NCAR's Computational and Information Systems Laboratory, UCAR, www2.cisl.ucar.edu.

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8.3 The LAPACK linear algebra library

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8.4 The DIERCKX spline fitting library

Copyright (c) Paul Dierckx, 1993

Reference:
Paul Dierckx, Curve and Surface Fitting with Splines, Oxford University Press, 1993

8.5 The Qt GUI framework

Qt is available under the GNU Lesser General Public License version 3.

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Contact: http://www.qt.io/licensing/

Reference: GNU Lesser General Public License, version 3:

http://www.gnu.org/licenses/lgpl-3.0.html

8.6 The casacore Measurement Set library

Copyright (C) 1996,1997,1998,2000,2001,2002,2003
Associated Universities, Inc. Washington DC, USA.

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8.7 The CFITSIO FITS file library

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8.8 The Random123 random number generator

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8.9 The ezOptionParser command line parser

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8.10 The Tiny Template Library

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8.11 The RapidXML XML parser

Revision History

Revision	Date	Modification
1	2012-04-23	Creation.
2	2012-04-27	Added reference to theory of operation document.
3	2012-11-23	Added reference to binary file format description.
4	2013-03-01	Added references to documents for pointing files and MATLAB interface for OSKAR 2.2.0.
5	2013-11-26	Added summary of OSKAR features (moved from the release notes document) and updated file names of settings and release notes documents.
6	2014-07-16	Updated feature summary and roadmap for OSKAR 2.5.0.
7	2015-04-27	Updated FAQ and roadmap. Added attribution for use of Random123 library.
8	2017-10-26	Updated FAQ. Added License section and reproduced third-party licenses to allow for binary distributions.