The Journal of Open Source Software

pyro: a framework for hydrodynamics explorations and prototyping

Alice Harpole[1], **Michael Zingale**[1], **Ian Hawke**[2], **and Taher Chegini**[3]

1 Department of Physics and Astronomy, Stony Brook University **2** University of Southampton **3** University of Houston

DOI: 10.21105/joss.01265

Software

- Review
- Repository
- Archive

Submitted: 15 February 2019
Published: 22 February 2019

Summary

`pyro` is a Python-based simulation framework designed for ease of implementation and exploration of hydrodynamics methods. It is built in a object-oriented fashion, allowing for the reuse of the core components and fast prototyping of new methods.

The original goal of `pyro` was to learn hydrodynamics methods through example, and it still serves this goal. At Stony Brook, `pyro` is used with new undergraduate researchers in our group to introduce them to the ideas of computational hydrodynamics. But the current framework has evolved to the point where `pyro` is used for prototyping hydrodynamics solvers before implementing them into science codes. An example of this is the 4th-order compressible solver built on the ideas of spectral deferred corrections (the `compressible_sdc` solver). This implementation was used as the model for the development of higher-order schemes in the Castro hydrodynamics code (Almgren et al., 2010). The low Mach number atmospheric solver (`lm_atm`) is based on the Maestro code (Nonaka et al., 2010) and the `pyro` implementation will be used to prototype new low Mach number algorithms before porting them to science codes.

In the time since the first `pyro` paper (Zingale, 2014), the code has undergone considerable development, gained a large number of solvers, adopted unit testing through pytest and documentation through sphinx, and a number of new contributors. `pyro`'s functionality can now be accessed directly through a `Pyro()` class, in addition to the original commandline script interface. This new interface in particular allows for easy use within Jupyter notebooks. We also now use HDF5 for output instead of Python's `pickle()` function. Previously, we used Fortran to speed up some performance-critical portions of the code. These routines could be called by the main Python code by first compiling them using `f2py`. In the new version, we have replaced these Fortran routines by Python functions that are compiled at runtime by `numba`. Consequently, `pyro` is now written entirely in Python.

The current `pyro` solvers are:

- linear advection (including a second-order unsplit CTU scheme, a method-of-lines piecewise linear solver⋆, a 4th-order finite-volume scheme⋆, a WENO method⋆, and advection with a non-uniform velocity field⋆)
- compressible hydrodynamics (including a second-order unsplit CTU scheme, a method-of-lines piecewise linear solver⋆, and two 4th-order finite-volume schemes, one with Runge-Kutta integration and the other using a spectral deferred corrections method⋆)
- diffusion using a second-order implicit discretization

- incompressible hydrodynamics using a second-order approximate projection method.
- low Mach number atmospheric solver*, using an approximate projection method.
- shallow water equations solver*

(solvers since the first `pyro` paper are marked with a *). Also, new is support for Lagrangian tracer particles, which can be added to any solver that has a velocity field.

Acknowledgements

The work at Stony Brook was supported by DOE/Office of Nuclear Physics grant DE-FG02-87ER40317 and DOE grant DE-SC0017955.

References

Almgren, A. S., Beckner, V. E., Bell, J. B., Day, M. S., Howell, L. H., Joggerst, C. C., Lijewski, M. J., et al. (2010). CASTRO: A New Compressible Astrophysical Solver. I. Hydrodynamics and Self-gravity. *Astrophysical Journal*, *715*, 1221–1238. doi:10.1088/0004-637X/715/2/1221

Nonaka, A., Almgren, A. S., Bell, J. B., Lijewski, M. J., Malone, C. M., & Zingale, M. (2010). MAESTRO: An Adaptive Low Mach Number Hydrodynamics Algorithm for Stellar Flows. *Astrophysical Journal Supplement*, *188*, 358–383. doi:10.1088/0067-0049/188/2/358

Zingale, M. (2014). pyro: A teaching code for computational astrophysical hydrodynamics. *Astronomy and Computing*, *6*, 52–62. doi:10.1016/j.ascom.2014.07.003