Development of the Persistent Actor Framework (PAF) version of the European Transport Simulator (ETS)

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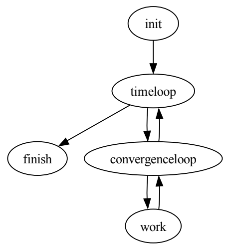
The first version of the ETS was developed within the EFDA Work Package on Integrated Tokamak Modelling [ETS-2008, ETS-2010a, ETS2010b]. That version was essentially a Fortran workflow using Consistent Physical Objects (CPOs)[CPO-2010] to couple a number of codes providing the standard building blocks of a core plasma simulation (equilibrium codes, the calculation of sources and transport coefficients, and the transport solver). To allow for the inclusion of components in other languages, KEPLER [KEPLER-2006] was used as a coupling environment [ETS-2012, ETS-2013a, ETS-2013b, ETS-2014, ETS-2018, ETS-2019, ETS-2021a], and after some years of using CPOs, these were replaced by Interface Data Structures (IDSs) [IMAS-2015] [ETS-2020, ETS-2021b, ETS-2022, ETS-2024]. This has been in use for a number of years, but the decision has been made to look at other coupling frameworks. This contribution describes the development of the ETS-PAF, which uses the MUSCLE3 framework [MUSCLE3-2020] to couple the various physics modules (mostly in fortran, C or C++), together with python modules to implement some of the workflow logic. The workflow takes the form of a number of separate programs (currently about 60) that communicate IDSs to other programs via one-way communication channels (currently about 150) sending/receiving IDSs.

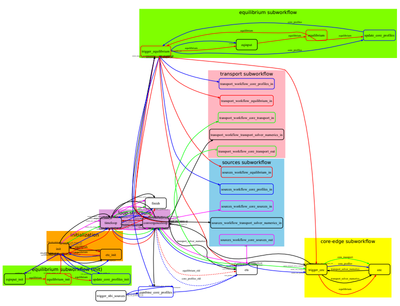
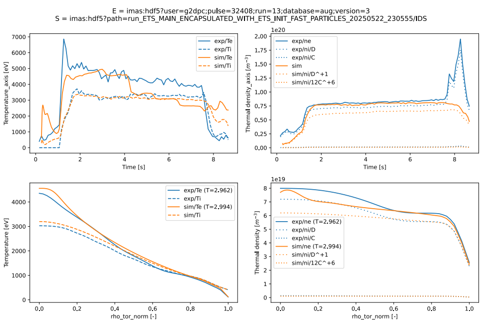
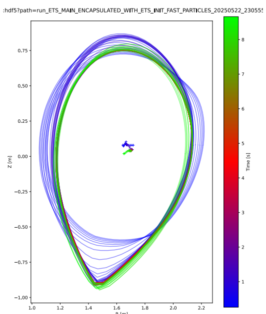
[1]*This work has been carried out within the framework of the EUROfusion Consortium, funded by the European Union via the Euratom Research and Training Programme (Grant Agreement No 101052200 — EUROfusion). Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Commission. Neither the European Union nor the European Commission can be held responsible for them.*

Minimal changes are needed to the physics codes, and scalar, OpenMP, MPI and hybrid codes are seamlessly supported for the components, and the MUSCLE3 framework will ensure that separate models will be run in parallel if the dataflow allows it. Test workflows have been implemented for AUG, JET and ITER. A MUSCLE3 workflow is represented in a YAML file which describes the components of the workflow, the connections between these components, the resources required by these components, the actual program to be run to instantiate the components, and the settings to be used. The Persistent Actor Framework (PAF) adds some restrictions to the normal MUSCLE3 – the only data to be transferred between components are Interface Data Structures (IDS) [described in IMAS-2015]



A prototype of the ETS workflow (with no physics) is given by the figure on the right. Initial data is read from the database by "init", serialized and then sent to "timeloop". Until the run has finished, "timeloop" sends data to "convergenceloop"; "convergenceloop" sends IDSes to "work" and receives results back, and iterates until convergence. Once convergence has been achieved, "convergenceloop" sends converged time-steps back to "timeloop". Once all of the time-steps have been completed, "timeloop" sends final results to "finish". In this no-physics version, "timeloop" performs a fixed number of time-steps, and "convergenceloop" performs a fixed number of iterations. This workflow is one of the test cases run in the CI/CD pipeline at every commit.

A more complicated workflow is shown below, which shares some common features with the simple workflow above. To make the workflows more maintainable, separate sub-workflows have been created to implement the calculation of sources and transport coefficients, which are then "used" by the main ETS workflow. These are represented as pink and blue blocks in the diagram below (left).

The results on the above middle show a comparison of the predicted temperature and density profiles based on a simulation with RABBIT [RABBIT-2018] for NBI heating, TORBEAM [TORBEAM-2018] for ECRH, NCLASS [NCLASS-1997] for neoclassical transport and

Bohm-GyroBohm [BGB-1999] for anomalous transport. CHEASE [CHEASE-1995] was used to solve for the equilibrium, with a plasma boundary provided by the reference shot.

The ETS-PAF repository [https://ets.pages.eufus.psnc.pl/ets_paf/, soon to be open source], contains a collection of workflows, about 65 python actors, and scripts that can be used to visualize results. Documentation can be found at https://ets.pages.eufus.psnc.pl/ets_paf/ which contains information about the available workflows and actors, as well as tutorials. Most of the workflows rely on external physics actors written in Fortran or C/C++. Many of these actors are shared with the KEPLER version of the ETS, and can be made available as Kepler actors, Python actors or PAF actors using IMAS tools.

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