

auto-AUTO: A Python Layer for Automatically Running the AUTO-07p Continuation Software

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Summary

auto-AUTO (or AUTO²) is a Python package that acts as an intermediate layer between the user and AUTO-07p continuation software (Doedel et al., 2007) (AUTO from here on). auto-AUTO automates the running of AUTO by monitoring the continuation, while also keeping track of bifurcation points. The package can automatically continue along these branching points, and continue branching along further bifurcation points to attempt to construct full bifurcation trees. To achieve this in a reliable way, AUTO computations are managed by auto-AUTO by setting appropriate stopping conditions, such as meeting other branches, looping branches, and specified bifurcations. These stopping conditions supplement the usual AUTO bounds and ensure that branches of detected solutions are unique and well defined.

In addition, auto-AUTO provides a comprehensive and documented Python API to investigate properties of the computed continuations and solutions. auto-AUTO can be run in Jupyter notebooks (Kluyver et al., 2016) and the results can be plotted with Matplotlib (Hunter, 2007) using predefined plotting methods (see Figure 1). This facilitates the integration of the results from AUTO with other Python workflows.

Statement of Need

AUTO is a highly optimised and tested continuation code base, and for this reason is one possible choice for use in bifurcation analysis studies when the number of variable is higher than 10. However, the use of AUTO in continuation analysis requires a steep learning curve as the existing Python integration is limited. In addition, there is limited support for automated tracking and continuation of branching points in AUTO. Therefore, when faced with problems of great complexity (typically when the dimensionality of the problem is greater than 10), the user must engage in a long and tedious analysis, restarting the computations many times, with the risk of losing tracks of computation and missing key elements in the process. This package aims to solve this problem, by automating the running of AUTO, and by systematizing the investigation of branching points.

auto-AUTO is currently used by the authors to investigate the bifurcations and stability of a coupled land-atmosphere model (Hamilton et al., 2025) using the qgs model (Demaeyer et al., 2020). This is part of a wider research project on the concept of climate tipping points (Armstrong McKay et al., 2022; Ashwin et al., 2012; Lenton et al., 2008; Wunderling et al., 2021), and which typically involves bifurcation analysis in high-dimensional dynamical systems¹. For this reason, robust but easy to use continuation software is of great importance in this analysis.

¹Although conceptual models, with a relatively low number of degrees of freedom, are still used extensively in increasing our knowledge about tipping points (Wunderling et al., 2021).

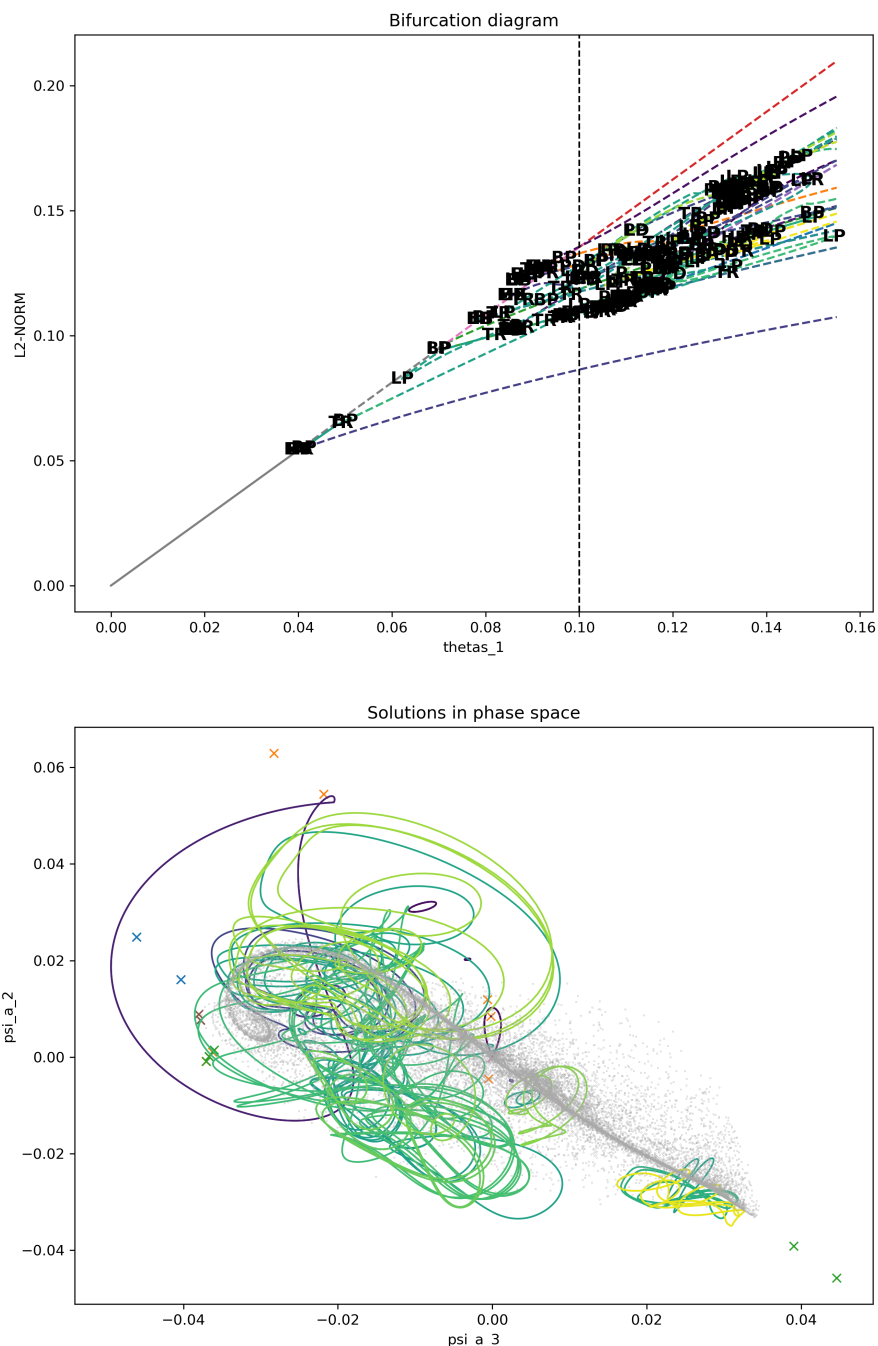


Figure 1: Example of plots using auto-AUTO functionalities to study a high-dimensional model (from the RP1982 example notebook studying the Reinhold and Pierrehumbert 1982 model (Reinhold & Pierrehumbert, 1982)).

Existing Alternatives

Over time, and alongside the development of AUTO, many tools were introduced to help the users deal with the complexity of the output data stream of AUTO. We can mention for example XPPAUT (Ermentrout, 2012), which provides a frontend to AUTO, making it easy to

continue the solutions to boundary value problems as well as equilibria, fixed points, and limit cycles (Ermentrout, 2007).

Another more recent development is [PyCoBi](#), which “provides a Python interface to Auto-07p, allowing for a more intuitive usage of Auto-07p commands within Python scripts.” (Gast, 2025)

Other bifurcation analysis software must also be mentioned here:

- BifurcationKit.jl (Veltz, 2020)
- PyDSTool (Clewley et al., 2007)
- Other useful tools can be found at <https://dsweb.siam.org/Software>

However, to the best of the authors' knowledge, these tools do not provide automatic continuation features relevant to the problems raised in the [Statement of Need](#). PyCoBi proposes limited automatic generation for codimension-2 bifurcation diagrams (regime diagrams), a feature that is also planned in auto-AUTO future developments.

Future Developments

Future development plans for auto-AUTO include:

- Automatic continuation of regime diagrams, i.e., codimension-1 bifurcation branch tracking and detection of codimension-2 bifurcations by AUTO (regime diagrams)
- Investigation of the formalization and abstraction of automatic continuation using graph theory, leveraging the functionalities already available in auto-AUTO, and allowing for a more insightful construction of the diagrams

However, while the latter proposed development is an obvious way to pursue the development of auto-AUTO, it is presently out of the scope of the authors' research.

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