Graph-based Methods for Orbit Classification

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Abstract

An important step in the quest for low-cost fusion power is the ability to perform and analyze experiments in prototype fusion reactors. One of the tasks in the analysis is the classification of orbits in Poincaré plots generated by the particles in a fusion reactor as they move within the toroidal device. In this paper, we describe the use of graph-based methods to extract features from orbits. These features are then used to classify the orbits into several categories. Our results show that existing machine learning algorithms are successful in classifying orbits with few points, a situation which can arise in data from experiments.

Keywords: orbit, Poincaré plot, classification.

1 Introduction

The quest for low-cost fusion power has led to the construction of devices such as the National Compact Stellarator Experiment (NCSX) at the Princeton Plasma Physics Laboratory (PPPL). These devices allow physicists to perform magnetic confinement experiments which determine the best shape for the hot reacting plasma and the magnetic fields necessary to hold it in place. In addition, advances in computational resources have made possible the computational simulation of these experiments in three dimensions over time. This allows the physicists to design new reactors and select the parameters to be used in experiments. The experimental results are, in turn, used to validate the simulations. Thus, the analysis of data from both simulations and experiments is a key step in the understanding and development of fusion reactors.

Figure 1 shows the schematic of the NCSX. A particle moving around the torus will trace out a three-dimensional trajectory over time. Consider a plane intersecting the torus perpendicular to the magnetic axis–a vertical slice through the torus. Let a point in this plane be the intersection of the trajectory of the particle with the plane as it starts to move through the torus. After it completes one round through the torus, it will likely intersect the plane at a different point. The intersections of this trajectory with the plane form an orbit.

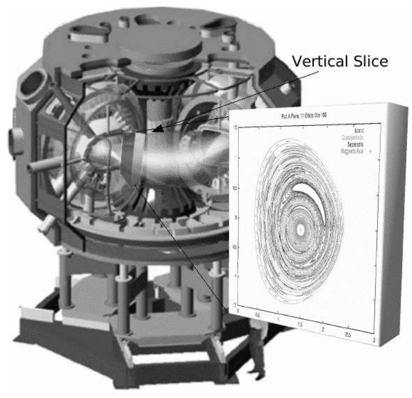

Figure 1: A schematic of the NCSX reactor. Inset shows a plane perpendicular to the magnetic axis illustrating the intersections of the particles.

Depending on the shape of the orbit, it can be assigned a class label. Figure 2 depicts three different orbits: a separatrix, an island chain, and a quasi-periodic orbit. There is also an additional class of stochastic orbits, which we will not consider in the present analysis. Note that the quasi-periodic orbit appears to be a closed curve with no apparent width. The island chain orbit has two distinct islands in this example. The separatrix orbit appears closed but has radial gaps called lobes; there are two such lobes in this orbit. Typically, all the orbits on a plane are provided together in what is referred to as a "puncture plot" or a "Poincaré plot", as in Figure 1, inset.

Orbits from computer simulations usually consist of a thousand or more points. In contrast, plots from experiments consist of 50 to 100 noisy points, which may be too few to correctly identify the shape. In our work, we will consider how the accuracy of a classifier changes as the number of points in an orbit is reduced. If we can correctly classify orbits using a few points, it reduces the time for the extraction of features and leads to a faster turnaround in the analysis.

We next briefly describe our approach to the classification of orbits. Further details are available in [1, 2].

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