論 文 の 内 容 の 要 旨

論文題目　Extracting and Visualizing Singular Fibers for the Analysis of Multivariate Data
(多変量データ解析のための特異ファイバー抽出と可視化)

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Scalar topology has provided computational tools that analyze and visualize data from scientific and engineering tasks. It became popular since exploring the topology of an isocontour of a function allows us to effectively encode the singularities embedded in the scalar field. This has often been accomplished by characterizing the topological transitions of such isocontours. For multivariate functions, isocontours generalize to fibers – inverse images of points in the range, and therefore this area is known as fiber topology.

However, establishing computational techniques for fiber topology of multivariate functions has had difficulties. Especially, extracting and visualizing the complex topology of a fiber, from the discrete set of sampling points has been a challenge.

Therefore, this thesis aims at establishing visualization techniques for fiber topology of multivariate functions. This includes extracting fiber topology for numerical data, exploring it, and eventually finding an application to visualizing realistic data. We target the multivariate functions in the form of $R^3 \rightarrow R^2$, since they are the simplest situation that has non-trivial topology, and the topology of fiber is classified in the singular fiber theory. Furthermore, it has analogies to the higher dimensional cases, and thus we can accumulate knowledge for visualizing multivariate topology in higher dimensional cases. The central idea of this work is to extract and visualize fiber topology on the basis of singular fiber theory. The advantage of this approach is that we can understand fibers, i.e. distribution of function values, with their connectivity across different function values.

The contributions are threefold. Firstly, we extract and identify the singular fibers, which characterizes the topological changes in the inverse images. Here, we also extract how the boundary of the domain interferes with the distribution of the values. This describes the complete fiber topology. To achieve these, the key idea is to extract the connectivity of fibers in the interior of data and that on the boundary. We demonstrate the descriptiveness of the approach by showing the results for test datasets.

Secondly, we apply our approach for exploring the fiber topology of analytic functions. Since finding a concrete use case is inevitable for designing a user interface, we target domain experts of fiber topology, making it possible to obtain informative feedbacks. In the discipline, exploring fiber topology has relied on manual visualization, which has had limitations on analyzing complicated topologies. In contrast, the interface can provide intuitive visualization by taking advantage of user interactions. Especially, it can show the connectivity of inverse images, their topological shapes, and their geometrical configuration in the domain. Such visualization can respect the conventional methods among domain experts, while offering new tools for providing further insight. For the evaluation, we set up a user study, in which an expert and learners of fiber topology verified the usability of our exploration interface.

Finally, we apply our approach to realistic data, in order to assess how well our approach fits to data with larger amount of singular fibers. We choose time-varying scalar field for the popularity of topology in this application. The advantage of popularity is that we have a better chance of finding collaborators, thus further applications. Again for the popularity, we extract and visualize the critical points, i.e. the points in domain at which the topological change of a fiber occurs. Existing techniques for visualizing critical points cannot reduce the number of critical points, especially regarding their continuity in time. In contrast, the proposed scheme overcomes this situation by setting time as an auxiliary function, and simplifying the underlying multivariate topology. The user can analyze data by controlling the level of details for the region of interest. We evaluate our approach by applying it to plasma simulation datasets.

To summarize the work, we discuss the effectiveness of our approach as a whole.