Master Student Project Proposal

AI-Enhanced PDE-based Parameterization Approach for Isogeometric Analysis

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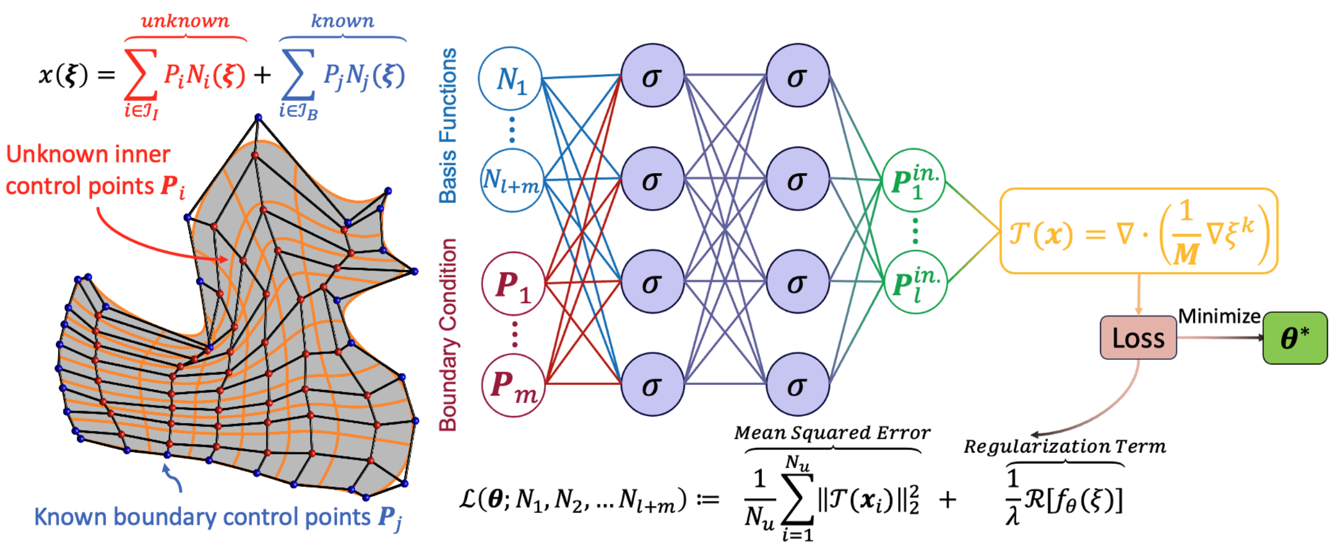

Figure 1: Crucial to isogeometric analysis, analysis-suitable parameterization involves determining unknown inner control points $\boldsymbol{P}_i$ from the boundary representation. It must ensure bijectivity and minimize angle and volume distortion for effective downstream simulation. This project endeavors to augment the existing PDE-based parameterization technique with the application of Physics-Informed Neural Networks (PINN), aiming to significantly enhance its capabilities and precision.

Description

Isogeometric analysis (IGA) has brought a paradigm shift in integrating Computer-Aided Design (CAD) and Computer-Aided Engineering (CAE). A critical step of IGA is to construct analysis-suitable parameterization of physical domains. Essential to this process is the construction of a spline-based parameterization, $x(\xi)$, from the Boundary Representation (B-Rep) of a physical domain.

Over the years, the supervisor's team has been involved in this field, developing robust PDE-based techniques for analysis-suitable parameterization [1]. Building on Physics-Informed Neural Networks (PINNs), our group has recently integrated physics-informed machine learning with the Isogeometric Analysis (IGA) framework, resulting in what we term IgANets. These networks are trained in a resource-intensive offline phase to accurately forecast the coefficients of solutions represented in B-Spline/NURBS form, enhancing the IGA process.

This project aims to leverage the strengths of IgANets [2] to enhance the existing PDE-based parameterization approaches. By integrating IgANets, the project seeks to improve the precision and efficiency of these techniques. The open-source IGA library G+Smo (Geometry + Simulatio Modules) that is developed by the supervisor's group together with colleagues in Europe can be used. Then implementations of different parameterization techniques developed by our group are available.

Milestones

- **Literature Review and Conceptual Framework**:
  - Conduct a comprehensive review of existing literature on analysis-suitable parameterization techniques for IGA and Physics-informed machine learning embedded into isogeometric analysis (IgANets).
  - Develop a conceptual framework for integrating IgANets into PDE-based parameterization.
- **Methodological Development**:
  - Formulate the mathematical and computational models for the enhanced parameterization technique.
  - Explore and finalize the neural network architecture and training methods for IgANets.
- **Implementation and Testing**:
  - Implement the proposed models and conduct initial tests to validate the models.
  - Refine the methodologies based on preliminary results and apply the developed method to complex physical domains.
  - Analyze the performance in comparison to the existing parameterization techniques.
- **Documentation and Dissemination**:
  - Document the research findings, algorithm design, and testing results.
  - Prepare a comprehensive thesis and presentation.

Prerequisites

Basic knowledge of linear algebra and numerical analysis is required. Good knowledge of at least one programming language is required, preferably Python or Julia. Experience with NURBS will be helpful.

References

[1] Y. Ji, K. Chen, M. Möller, C. Vuik, On an improved pde-based elliptic parameterization method for isogeometric analysis using preconditioned anderson acceleration, Computer Aided Geometric Design 102 (2023) 102191.

[2] M. Möller, D. Toshniwal, F. van Ruiten, Physics-informed machine learning embedded into isogeometric analysis, KEY ENABLING TECHNOLOGY FOR SCIENTIFIC MACHINE LEARNING 57 (2021).