Multi-physics couplings using isogeometric analysis

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Context

The current situation, marked by the need to reduce our environmental impact and the scarcity of raw materials, leads to a deep questioning of the current production solutions and makes the development of multi-physics optimal design tools critical. In this context, ACUMES Project-Team (http://team.inria.fr/acumes), joined team from Inria Sophia-Antipolis Research Center and mathematics laboratory Jean-Alexandre Dieudonné at Université Côte d'Azur, conducts research activities on the analysis and optimization of systems governed by PDEs (Partial Differential Equations), with applications ranging from fluid and structural mechanics to modeling of biological phenomena, road and pedestrian traffic.

For some years, a new simulation paradigm has been emerging, the *isogeometric analysis*, which consists in solving partial differential equations by a variational approach, using NURBS (Non-Uniform Rational B-Spline) bases originating from CAD (Computer-Aided Design). This approach has the advantage to allow a resolution without geometrical approximation, i.e. with a computational domain supported *exactly* by the CAD geometry, contrary to methods based on classical piecewise linear grids that approximate the geometry. Consequently, isogeometric analysis relies on a unique high-order representation for both the geometry and the fields to solve, yielding a significant gain in terms of accuracy and ease of interaction. This approach has been popularized by T. Hughes [CHB09], mainly for elliptic and parabolic problems.

ACUMES Project-Team has recently proposed a formulation dedicated to hyperbolic systems, based on a Discontinuous Galerkin method [Duv18, Duv20, PD21]. This approach has been applied to compressible aerodynamics in the context of Euler and Navier-Stokes equations including local refinement, shock capturing and moving meshes.

Objective

The aim of this work is to study the extension of the proposed isogeometric Discontinuous Galerkin method to multi-physics problems, e.g. aero-elasticity, for which different PDE models interact through a common geometrical interface. The isogeometric paradigm has a great potential for such problems because NURBS properties allow to define the coupling interface as a parameterized surface that matches exactly the curved meshes on both sides whatever their respective size. For instance, one can use a coarse mesh for the structural model and a fine mesh for the fluid model without any holes or overlap at the interface, which is not possible using classical piecewice linear grids. The objective of the work is therefore to investigate the coupling strategies in this context, quantify the gain in terms of accuracy and ease of interaction.

Work to achieve

The doctoral student will be part of ACUMES Project-Team at Inria Sophia-Antipolis Research Center. At first, he/she will have to formalize the model coupling in the context of the isogeometric method. Fluid-structure interactions are espacially targeted, by using a continuous Galerkin formulation for the structural model and a discontinuous one for the fluid model. The coupling between the two models will be achieved by an exchange of data (efforts, displacements) through the common parameterized interface. He/she will in particular investigate different exchange strategies and time integration approaches.

On the basis of the open-source code Igloo (https://gitlab.inria.fr/igloo/igloo/-/wikis/home) solving Euler/Navier-Stokes equations on NURBS domains, the doctoral student will implement the proposed approaches and will conduct a set of numerical tests based on academic and then industrial problems, in order to qualify the methods and quantify their accuracy. The targeted applications concern compressible flows around airfoils or tubine blades.

Profile

The candidate must hold a Master's degree (or equivalent) in scientific computing / applied mathematics. Knowledge in C ++ is required. An experience in numerical simulation, high-performance computing, high-order schemes is a plus.

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Link: http://team.inria.fr/acumes

Duration: 3 years

Location: Inria Sophia-Antipolis Research Center

Salary: around 2000€(without tax)

References

[CHB09] J.A. Cottrell, T.J.R. Hughes, and Y. Bazilevs. *Isogeometric analysis : towards integration of CAD and FEA*. John Wiley & sons, 2009.

[Duv18] R. Duvigneau. Isogeometric analysis for compressible flows using a Discontinuous Galerkin method. *Computer Methods in Applied Mechanics and Engineering*, 333(443–461), 2018.

[Duv20] R. Duvigneau. CAD-consistent adaptive refinement using a NURBS-based Discontinuous Galerkin method. *Int. J. for Numerical Methods in Fluids*, February 2020.

[PD21] Stefano Pezzano and Régis Duvigneau. A NURBS-based Discontinuous Galerkin method for conservation laws with high-order moving meshes. *Journal of Computational Physics*, 434(1), 2021.