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UNTRIMMED SPLINES I: ANALYSIS SUITABLE CAD

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ABSTRACT

Current CAD technologies describe geometry by means of the boundary representation or simply B-rep. Boolean operations, ubiquitous in computer aided design, use a process called trimming that leads to a non-conforming description of geometry that is un-editable and incompatible with all downstream applications, thereby inhibiting true interoperability across the design-through-analysis process.

We propose a modeling paradigm in which designers are given the tools to create watertight, editable and conforming descriptions of geometry with interactive control over the boundary surface parameterization.

The methodology is based on recent advances in topological vector field design and processing. First, a smooth frame field is computed, by minimizing an appropriate energy functional on a background mesh of the initial B-rep, that is compatible with sparse or dense input constraints on alignment and size [1]. Frame-field singularities, which together satisfy the topological invariant known as the Poincaré-Hopf theorem, are automatically placed and can be modified by the user. The frame field is used as a guide for the re-parameterization [2] of the initial B-rep into a conforming watertight and editable spline description.

In line with the main rationale of isogeometric analysis, the meshing and re-parameterization techniques are applied within CAD as part of the design process, instead of as a post-processing step. The modeling tools actively support the design, analysis and manufacturing process as a whole, enabling true interoperability across these different disciplines and thereby support efficient product development.

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QUAD/HEX AUTO-PARTITIONING OF CAD FOR IGA

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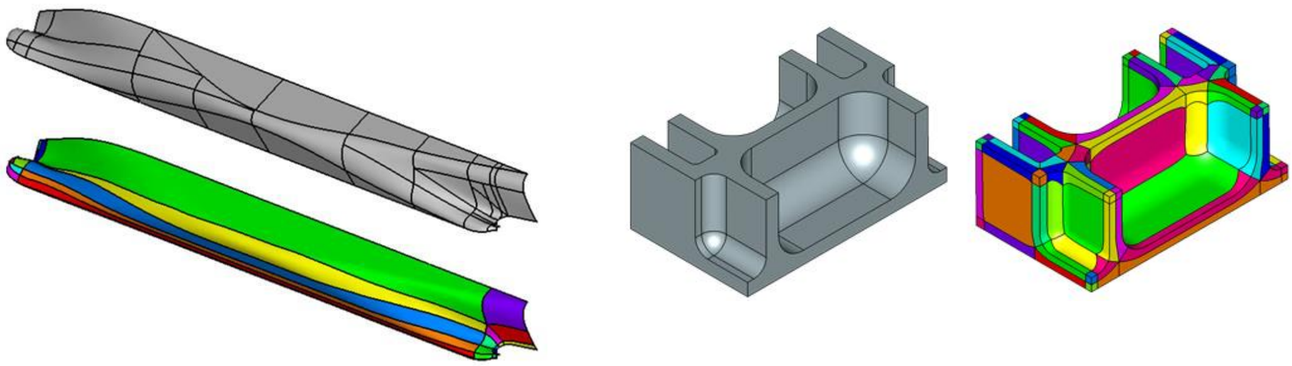
ABSTRACT

ITI has been working in the field of CAD geometry re-use for simulation for many years, delivering novel solutions via its commercial CADfix product. In recent years ITI R&D efforts have been focused on automating the decomposition of complex CAD models in to simpler non-manifold block/partition representations. The driving motive behind automatic partitioning being to enable faster, more accurate and more efficient quad/hex mesh generation for CAE simulation. The partitioning tools being developed start from standard commercial CAD geometry, e.g. trimmed B-Rep surfaces and volumes. The medial axis transform[1] and cross-fields[2] are two key enabling technologies behind the 2D and 3D partitioning algorithms. Below are examples of the partition tools applied to CAD surface and volume geometry:



In this presentation we will present the philosophy behind the ITI CAD partitioning tools and demonstrate their current status on real-world CAD geometry. The presentation will attempt to draw comparisons between the partitioning goals for traditional quad/hex mesh generation and ITI's current understanding of the partitioning needs for IGA.

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STANDARDIZATION AND INNOVATIVE APPLICATIONS ESSENTIAL FOR DEPLOYMENT OF IGA IN INDUSTRY

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ABSTRACT

Two of the ongoing challenges for the deployment of IGA in industry are the availability of industrial accepted solutions (CAD, FEA) and the legacy and bulk of preexisting digital information. Rather than focusing on application areas dominated by FEA, IGA should focus on novel application areas where fewer established solutions exist and the legacy of exiting digital information is minor. One such area is additive manufacturing (AM). In AM, trivariate spline representations are superior to traditional finite elements with respect to representation of variable and anisotropic material, whilst preserving geometric quality of the design model.

However, even for AM, a prerequisite for deployment of IGA on a broad scale is near seamless interoperability between boundary structure (B-rep) CAD and IGA. The integration of sculptured surfaces (B-splines and NURBS) into solid CAD models (B-rep) was a central research topic in the 1980s, then standardized as part of ISO 10303 (STEP) in the 1990s. The development of B-rep CAD focused on the needs of CAM (Computer Aided Manufacturing) where small gaps between surfaces were not regarded as a major issue. STEP was introduced to provide interoperability between CAD-systems. Direct translators between CAD-systems are still in wide use as they can exchange information not supported by STEP. However, for product life cycle management (PLM) and long-term archiving and storing (LOTAR) the use of standards is important for ensuring that data is accessible also in the future. There is no guarantee that vendor proprietary formats will have future support.

For these reasons, STEP has been the natural standard to augment with IGA capabilities. The EC Factories of the Future Project TERRIFIC (2011-2014) focused on trivariate spline models and IGA. TERRIFIC proposed several extensions to STEP to support IGA with respect to Locally Refined Splines (T-splines, LR B-splines), in addition to trivariate spline models. Some of these extensions have been published as part of STEP in 2018. In the EC Factories of the Future Project CAxMan [1] (2015-2018) the STEP work of TERRIFIC has been continued. Further augmentations of STEP related to IGA are also underway supported by other members of the STEP community. The focus of the CAxMan project has been on computer assisted technologies for AM with a special attention to analysis-based design, trimmed trivariate CAD-models and IGA. This exposes IGA to an application domain where many challenges are still unsolved.

The CAxMan-project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 680448.

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Integration of Enriched Isogeometric Analysis with Commercial CAD software

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ABSTRACT

The past decade has seen rapid development of isogeometric analysis techniques (IGA, [1,2]). While the goal of IGA is to seamlessly integrate CAD with CAE, arguably much work remains to integrate IGA analysis tools with commercial CAD tools. The goal of the present study is to develop techniques to enable such integration using Enriched IGA (EIGA, [3]). In EIGA, the boundaries as well interfaces are explicitly represented by a lower-dimensional NURBS entity with additional degrees of freedom directly specified on the control points of the interface. In the present study, EIGA is implemented in a parallelized Fortran code termed OOF-HiDAC (Object-Oriented Fortran based Hierarchical Design and Analysis Code) and integrated with commercial CAD software including Rhino and Solidworks. The CAD model is imported into OOF-HiDAC as IGES files. The analysis is carried out directly on the B-rep surfaces created by the CAD software without further generating volumetric discretization. The present framework includes modules to build the approximation, compose the approximations to build more complex ones, a matrix solver and a post-processor to visualize results. Several validation problems are solved to demonstrate the framework.

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ANALYSIS SUITABLE HYBRID B-REPS AND HYBRID V-REPS FOR TRIMMED SOLIDS

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ABSTRACT

Untrimmed CAD models can be used directly in IsoGeometric Analysis (IGA) simulations, but performing volumetric simulations requires model completion. Model completion using only semi-structured B-splines or NURBS variants is a difficult problem, so a hybrid model completion has been introduced to take advantage of the properties of semi-structured trivariate B-splines near the boundary and flexibility of unstructured Bezier tetrahedra near the midstructure. However, that approach is not applicable to trimmed B-rep models that result from Boolean operations on NURBS surfaces, a sculptured Constructive Solid Geometry (CSG) model. One reason is that trimming is not represented exactly in CAD systems. In this work, we present analysis suitable hybrid representations for trimmed B-rep models for both the boundary and the volumetric representations. They keep the original surface and parameterization as much as possible, and also complete a volumetric representation. We demonstrate the models and isogeometric analysis simulations on the new hybrid representations.

DATA REPRESENTATION AND EXCHANGE ISSUES IN ISOGEOMETRIC ANALYSIS (IGA)

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ABSTRACT

Isogeometric Analysis (IGA) offers the possibility of integrating Finite Element Analysis (FEA) into conventional design tools, bridging the chasm between the current industrial verticals of Computer-Aided Design (CAD) and Computer-Aided Engineering (CAE). Although this presents a theoretical approach, one central problem inhibiting the realization in practice is that conventional CAD and CAE data representations and file formats limit the ability to store and share IGA modeling data [1]. Classical CAD-CAE implementations present historic barriers in both breadth of support (unstructured splines, local refinement, volumetric splines, etc.) [2,3], as well as adherence to the fundamental representational divide and meshing paradigm. Currently, as an alternative, users are forced to create their own definitions and file formats, rely on academic researchers' personal implementations, or use specific CAx application formats for the translation and storage of IGA data, often compromising the users' design intent. This has severely hindered both the potential for collaboration between users as well as the more critical objective: large-scale commercial adoption of IGA as an industrial technology. As part of its Digital Thread for Smart Manufacturing Project [5], The National Institute of Standards and Technology's (NIST) Engineering Laboratory (EL) has taken an active role in resolving the IGA data exchange problem. These activities have shed new insights on integrated CAx model representations (isogeometry) in a IGA-centric view, where CAD-CAE model definition is simultaneous. As such, the ISO 10303 (STEP) standard plays an indispensable role as the de facto neutral file format in the world's engineering data exchange.

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SYMMETRY-AWARE REPARAMETERIZATION

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ABSTRACT

Reparameterization of the CAD model is an effective pre-process to minimize the analysis error of isogemetric methods, especially when the model is trimmed. However, current reparameterization methods generally ignore the symmetry property of the design model, which is a powerful tool to reduce the computational cost and improve the analysis accuracy.

This research proposes a novel and fast method to detect the global and partial symmetries of the CAD model, and utilize the symmetries as guides to reparameterize the CAD model to be an isogemetric analysis-suitable model. We also present the method to automatically utilize the detected symmetries as tools to simplify the analysis process.

The methodology utilizes tools from symmetry extraction [1], directional field design [2] and surface parameterization [3]. First of all, the CAD model is approximated by a coarse triangle mesh. Secondly, a cross field is generated on the mesh vertices based on the feature curves and the local curvatures. Thirdly, the generated cross field is utilized as local shape descriptors, based on which global and local symmetries are detected. Then, by tracing the singularity of the cross field, extraordinary points are determined. The locations of the extraordinary points are further adjusted by the symmetries. The surface information of the original CAD model also plays important role at this step. Finally, the original surface is separated by the extraordinary points and the adjusted cross field as branched coverings, and each branched covering is reparameterized respectively.

With the symmetric property built in, we could do analysis for the reparameterized model with only a small portion of the original model, which means much less computational effort or higher accuracy. The result can also benefit various other applications such as computer aided manufacturing.

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UNTRIMMED SPLINES II: SEMIAUTOMATIC CONVERSION FROM TRIMMED BREPS TO WATERTIGHT MODELS

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ABSTRACT

In this work we discuss a streamlined, semiautomatic methodology to convert trimmed CAD geometries into analysis-suitable CAD geometries—built in the framework of existing CAD functionality. Through this conversion, the challenges associated with analysis of trimmed objects (which is the current bottleneck in the engineering design/analysis process) can be altogether avoided.

The techniques employed use tools from the fields of algebraic, differential, and computational topology and geometry. Using a simple mesh approximation of the original CAD geometry, a frame-field is generated that minimizes an appropriate energy of the structure [1]. To capture features (e.g. boundaries, changes in continuity) of the CAD geometry, the field is constrained using a geometry-specific metric [2]. By mapping this frame-field to a covering space and accounting for the cohomological structure of this covering space [3], a global quadrilateral parameterization (called a "quad layout") of the original CAD geometry is extracted. Extraordinary points in the quad layout correspond to singularities of the previously computed frame-field. This quad layout coarsely approximates the original CAD object in a topologically consistent manner. The quad layout serves as the scaffolding for new surface patches, which are finally mapped onto the original geometry. Appropriately constraining these mappings ensures the desired amount of continuity between patches in the rebuilt model. This process yields a trim-free, watertight, editable representation of the original object that can be immediately analyzed by existing tools.

These tools used to rebuild the trimmed geometry are constructed in existing CAD software, enabling user-interaction, visualization, and modification as desired. Ultimately, the work represents another step towards true integration of CAD and FEA, giving a streamlined approach for analysis of geometries that are not inherently analysis-suitable.

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SuperD: SubD Modeling without Subdivision

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The SuperD modeling technology employs the same modeling interface for design as recursive subdivision (SubD), but without the troublesome extraordinary points or patch clusters at those points. And no recursion. We adapt the generalized N-sided Coons patches of Varady-Rockwood, which nicely correspond to the control mesh topology. The N-sided patches also enable G^2 continuity in many cases, good triangulation, and efficient implementation. We present this technology as a candidate for use in isogeometric analysis. In spite of many advantages, like general topology handling and fast organic design, issues like L^2 integrability at isolated points loom in the corners.