GRAPES: Learning, processing and optimising shapes

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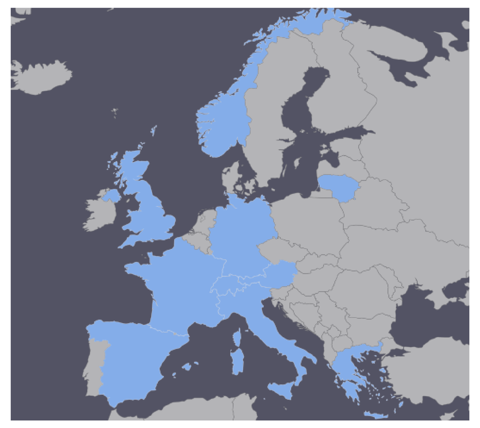
Introduction

GRAPES aims at considerably advancing the state of the art in Mathematics, Computer-Aided Design, and Machine Learning in order to promote game changing approaches for generating, optimising, and learning 3D shapes, along with a multisectoral training for young researchers. Recent advances in the above domains have solved numerous tasks concerning multimedia and 2D data. The CAD industry, although well established for more than 20 years, urgently requires advanced methods and tools for addressing new challenges.



This poster showcases several results and future plans involving geometric design, representations, reconstruction and processing suitable for manufacturing.

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A. B. Nair (Univ. Barcelona): μ-bases of translational surfaces

Translational surfaces are surfaces generated by sliding one space curve along another space curve. Due to their simplicity, these surfaces are used in geometric modelling and computer-aided geometric design. In particular, any two intersecting curves are interpolated by the translational surface generated by these curves.

Rational surfaces can be represented by a μ-**basis**, expressing the surface as the intersection of three moving planes that represent the μ-basis. Compared to other representations, the μ-basis is compact and offers computational advantages due to its low degree. A μ-basis can be used to get the implicit equation of a rational surface as well as to recover the parametric equations.

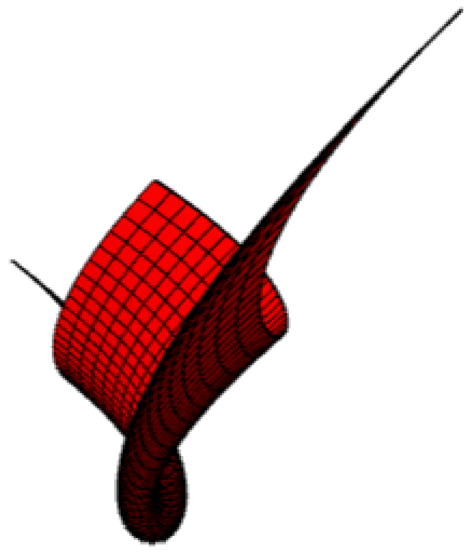
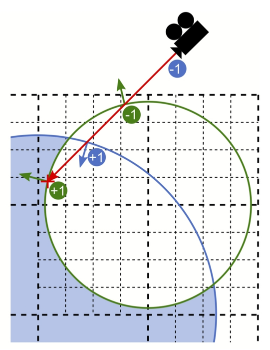


Figure: Translational surfaces generated by sliding a twisted cubic along itself.

This project aims to develop an algorithm for finding the μ-basis of a translational surface from its generated curves, as well as finding degree bounds.

C. Checa (ATHENA): Symmetry and structure for geometric processing

This project seeks to develop efficient algorithms for exploiting the symmetry and structure of algebraic varieties in order to solve problems in geometric processing. Our starting point is the algebraic and combinatorial study of optimal representations for the **(sparse) resultant**. We focused on specific important instances that admit a complete characterization but also study theoretically efficient computational methods for the general case.



We aim to apply our algorithms to handle objects given implicitly, parametrically, point clouds, or by powerful and **novel representations** such as matrix representation. We target problems from our industrial partners: self-intersection for **milling**, (choice of milling tools, computing envelopes), computation with offsets, (esp. circular meshes), distance measurement for error estimation of milling simulations, and surface intersection for swept volume computation.

A. Berzins (SINTEF): Neural implicit reps for design and digital twin

Classic geometry representations in CAD were developed to accommodate classic manufacturing techniques. Their recent advances (AM, CAM) also demand advances in shape representations to be able to deal with more complex, **freeform shapes** with rich topologies and **heterogeneous materials**. Similarly, quality management trends in Industry 4.0 also require the ability to digitize and computationally process the manufactured parts. Neural networks, specifically **neural implicit representations**, have recently gained the ability to represent complex, detailed, smooth and watertight shapes with topological flexibility, while being very compact to store. In this project, we investigate the use of neural implicit representations for both design and digital-twin needs, including shape and topology optimization, generative design, geometric modeling, and simulation.

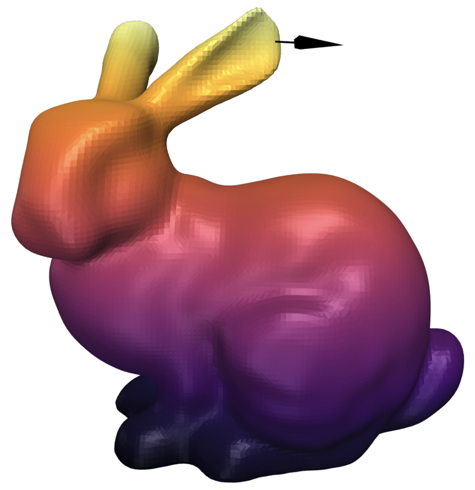
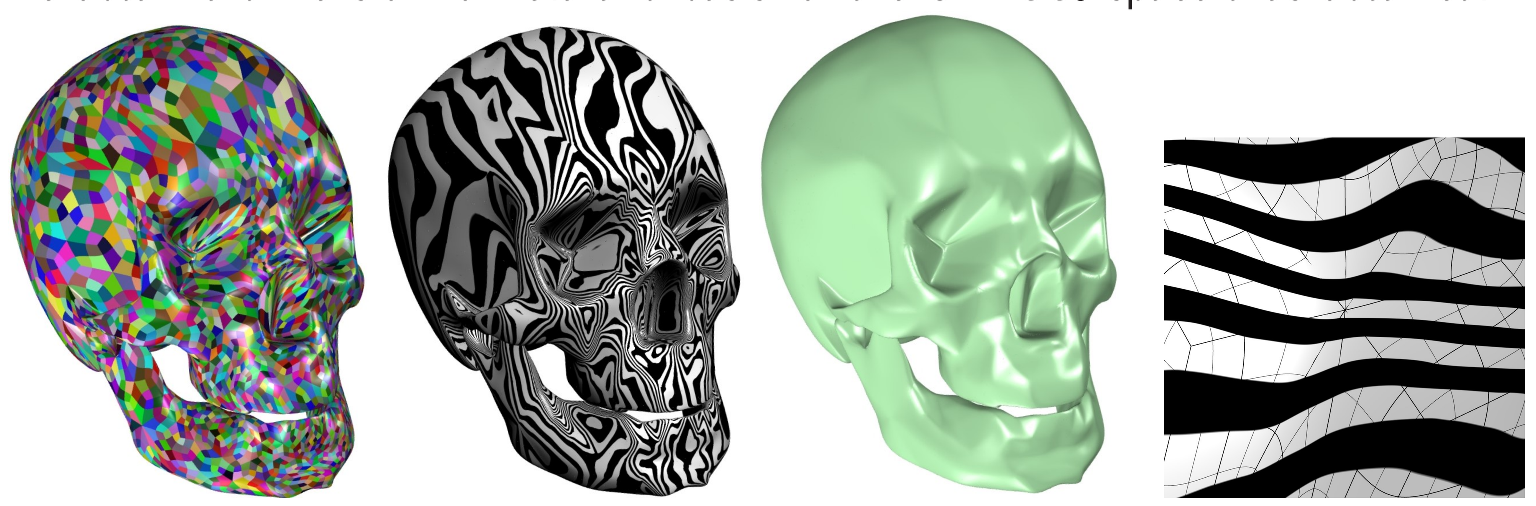


Figure: Normalized displacement of bending an ear and fixing the base of a thin-shell bunny. Both the geometric model and the deformation are represented using neural fields.

M. Marsala (INRIA): G^1-smooth Approximate Catmull-Clark scheme

Subdivision schemes are widely used numerical methods to reconstruct smooth curves or surfaces starting from a small number of points. The **Approximate Catmull-Clark smoothing scheme** generates a limit surface with reduced regularity at some special points, causing a bad rendering of the surface at these extraordinary vertices. To obtain a good rendering everywhere, we modify the scheme to impose $\mathbf{G^1}$ **continuity** on its degree elevated biquintic masks. In addition we obtain a dimension formula and basis for the G^1 ACC5 space thus obtained.



P. González-Mazón (INRIA): Birational 3D Free-Form Deformations

Free-Form Deformation (FFD) stands for a simple and intuitive method for the geometric manipulation of 2D and 3D objects of arbitrary shape, which has multiple applications in Computer-Aided Geometric Design and related fields. It consists of the transformation of the ambient space following a rational map that roughly captures the desired geometry. Interestingly, birational maps are globally injective and allow the exact computation of preimages avoiding numerical methods, which is convenient for most applications. Effective tools for the manipulation of birational 2D FFDs have previously been developed. This project aims to develop effective methods for the manipulation of birational 3D FFDs of degree $1 \times 1 \times 1$.

Together with industrial partner RISC-Software, we seek to explore the use of **Bézier triangles** as representation for swept volumes. This requires developing an efficient computation of the intersection between a scan-line (ray) and the representation primitive (Bézier triangles).

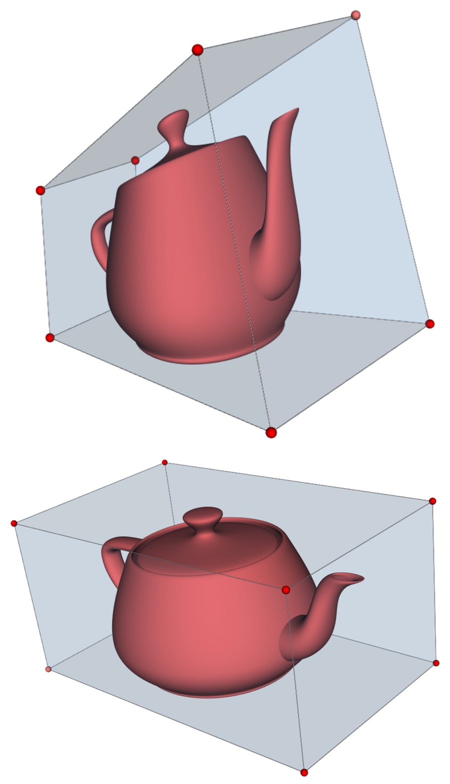


Figure: FFD of a teapot

T. Zoumpekas (U. Barcelona): Identify machining tools from point clouds

This project seeks to **identify machining tools** from temporal point cloud data. First, we demonstrate a novel approach to create intelligent models using such data. Then, utilizing the **PointNet neural network** and two of its versions, we conduct an experimental analysis using two labelled 3D point cloud datasets. The analysis' findings indicate a promising level of accuracy in machining tool identification. The prototype of an intelligent end-to-end machining tool identification system will be published soon.

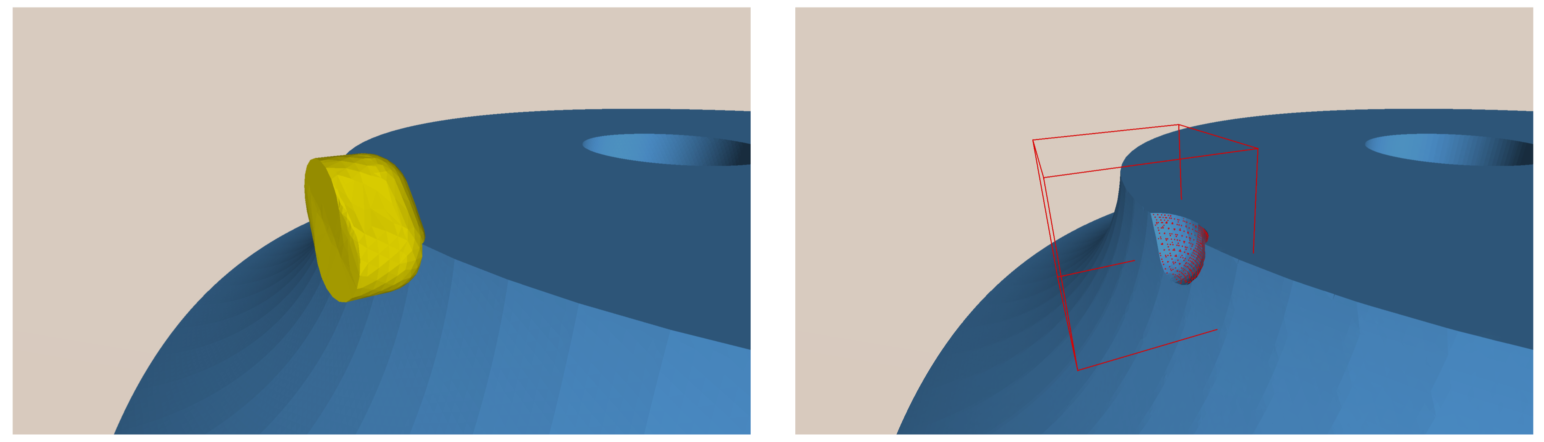


Figure: Identification of machining tool

A. Ramanantoanina (Univ. Della Svizzera Italiana): Interpolatory design

Traditional methods in curve design involve Bézier methods. Our research analyses the **correspondence of the Bézier method and an interpolation method**. The aim is to allow direct control over curves. In particular, cubic Bézier curves are defined and controlled by 2 points and their respective tangents. We convert these into 4 points that are on the curve. This induces additional control over a curve: we can drag these new points, or slide them along the curve, or flatten/bend the curve around these points, or insert new points without changing the shape of the curve. We also show the generalisation of this correspondence to higher degree curves.

In the future, we wish to extend this method to closed curves that are defined by periodic functions, as well as surfaces.

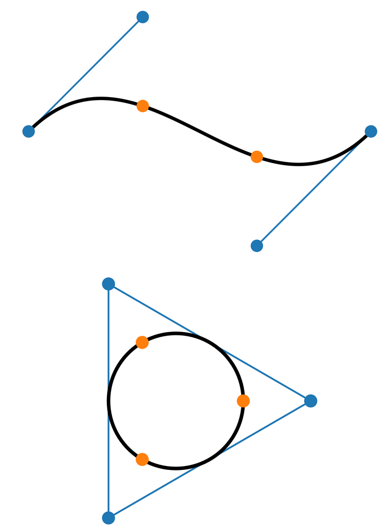


Figure: Bézier-type vs. interpolatory control points

R. Fu (GeometryFactory): Geometry reconstruction from point sets

This project seeks to design a pipeline for **reconstructing complex 3D piecewise-smooth objects** from raw point sets. We design a neural network to learn a Bézier decomposition directly on point clouds. It utilizes Bézier decomposition on CAD models to guide learning piecewise smooth segmentation for point clouds, which could also be served as a pre-processing step for piecewise smooth reconstruction.

Despite training the network on the man-made ABC dataset, the shape symmetries are captured for point clouds sampled on free-form surfaces and real-scan data. In the future, we wish to use the segmentation of point clouds as a prior guiding surface reconstruction to preserve sharp features, and we also wish to add adaptivity for the extracted surface mesh.