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Intelligence artificielle et mathématiques appliquées aux matériaux

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Deep Learning and Computer Vision for Knee Joint Modelling

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Knee joint modeling from medical images involves several steps such as image segmentation and 3D shape matching. We present our contribution in each of these two steps as follow:

(a) When it comes to clinical images, automatic segmentation has a wide variety of applications and a considerable diversity of input domains, such as different types of Magnetic Resonance Images and Computerized Tomography scans. This heterogeneity is a challenge for cross-modality algorithms that should equally perform independently of the input image type fed to them. The multi-modal or cross-modality architectures proposed in the literature frequently require registered images, which are not easy to collect in clinical environments, or need additional processing steps, such as synthetic image generation. We propose a simple framework to achieve fair image segmentation of multiple modalities using a single conditional model that adapts its normalization layers based on the input type, trained with non-registered interleaved mixed data and we show that it brings significant improvements to the resulting segmentation.

(b) Point cloud matching, a crucial technique in computer vision, medical and robotics fields, is primarily concerned with finding correspondences between pairs of point clouds or voxels. In some practical scenarios, such as bones, emphasizing local differences is crucial for accurately identifying a correct match, thereby enhancing the overall robustness and reliability of the matching process. Commonly used shape descriptors have several limitations and often fail to provide meaningful local insights about the paired geometries. We propose a new technique, based on graph Laplacian eigenmaps, to match point clouds by considering fine local structures. To deal with the order and sign ambiguity of Laplacian eigenmaps, we introduce a new operator, called Coupled Laplacian, that allows to easily generate aligned eigenspaces for multiple registered geometries. We define a new medical task, called automatic Bone Side Estimation (BSE), which we address through a global similarity score derived from coupled eigenspaces. To test it, we propose a benchmark collecting bone surface structures from various public datasets. Our matching technique, based on Coupled Laplacian, outperforms other methods by reaching an impressive accuracy.

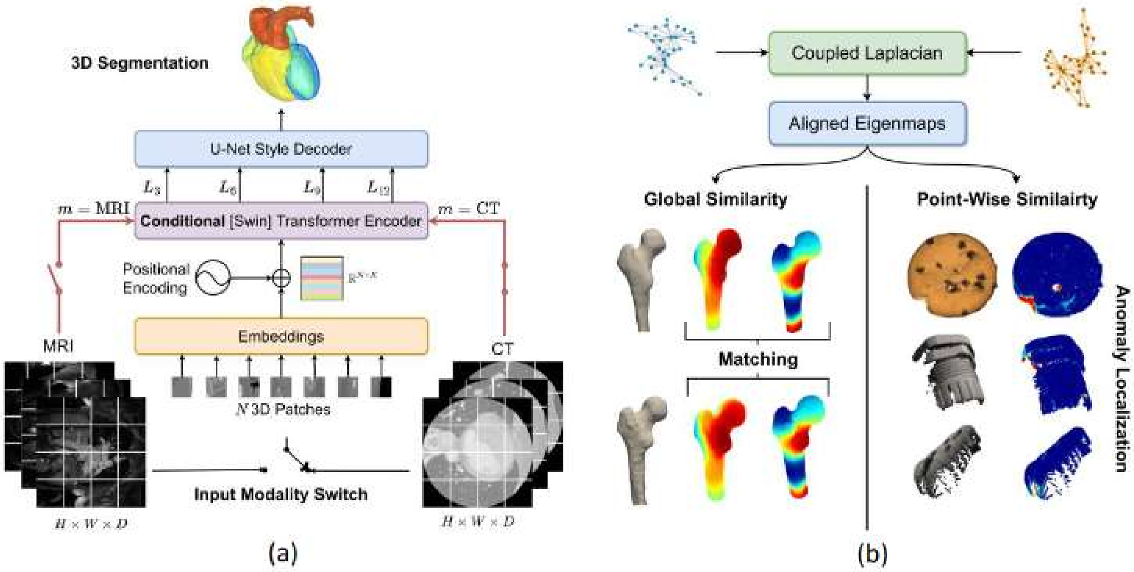

Figure 1: Overview of our approaches for 3D medical image segmentation (a) and Coupled Laplacian

Deep Learning for the Segmentation and Optimization of Composite Materials

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Two Deep Learning frameworks will be presented with applications to composite materials. The first one, a Physics Informed Deep Learning framework for both surrogate modelling of composite materials and segmentation of their images. The surrogate modelling approach prioritizes model generalizability and does not impose domain specific Dirichlet boundary conditions, unlike a conventional Physics Informed Neural Network setup [1]. The segmentation is then conducted in a self-supervised manner, where in the absence of ground truth images, the stress field predicted by the surrogate model is used as target for the deep learning model with a novel loss function.

While each individual material has its own mechanical properties, the global effective mechanical properties of the composite vary with the composition and distribution of its components. In the case of glass fibers as reinforcement for example, the orientation and proximity of the fibers exert an influence on the effective global response of the material. In mechanics, homogenization is the study of the relationship between the local structure of a non-homogeneous medium and its meso/macroscopic behavior. Deep learning techniques can be employed to find this relationship between the local structure of the material and its global properties, by taking image representations of microstructures and predicting their effective mechanical properties. On the contrary, Generative Deep Learning techniques can be applied to obtain the microstructure design for specified properties [2].

The second framework is an ongoing work that aims to develop a Generative AI model for the optimization of microstructures' properties and mechanical response. Thousands of microstructures were randomly generated and submitted to tensile tests simulations to obtain an informative dataset as initial data. Two evaluator Deep Learning models are developed for assessing both.

Références

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Prise en compte a priori de contraintes de voisinage dans la segmentation d'images par apprentissage profond

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Peut-on exploiter l'information connue a priori sur la structure d'une image pour améliorer des modèles de segmentation par apprentissage profond ? Dans cette étude nous montrons que c'est en effet possible grâce à la morphologie mathématique. On peut ainsi réduire le nombre d'images annotées nécessaires pour atteindre un bon résultat et exploiter des images non annotées. Des expériences menées avec des coupes histologiques de la peau illustrent la méthode et montrent quantitativement son intérêt.

Laplacian Embedding pour modéliser les défauts géométriques de fabrication

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La correspondance ou l'appariement entre deux nuages de points en 3D ou 2D est un problème central en modélisation géométrique et en imagerie. Nous proposons une méthode d'appariement entre deux géométries à savoir une géométrie théorique, réalisée par une conception assistée par ordinateur (CAO) d'un noyau d'une aube de turbine et une géométrie de la pièce réelle produite à la suite du processus de fabrication. Les deux géométries sont représentées par des maillages triangulaires en 3D. Nous utilisons une approche spectrale basée sur l'opérateur de Laplace Beltrami. En effet, les vecteurs propres associés aux petites valeurs propres de cet opérateur nous permettent d'une part de sélectionner, par un algorithme de Spectral Clustering, quelques nœuds du maillage CAO qui seront appariés aux nœuds du maillage de la pièce réelle et d'autre part de définir une nouvelle métrique pour la recherche des correspondances entre les deux maillages dans des cas où la distance euclidienne par coordonnées cartésiennes échoue. De plus, le spectre de cet opérateur calculé sur le maillage CAO donne une représentation de sa géométrie dans une base de vecteurs propres réduites, ce qui nous permettra de faire du Mesh Morphing, c'est à dire passer d'un maillage théorique à un maillage qui prend en compte les variations géométriques de la pièce réelle par une méthode de régularisation de Tikkonov.

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