Medical Image Analysis

SIMON FRASER UNIVERSITY
THINKING OF THE WORLD

MIAL
MEDICAL IMAGE ANALYSIS LAB

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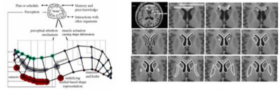
Abstract: Anatomical and functional medical imaging modalities are allowing clinicians and scientists to peer inside the human body and provide a wealth of information indispensable for understanding, modeling, diagnosis and treatment of diseases. The number of medical images acquired on a daily basis has grown, finer details are captured with larger image sizes, and the dimensionality of images has increased from two dimensional scalar images to dynamic 3D multi-valued fields. This is results in image data that cannot be effectively and accurately processed with traditional visual inspection techniques. The development of computational tools for medical image analysis (primarily segmentation, registration, and shape analysis) therefore has tremendous value and is the focus of the research at MIAL. An overview of the research and a selected set of projects are summarized here.

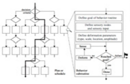
Research Overview: our research is motivated by different clinical applications related to neurological, musculoskeletal, cardiac diseases and oncological studies, including Multiple Sclerosis, Parkinson's, shoulder maladies, tumour localization, etc. We work with local, national, and international clinical collaborators, who provide motivation, image data, and feedback, including Multiple Sclerosis/MRI, Pacific Parkinson's Research Centre, TRIUMF, Vancouver General and Lion's Gate hospitals, Hospital for Joint Diseases – New York University Medical Center. The overarching theme of our research is on the design of computational algorithms for extracting clinically relevant information from medical images with varying dimensionality and complexity, including scalar, vector, tensor, spatial and time-varying 2D and 3D image data, and of different modalities including MRI, CT, Ultrasound, PET, SPECT, fMRI, DT-MRI. The focus of our research is in these areas: image processing (image filtering, enhancement, noise reduction, edge detection); image segmentation (identifying anatomical structures of interest in medical images for quantification, visualization); image Registration and shape matching (fusion of medical images of different modalities, establishing correspondence between images and shapes); shape analysis (3D shape representation, modeling anatomical shape variability, detecting shape abnormalities); and the development of software tools.

Artificial Life Modeling for Medical Image Analysis

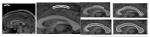
Our lab pioneers the development of artificial organisms, that are embedded in medical images in order to identify and analyze anatomical structures. Our deformable organisms are equipped with models of geometrical bodies, physical deformation capabilities, behaviours, cognitive models, and perception capabilities, which combine top-down knowledge-driven decision making strategies with bottom-up image processing capabilities.



Schematic of deformable organisms.

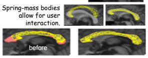


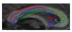
Procedural plan of a deformable organism.



Deformable organisms segmenting and labeling brain structures.

Spring-mass bodies allow for user interaction.





Modeling evolution. Parents (R,G) and offspring (B), and final segmentation after simulating generations and survival of the fittest model.

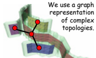
Shape Modelling and Analysis

Our research in this area focuses on intuitive ways to synthesize, visualize, and analyze shape variability. We adopt medial (skeleton)-based shape representations that follow the natural geometry and topology of the object. We perform statistical shape analysis that is location-, scale-, and deformation-specific.

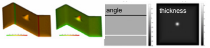
Synthesizing deformations: bending, bulging, stretching at different locations and scales.

Location-, scale-, and deformation-specific principal component analysis of shape.

Decomposing main modes of shape variability into intuitive types.

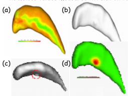


We use a graph representation of complex topologies.

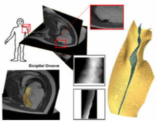


Toy examples showing bends and bulges captured by angles and thickness values measured in relation to medial sheets.

We use manifold learning to describe intrinsic medial and surface parameters.

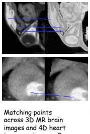


Our representation highlights bending (warm colours in (a)), and distinguishes a thickness pathology (d) that is difficult to see using conventional visualizations (b,c).

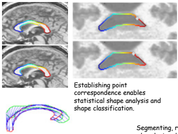


Our techniques are applied to medical research studies of musculoskeletal pathology, including shape analysis of the bicipital groove of the proximal humerus (above and left).

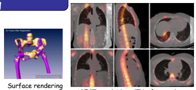
Medical Image Registration and Shape Matching



Matching points across 3D MR brain images and 4D heart images using an n-D extension of SIFT.

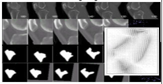


Establishing point correspondence enables statistical shape analysis and shape classification.



Surface rendering after alignment.

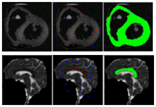
SPECT overlaid on CT before and after 3D image registration.

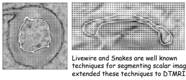


Segmenting, registering, and analyzing deformation fields between knees at different flexion angles.

Analysis and Visualization of Diffusion Tensor MRI

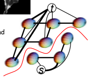
Diffusion Tensor MRI provides data about the diffusion properties of water molecules in the tissue and fibre orientation. An image is produced where a 3x3 tensor is calculated at each voxel. Classical image processing, segmentation, and visualization techniques cannot be simply applied any longer. We are extending different algorithms and proposing new ones.

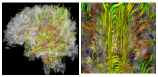




Livewire and Snakes are well known techniques for segmenting scalar images. We extended these techniques to DTMRI data

We extended "Graph Cuts" to DT-MRI. The user enters object (heart muscle and corpus callosum shown in the image) and background seeds. Globally optimal cut that segments the objects is calculated based on DT dissimilarity metrics. The schematic shows graph vertices as ellipsoids representing voxel tensors





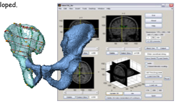
We developed an algorithm to visualize fibre tracts using stream tubes, which in turn use an adaptive seeding strategy to minimize clutter

Practical Medical Image Computing Tools

The following are some examples of software tools we developed.

MATITK itk

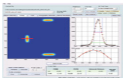
ITK is a powerful open-source toolkit implementing state-of-the-art algorithms in medical image processing and analysis. MATLAB, on the other hand, is well-known for its easy-to-use, powerful prototyping capabilities that significantly improve productivity. We developed MATITK, a wrapper allowing ITK algorithms to be called in MATLAB. This allows biomedical image computing researchers familiar with MATLAB to harness the power of ITK algorithms while avoiding learning C++ and dealing with low-level programming issues. MATITK has been extremely popular with thousands of downloads from universities and companies worldwide.



We developed a 3D extension of livewire (3DLW), allowing for highly-automated segmentation of 3D objects with complex anatomy and topology. The tool is intuitive as it allows the user to select a small number of key points on a few slices and the globally optimal delineations on any slice are calculated automatically. Above you see an example of a 3DLW-segmented human pelvis with concavities and holes.

itkDefOrg

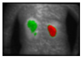
We developed an ITK-based Deformable Organisms framework (I-DO). I-DO bridges the ITK framework and coding style with deformable organism design methodologies and serves as a basis for the medical image analysis community to develop new deformable organisms and exchange components (spatial objects, dynamic simulation engines, image sensors, etc.) enabling fast future development of new custom deformable organisms for various clinical applications.

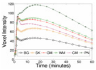


We have a cross-platform software application implementing all basic standardized nuclear medicine scintillation camera quality control analyses, thus serving as an independent complement to camera manufacturers' software.

Analysis of Time Varying Medical Image Data

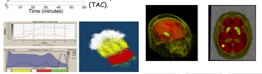
Dynamic functional imaging, such as PET and SPECT, allow observation of metabolic changes in tissue well before structural changes are visible. We are developing techniques that incorporate physiological parameters, clustering, segmentation, visualization, and user-interaction to create systems which allow intuitive, rapid, reproducible, and accurate data analysis.



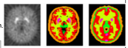


Each image voxel represents multiple observations of a functionally distinct Time Activity Curve (TAC).

Proper choice of metric and template TACs allow the design of transfer functions for time varying medical data. This enables the visualization of healthy and unhealthy tissue (red and green above) or key functional areas, such as the striatum (green) below.

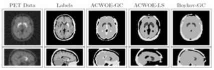


Our software allows users to probe TACs, perform nonlinear dimensionality reduction, and design transfer functions for visualization.



Nuclear data is noisy and uncertain. Allowing physician to interactively correct uncertain regions improves results, and alleviates these issues.

The dynamics of tissue behavior can be characterized using compartmental models, with rates of exchange of clinical importance.

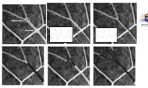


Identifying regions of interest: We improve this time consuming precursor to further analysis with semi-automated approaches.

Medical Image Crawlers

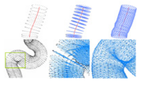
"Image Crawlers" are an example of deformable organisms (the artificial life approach to medical image analysis described earlier), that are specifically designed for the segmentation, visualization, and analysis of tree-like and tubular anatomical structures.

Image crawlers have attracted attention from the computational and clinical communities and the media; e.g. they were featured on the front page of the Vancouver Sun, IEEE Intelligent Systems' "In the News", and ACM Tech-News

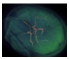


2D crawlers segmenting and labeling retinal angiograms. Using an "arc sensor", they discriminate between overlaps and bifurcations and spawn child crawlers in discovered branches.

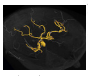
In 3D, the arc-sensor is replaced by a hemi-spherical sensor, that allows the 3D crawler to identify bifurcations.



3D crawlers make use of underlying tubular, medial axis based geometry, and radial/circumferential springs to facilitate needed locomotion maneuvers.

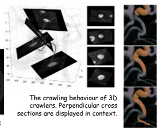


An example volume rendering of a 3D MR angiography image

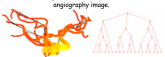


Semi-automatic segmentation (orange) of above image using the "Image Crawlers"

Automatic analysis of vasculature from above MR angiography image.

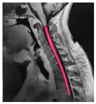


The crawling behaviour of 3D crawlers. Perpendicular cross sections are displayed in context.

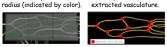


Connectivity and vessel radius (indicated by color).

Tree representation of extracted vasculature.



Extension to 3D spinal cord MR images. Filters locally adapt to changes in cord eccentricity.



3D phantom angiography.

Automatic segmentation.