MP574 Lecture 17: Introduction to Module 2, Image Post-Processing

Learning Objectives
- Introduce the 2nd module of the course, lecture schedule, in-class activities and course materials.
- Provide a rationale for bridging the optimization content in Module I with Module 2.

Overview
- Pattern of image processing tool development and workflow
    - Global approaches -> Local adaptation -> More fully (semi-automated) adaptive methods
    - Adaptive image processing tools are an optimization problem
        - Transform of some kind is applied
        - Cost function is calculated
        - Numerical optimization is performed
        - Iterate until a threshold for convergence of the cost function is reached.
- What we will cover…
    - Image registration
    - Segmentation
    - Classifiers as an introduction to machine learning

Lecture Schedule:

Date	Lecture	Homework Assignment	In-Class Activity
3/11 (Proposed start)	**Registration Concepts:** Matrix mappings and transforms		
3/13	Degrees of freedom and strategies for minimizing registration error: rigid, affine, and deformable (elastic) registration	Homework #4 Assigned	
3/15	Registration and optimization considerations: Cost Function, Numerical Optimization		
3/25	Student Project Proposals		Student Presentations
3/27	In-Class introduction to ITK/VTK (C++ image processing tool box)		
3/29	Set-up virtual machine loaded with ITK/VTK package*	Homework #4 Due	Introduce VM and Cmake for image load and display [Drs. Hahn/Fain]

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4/1	Registration Basics	Homework #5 Assigned (ITK/VTK Problems)	Registration Activity (Day 1) [Dr. Hahn]
4/3	Registration Exercises and Discussion	ITK/VTK	Registration Activity (Day 2) [Dr. Hahn]
4/5	**Segmentation Concepts:** Overview		
4/8	*General Approaches*: Segmentation Basics, Thresholding	ITK/VTK	Segmentation Activity (Day 1) [Dr. Hahn]
4/10	Region Growing, Morphological Operators, Gradients and Edge Detectors		
4/12	*Topological Methods*: Watershed Transform		
4/15	Level Sets ("Graph Cut" as a related approach)		
4/17	Active Contour introduction		
4/19	Active Contour cost functions and numerical optimization		
4/22	*Classifiers*: Bayesian and K-means		
4/24	Machine Learning		
4/26	Neural networks		
4/29	Convolutional neural networks (CNN) and segmentation approaches	Homework #5 Due	
5/1	Final Projects 1		In-Class Presentations
5/3	Final Projects 2		In-Class Presentations
5/6		Final Reports Due	
* https://itk.org; https://vtk.org;			

Registration

- Matrix mappings/transforms
    - Fiducial methods
- Cost functions and semi-automated approaches

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  - Revisit entropy and image information theory
  - Revisit interpolation methods and consequences
  - Revisit numerical optimization
- Registration examples
  - Multi-modality, 2D, 3D
- In-class activity introduction to itk/vtk (https://itk.org; https://vtk.org)

Segmentation and Measurement

- Thresholding and Region Growing
  - Revisit the image histogram and adaptive thresholding
  - Morphological operators and connectivity
- Gradient and Edge Detectors
  - Revisit filters and spatial gradient concepts
  - Gradient-based set theory (level sets, watershed transform)
- Adaptive contours and optimization
  - itk/vtk examples
- Measurement concepts
  - Introduction to radiomics

Image-Based Classifiers

- Bayesian classifier concepts
  - Revisit Bayes' theorem and a priori conditional probabilities
- Adaptive methods
  - K-means
  - Neural networks
- Segmentation examples using classifiers
- Convolutional neural networks and implementation
  - tensor flow examples

Connections between Module 1 and 2

Most real-world image processing problems are ill-posed in that the number of parameters to estimate is much greater than the number of constraints. Two good examples are image registration (Figure 1) and topological segmentation (Figure 2). Image registration seeks to estimate a vector mapping of a scalar signal intensity for every voxel in a "fixed" image for a new position in a "moving" image. Segmentation seeks to identify and isolate objects within a sometimes complicated background of other tissues, noise, and motion.

The computational and mathematical complexity of image registration will depend on the allowed degrees of freedom (DOF), which in turn will depend on the application. The rigid registration problem in 3D involves 6 DOF (Note that this depends on what you define as "rigid"; here I do not allow for scale changes or shear), while a deformable model can have the number of DOF in the millions. While increasing the dimensionality enriches the descriptive power of the registration model, the problem may be difficult to constrain and computationally complex. Both interpolation and optimization strategies are needed that will depend on the application. Registering two images of the brain may be a very different problem than

Registration Workflow

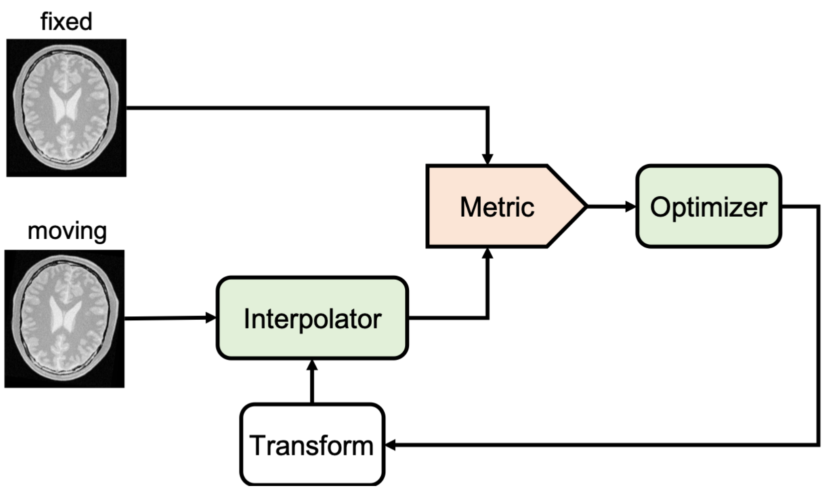

Figure 1: Image registration is an optimization problem consisting of four basic elements: 1) a deformation model or "transform," 2) an objective function or "metric," 3) an optimization method, and 4) interpolation to resample the scaler pixel values in the transformed image.

Active Contour Models: Example

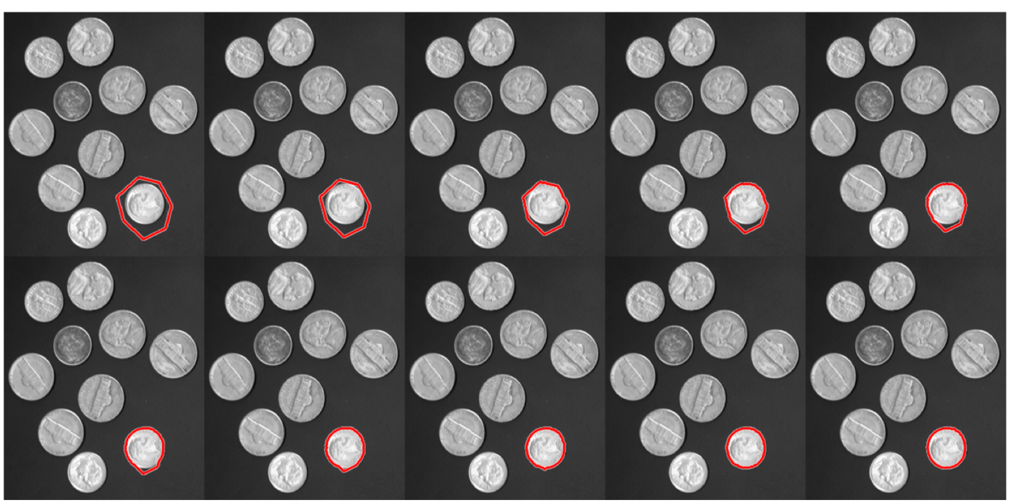

Figure 2: Active contour segmentation uses: 1) an initial set of control points that approximate the location of the boundary connected with cubic splines 2) fitting of local gradients to minimize an energy cost function, 3) iterative application of an optimizer, typically a gradient descent or Nelder-Meade simplex search, to adaptively segment structures in an image.

registering two images of the liver. Similarly, multi-modal image registration will differ in complexity from mono-modal.

Similarly, the challenges of topological segmentation build on linear deterministic approaches such as edge detection but can adapt to real-world conditions of noise and motion commonly found in medical images. One approach is to incorporate physical models that seek to minimize energy conditions drawn from measured gradients in the image to find boundaries that can adapt or move based on some optimization strategy. Examples of such topological segmentation methods are active contours, sometimes called “snakes”, and level-sets.

In conclusion, by focusing on these two major challenges of image post-processing, registration and segmentation, we will build on the fundamental concepts taught in MP573 and in Module 1 of MP574. This approach will continue our development of both conceptual and practical skills in medical imaging.