Lecture 17
Introduction to Module 2: Image Processing and Measurement

MP574: Applications

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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.

Date	Lecture	Homework Assignment	In-Class Activity
3/11	**Registration Concepts:** Matrix mappings and transforms		
3/13	Degrees of freedom and strategies for minimizing registration error: Interpolation, 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]
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;

Module 2 Outline

- Module 2 Grading:
  - Two Homework Assignments: first a mix of pen/paper and Matlab; second a mix of Matlab and itk/vtk exercises (25%)
  - Two In-Class Activities: basically preparation for itk/vtk exercises that make of the second homework (5%)
  - Final Student Project: In-Class Presentation and Final Report (Now 25%, Proposed 50%)
  - Midterm for Module I (20%)
  - Does the class prefer a Final Exam for Module II?
  - Office Hours: Wednesday 3-4 pm or by appointment
- Pattern of image processing tool development and workflow
  - Global approaches -> Local adaptation -> More fully (semi-automated) and 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

Connections between Module 1 and 2

- Most real-world image processing problems are ill-posed
  - The number of parameters to estimate is much greater than the number of constraints
- Two examples: Image Registration and Segmentation
  - 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.

1. Registration

- Matrix mappings/transforms
  - Degrees of Freedom
  - Fiducial methods
- Cost functions and semi-automated approaches
  - Revisit entropy and image information theory (cost functions)
  - 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)
  - Specific examples for image registration and segmentation…

Registration Workflow

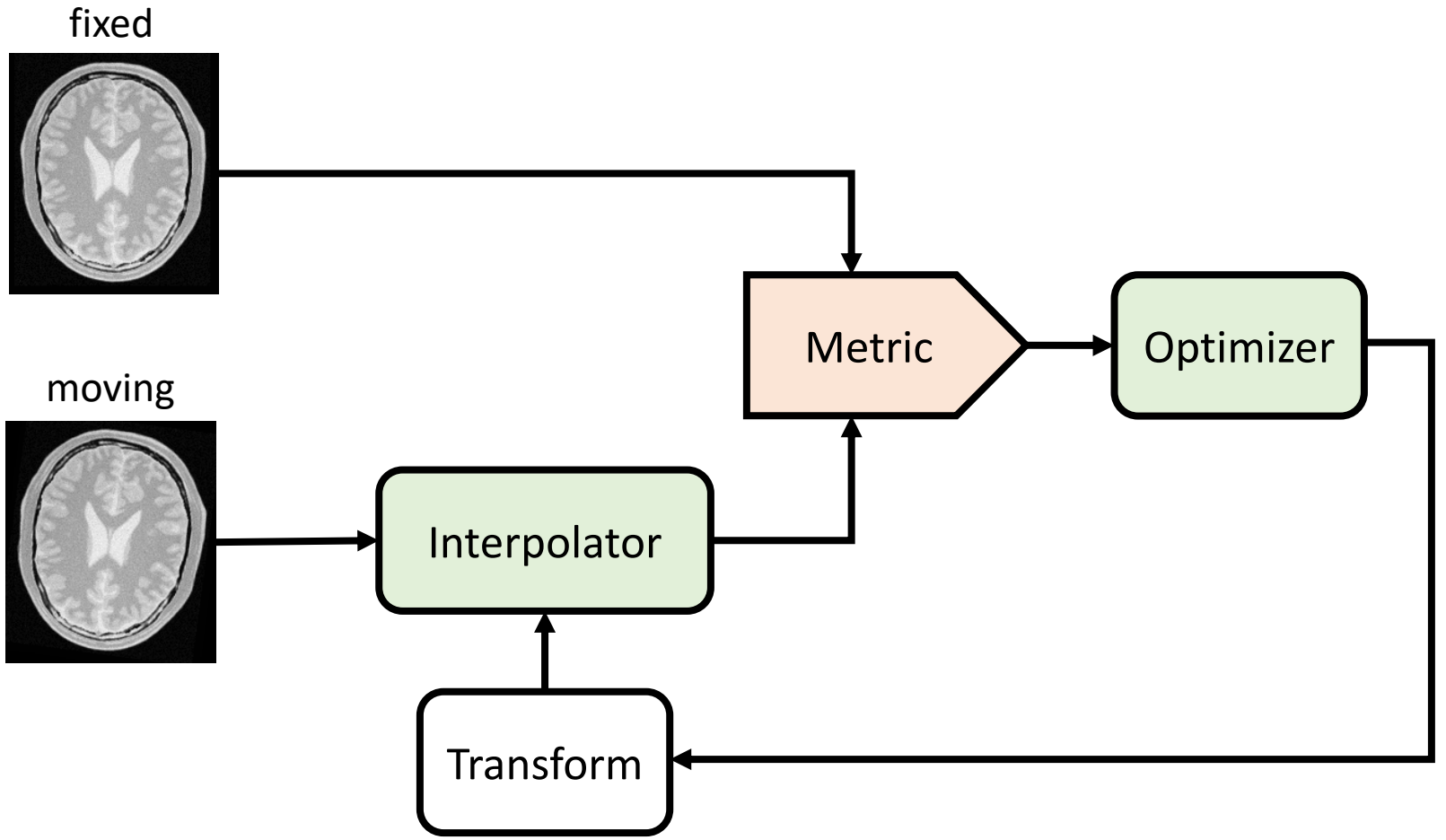
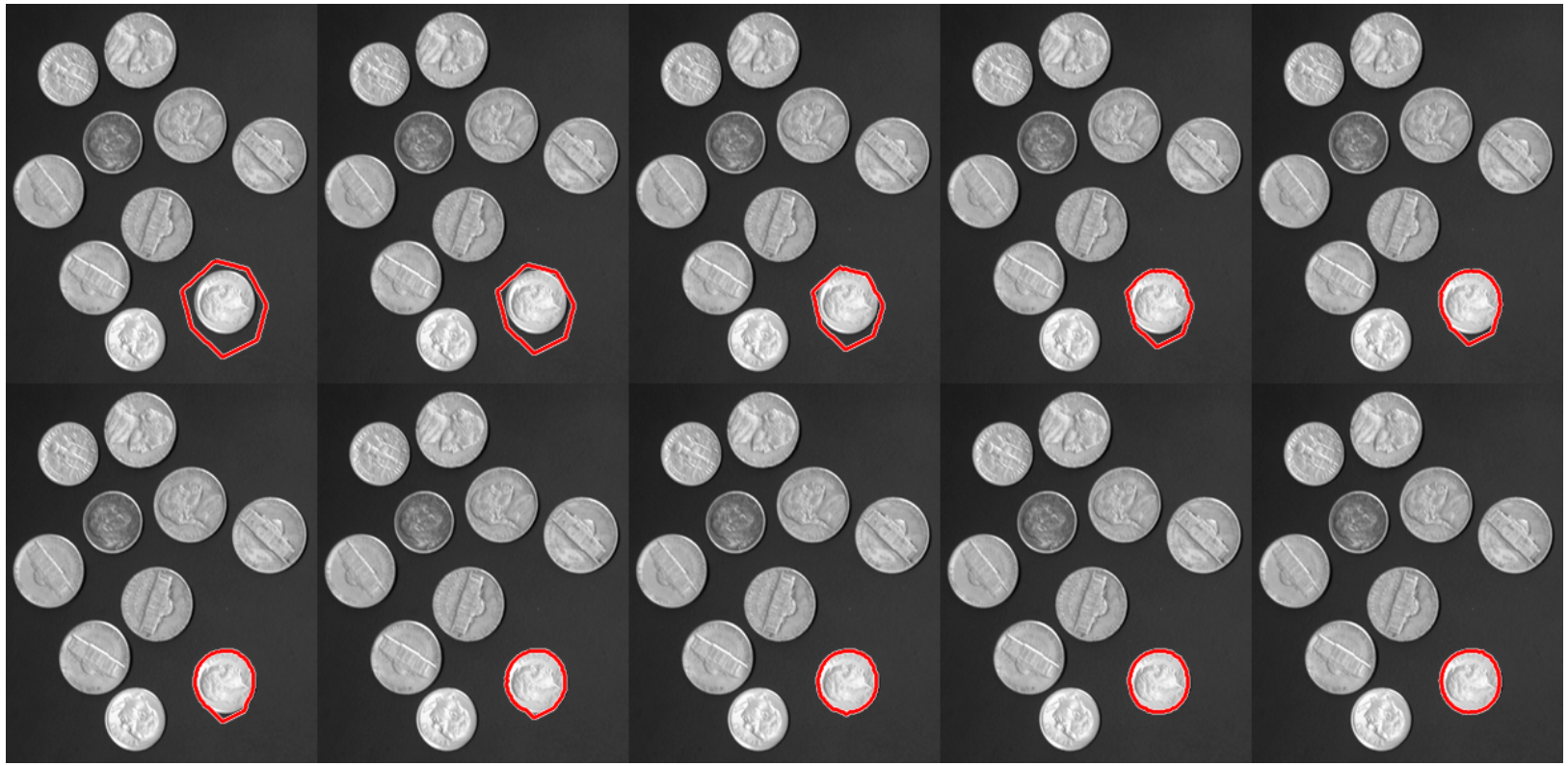


Image registration is an optimization problem consisting of four basic elements:
1) a deformation model or “transform,” 2) an objective function or “metric,” 3) an optimization method, and 4) interpolation to resample the scaler pixel values in the transformed image.

2. 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
- Topology-Based Methods
  - Gradient-based (watershed transform)
  - Level sets (Graph cut)
- Adaptive contours and optimization
  - itk/vtk problems
- Spatial measurement concepts
  - Introduction to radiomics concepts

Active Contour Models: Example



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.

3. 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

Start (or Keep) Thinking About Final Projects…

- Final Project Scope – Find a relevant journal article or set of articles that could be presented in detail.
  - Detailed reviews or simulations of results in a scientific journal article are encouraged.
- Potential Topic Areas:
  - Image reconstruction
    - Geometries and approximations of image reconstruction
    - Compressed sensing and consequences of constrained reconstruction
    - Statistical vs. deterministic constraints in image reconstruction
  - Registration
    - Deformable image registration for radiation therapy planning
    - Registration metrics and methods for estimating mechanical properties.
  - Signal processing/segmentation
    - Adaptive filter design: Wiener filters and related topics
    - Pattern recognition: Phase-based cross-correlation
    - Radiomics and applications: Texture-based measures, spatial measures of heterogeneity.
    - Machine or deep-learning based approaches to segmentation

Summary

- We will be focusing on two major challenges of image post-processing, registration and segmentation
- 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.
- Next Lecture will introduce linear matrix transforms.