Methods In (Bio)Medical Image Analysis

Spring 2026

16-725 (CMU RI) : BioE 2630 (Pitt)

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What Are We Doing?

- Theoretical & practical skills in medical image analysis
  - Imaging modalities
  - Segmentation
  - Registration
  - Image understanding
  - Visualization
- Established methods and current research
- Focus on *understanding* & *using* algorithms

Why Is *Medical* Image Analysis Special?

- Because of the *patient*
- Computer Vision:
  - Good at detecting irregulars, e.g. on the factory floor
  - But no two patients are alike—everyone is "irregular"
- Medicine is war
  - Radiology is primarily for reconnaissance
  - Surgeons are the marines
  - Life/death decisions made on insufficient information
- Success measured by patient recovery
- You're not in "theory land" anymore

What Do I Mean by *Analysis*?

- Different from “Image Processing”
- Results in identification, measurement, &/or judgment
- Produces numbers, words, & actions
- Holy Grail: *complete image understanding* automated within a computer to perform diagnosis & control robotic intervention
- State of the art: segmentation & registration

Segmentation

- Labeling every voxel
- Discrete vs. fuzzy
- How good are such labels?
  - Gray matter (circuits) vs. white matter (cables).
  - Tremendous oversimplification
- Requires a model



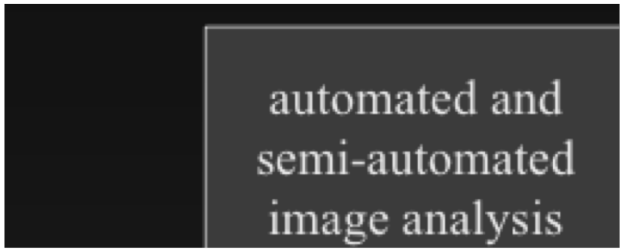

Registration

- Image to Image
  - same vs. different imaging modality
  - same vs. different patient
  - topological variation
- Image to Model
  - deformable models
- Model to Model
  - matching graphs

Visualization

- *Visualization* used to mean *to picture in the mind*.
- Retina is a 2D device
- Analysis needed to visualize surfaces
- Doctors prefer slices to renderings
- Visualization is required to reach visual cortex
- Computers have an advantage over humans in 3D

Model of a Modern Radiologist



How Are We Going to Do This?

- The Shadow Program
  - Observe & interact with practicing radiologists and pathologists at UPMC (in person and/or virtually on Zoom or MS Teams; details TBD)
- Project oriented
  - Python and/or C++ with (Simple)ITK/MONAI
  - National Library of Medicine Insight Toolkit (ITK)
    - A software library developed by a consortium of institutions including CMU and Upitt; www.itk.org
  - Medical Open Network for Artificial Intelligence (MONAI)
    - A software library developed by a consortium of institutions with initial funding and ongoing support from NVidia; monai.io
  - Both are open-source projects with large online communities

The Practice of Automated Medical Image Analysis

- A collection of recipes, a box of tools
  - Equations that function: crafting human thought.
  - ITK & MONAI are software SDKs/libraries, not programs.
- Solutions:
  - Computer programs (fully- and semi-automated).
  - Very application-specific, no general solution.
  - Supervision / apprenticeship of machines

Syllabus

- On the course website
  - http://www.cs.cmu.edu/~galeotti/methods_course/
- Prerequisites
  - Vector calculus
  - Basic probability
  - Knowledge of Python and/or C++
    - Including command-line usage and command-line argument passing to your code
  - Helpful but not required:
    - Knowledge of C++ templates & inheritance

Class Schedule

- Comply with Pitt & CMU calendars
- Online and subject to change
- Big picture:
  - Background & review
  - Fundamentals
  - Segmentation, registration, & other fun stuff
  - More advanced ITK programming constructs
  - Review scientific papers
  - Student project presentations

Requirements and Grading

- Engagement: 5%
- Quizzes: 15%
  - Can (and should!) take in advance, so late submissions not normally accepted (except in more extreme extenuating circumstances)
- Homework: 30%
- Shadow Program: 10%
- Final Project: 40%
  - 15% presentation
  - 25% code

Textbooks

- **Required**: *Machine Vision*, Wesley E. Snyder & Hairong Qi
- **Recommended**: *Insight into Images: Principles and Practice for Segmentation, Registration and Image Analysis*, Terry S. Yoo (Editor)
- Others (build your bookshelf)

Anatomical Axes

- Superior = head
- Inferior = feet

- Anterior = front
- Posterior = back

- Proximal = central
- Distal = peripheral