CSC 621-821
Biomedical Imaging & Analysis

Spring 2017
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Department of Computer Science
San Francisco State University

Course Overview

CSC621-821
Biomedical Imaging and Analysis
Course Information

- **Course Web:** [http://cose-stor.sfsu.edu/~kazokada/csc621-821](http://cose-stor.sfsu.edu/~kazokada/csc621-821)
- **Instructor**
  - Dr. Kaz Okada, kazokada@sfsu.edu
  - OH: TH911, Tue: 1:00 – 2:00pm
- **TA:**
  - TBD, tbd@mail.sfsu.edu
- **Grading:** midterms/final project (for 621)
  - 40% (60%): Midterms
  - 40% (40%): Final Project
  - 20% (0%): Literature Review Report
  - **Policies:** Please read the course web.

Course Overview

- Framework/History/App (1)
- Imaging Methods & Physics (2)
- Image Data Structure (0.5)
- Image Visualization (0.5)
- Digital Image Processing (1)
- Image Filtering (1)
- Edge Detection (1)
- Morphological Operation (1)
- Image Segmentation (2)
- Image Registration (2)
- Image Quantification (1)
### Course Overview

<table>
<thead>
<tr>
<th>Physics &amp; Data (4)</th>
<th>Image Processing (4)</th>
<th>Medical Image Computing (5)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Framework/History/App (1)</td>
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<td>Image Quantification (1)</td>
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### Course Events

- **Midterms**
  - Two midterms: Physics/Data & Image Processing
  - Tentatively on 2/28 and 4/11

- **Final Project**
  - Build a real medical image computing/diagnosis system!
  - Group Project (Grads will be project leads)
  - Up to eight groups
  - In-class group presentation - individual final report
  - Data from National Institute of Health
  - Insight Toolkit (ITK) with C++, your choice of IDE, Cmake, SVN
  - Read assignment at the course web

- **Literature Survey Report**
  - Only for CSC821
  - Read assignment at the course web
Milestones for Group Project

- **Everyone**: read the project assignment carefully to familiarize yourself with projects starting today.
- Project groups will be announced in a few weeks.
- Each group is to meet to set up:
  - Meeting schedules, OS, IDE, code sharing, methods, task-divisions
- Finalize project design by **2/21**!
- Some tool/data set up hints will be given through HWs and tutorials by a TA to be named.
- An example video demo from last year:
  - [http://www.youtube.com/watch?v=bzjrBqQdJBo](http://www.youtube.com/watch?v=bzjrBqQdJBo)

Text Books

- Gonzalez & Woods: Digital Image Processing 3rd Ed
- Suetens: Fundamentals of Medical Imaging 2nd Ed
- Webb: Introduction to Biomedical Imaging

- **Read the assigned chapters before the classes**
- Course Slides published online **AFTER** lectures
Imaging Fundamentals

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Biomedical Imaging and Analysis
Images: What are they?

- They all point to the same...
- Image represents the world/information
- In many formats: each capture different info.
- Why?
Imaging Process: Formation

3D Real World → Image formation → Image

Imaging Device

Imaging Process: Processing

3D Real World → Image formation → Image

Imaging Device

Image processing
analyze images
then infer about the world…
Imaging Process: Issues

Always lose information!!!
Depends on the devise.

3D Real World
Difficult Guess Work!!!
Needs to learn about the devise
Needs to look at different formats

Images as Data: Digital Image

• Digital Image
  – Discrete two-dimensional function \( f(x,y) \)
  – \( x, y \): spatial coordinates
  – \( f \) value: intensity or gray value
  – All \( x, y, f \) have discrete finite values!
  – \( f_m(x_i, y_j) \)

Pixel \( (x_i, y_j) \)
Images as Data: Digital vs Analog

• Analog image:
  – Continuous function
  – Chemistry-based Photography
  – Sheet X-ray

Images as Data: 3D image

• Three-dimensional discrete function
  – \( f_m(x_i, y_j, z_k) \)
  – No projection loss
  – Voxel

No reduction of Dimensionality!
Images as Data: 3D image vs model

- 3D model: only surface
- 3D image: everything in 3D
- Visualization is hard in 3D!

2D-rendered 3D surface  dense data on 3D grid

break
Basic Imaging Framework

Light Signals!!

Images as Signals

**Source:** Physics of light waves and Color

**Physical Model:** Reflection vs Absorption

**Reception:** Camera & Human Perception

- Images are the results of the reception of signals. Thus we must understand the nature of signals and their physics, as well as the receptor like human vision system
Physics of Lights: Light Wave

• Electromagnetic waves (EM waves)
  – Photons: no mass particle traveling with the speed of light
  – Photons with different energy – Different wave length
Physics of Lights: Color in Visible Range

- Visible lights: EM waves that our eyes can see
  - 380 – 750 nm

Specific Color Light = EM waves with the specific wavelength!!!

Physics of Lights: Color

- White: adding all colors = wave with all visible spectral range
- Black: no visible light
- Prism: Isaac Newton (17th Century)
**Imaging Models: Interaction w/ Object**

- **Source Lights**
- **Receiver**
- **Scatter**
- **Reflection**
- **Absorption**
- **Attenuation**
- **Shadow**

**Imaging Models: Attenuation**

- Attenuated Light: What is left of lights after reflection, absorption and scatter
- Strength of shadow depends on light power, object composition and thickness

\[ I(x, z) \]
Imaging Models: Reflection

• Different materials reflects certain wavelength/color and absorbs others.

If white lights is put to an object and it absorbs all visible range waves except for green wave, then we see green! White? Black?

Color Theory

• Primary Colors: Red, Green Blue (James Maxwell, 19th C)
• Additive color mixing: TV, human
• Subtractive color mixing: printing
  – Cyan is the color of material that absorbs red but reflects green and blue
  – Magenta is the color that absorbs green but reflects red and blue
Human Perception: How We See

• One of the best imaging systems around
• Optical camera is inspired by human vision
  – Lens auto-focused by muscles
  – Retina/photoreceptors as film
  – Optic nerve as USB cable
  – Brain as your PC!!!

Human Eye

• The lens focuses light from objects onto the retina
• The retina is covered with light receptors called **cones** (6-7 million) and **rods** (75-150 million)
  • Cones are concentrated around the fovea and are very sensitive to colour
  • Rods are more spread out and are sensitive to low levels of illumination
Three types of photoreceptor cones
Corresponds to the primary color!

Brightness Discrimination & Adaptation

- The human visual system can perceive approximately $10^{10}$ different light intensity levels
- However, at any one time we can only discriminate between a much smaller number – brightness adaptation
- Similarly, the perceived intensity of a region is related to the light intensities of the regions surrounding it
Mach Bands

Optical Illusion: Imperfection
### Optical Illusion: Imperfection

- **Blind Spots**
  - Draw an image where the dot and cross are about 6 inches apart on a piece of paper
  - Close your right eye and focus on the cross with your left eye
  - Hold the image about 20 inches away and move it slowly towards you…. The dot disappear!

![Imperfect Image](image.png)

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### Basic Imaging Framework

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Biomedical Imaging and Analysis
Processes involved in Imaging

- **Formation Physics**
- **Data Structure**
- **Images**
- **Data Analysis**
- **Visualization**

**Formation Physics**

- Physical transformation of source light to images
  - Optical Imaging: Visible, Infrared, Thermal, Radar, multiband
  - Electron Microscopy
  - Florescent Microscopy
  - X-ray
  - Computed Tomography (CT)
  - Magnetic Resonance Imaging (MRI)
  - Positron Emission Tomography (PET)
  - Ultrasound Imaging (US)
Data Structure

- **Spatial Dimension**
  - 2D Imaging
  - 3D Imaging
  - Pyramidal Multi-scale Imaging

- **Temporal Dimension**
  - Video (2D + time)
  - 4D Imaging (3D + time)

- **Intensity Dimension**
  - Grayscale Intensity
  - Color
  - Multiband Imaging

Visualization

- **3D surface model: VRML**
- **3D Image Visualization**
  - Intensity-Windowing
  - Axial Cine View (Video)
  - Multi-Planar Reconstruction (MPR, re-sampling)
  - Maximum Intensity Projection (MIP)
  - Volume Rendering
Data Analysis

- Segmentation
  - Region vs Contour-based

- Registration
  - Geometric vs Intensity-based
  - Rigid vs Non-Rigid

- Quantification
  - Detection: Cancer Screening
  - Size Measure: Cancer Screening/Surgical Staging
  - Change Analysis: Therapy Monitoring
  - Classification: Computer-Aided Diagnosis

Why Biomedical?

Imaging plays an important role in clinical medicine and biological research because...

- **Non-invasive**: mitigate damage to patients
- **In Vivo**: can study things in living organisms
- **Repeatable**: provide standardized results
- **Non-fatigue**: computer does not get tired (MD?)
- **Mission-Critical**: patient’s life may depend on it
Why Computer Science? BREAK

Typically taught in Eng. and Med. School
But the role for CS is ever increasing for …

- **Scaling**: data is ever increasing in quantity and quality. *Computer does not get tired!*
- **Speed**: increasing real-time surgical assistance demands. *Better and Faster Algorithms!*
- **Reliability**: increasing medical malpractices. *MDs need a reliable help of computer systems!*
- **Usability**: needs better UI for the complex system!

History of Imaging: Analog

1519 – da Vinchi: Cameras Obscura
1609 – Galileo: Optical Telescope
1624 – Snell: Law of Refraction
1665 – Newton: Prism experiment
1668 – Newton: Reflection Telescope
1839 – Daguerre: Daguerreotype
1855 – Maxwell: Primary Colors
1861 – Maxwell: First Color Photo
1873 – Maxwell: Electromagnetic waves
1876 – Gray/Bell: Telephone
1902 – Marconi: Radio detection
1931 – Owens: Fiber glass
History of Imaging: Digital

1920s – Bartlane cable picture: newspaper industry using submarine cable between London and New York. Coded in 5-15 levels, Teletyped on special papers.

1960s – Ranger 7 probe: improved quality of photos applied to the US space missions

1970s – Digital Image Processing started to be applied to medicine

Today – The use of digital image processing techniques has exploded and they are now used for all kinds of tasks in all kinds of areas

History of Biomedical Imaging

<table>
<thead>
<tr>
<th>Imaging Modality</th>
<th>Year</th>
<th>Inventor</th>
<th>Wavelength Energy</th>
<th>Physical principle</th>
</tr>
</thead>
<tbody>
<tr>
<td>X-Ray</td>
<td>1895</td>
<td>Röntgen (Nobel 1901)</td>
<td>3-100 keV</td>
<td>Measures variable tissue absorption of X-Rays</td>
</tr>
<tr>
<td>Tomography (SPECT)</td>
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</tr>
<tr>
<td>Positron Emission Tomography</td>
<td>1953</td>
<td>Brownell, Sweet</td>
<td>150 keV</td>
<td>SPECT with improved SNR due to increased number of useful events.</td>
</tr>
<tr>
<td>PET</td>
<td></td>
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</tr>
<tr>
<td>Computed Axial Tomography</td>
<td>1972</td>
<td>Hounsfield, Cormack (Nobel 1979)</td>
<td>keV</td>
<td>Multiple axial X-Ray views to obtain 3D volume of absorption.</td>
</tr>
<tr>
<td>(CAT)</td>
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</tr>
<tr>
<td>(MRI)</td>
<td></td>
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<tr>
<td>Ultrasound</td>
<td>1940-1955</td>
<td>many</td>
<td>MHz</td>
<td>Measures echo of sound at tissue boundaries.</td>
</tr>
</tbody>
</table>
History of X-Ray

Nov. 1895 – Announces X-ray discovery
Jan. 13, 1896 – Images needle in patient's hand
   – X-ray used pre-surgically
1901 – Receives first Nobel Prize in Physics
   – Given for discovery and use of X-rays.

Radiograph
of the hand
of Röntgen’s
wife, 1895.

History of Nuclear Medicine Imaging

• Grew out of the nuclear reactor research of World War II, uses **Gamma ray**
• 1948 - Ansell and Rotblat: Point by point imaging of thyroid
• 1952 - Anger: First electronic gamma camera
History of Computed Tomography

1972: Hounsfield announces findings at British Institute of Radiology
1979: Hounsfield, Cormack receive Nobel Prize in Medicine
(CT images computed to actually display attenuation coefficient $\mu(x,y)$)

Important Precursors:
1917: Radon: Characterized an image by its projections
1961: Oldendorf: Rotated patient instead of gantry

Applications for Imaging

• Numerous biomedical applications exist today and new one coming up every year.
• Existing technology is also rapidly enhancing its quality and quantity
• Even more applications for non-biomedical tasks!
Application: Breast Diagnosis

- Mamography, Breast MRI

National Cancer Institute  
Mayoclinic.com

Application: Angiography

- Study of vessels
  - Cardiovascular diseases
  - Stroke

CT  
MRI
Application: Neuro Imaging

• Comprehensive Study of Brain

MRI anatomy  PET physiology  Function-MRI activity

Application: Computer-Assisted Surgery

http://ftp.queois.queensu.ca/mcl/about.htm
Application: Image-Guided Needle Biopsy

Application: Cell Biology

- Electron Microscopy
  - Very high resolution images of living organism
Application: Pharmaceutical

• Fluorescence Microscopy
  – Fluorescent labeling and imaging allows in-vivo evaluation of the location and mechanism of a drug’s activity.

![Image of living tissue culture cells. Three agents are used to form this image. They bond to the nucleus (blue), cytoskeleton (green) and membrane (red).]

Application: Non-Biomedical...

Hubble telescope: launched in 1990, taking pictures of very distant objects
• Image Processing was used to correct mistakes caused by incorrect mirror.
Application: GIS Systems

- Geographic Information Systems
  - Digital image processing techniques are used extensively to manipulate satellite imagery
  - Terrain classification
  - Meteorology

Application: Law Enforcements

- Image processing techniques are used extensively by law enforcers
  - Number plate recognition for speeding cameras/automated toll systems
  - Fingerprint recognition
  - Enhancement of CCTV images
Application: CGI Films

Computer-Generated-Imagery (CGI)
- Artistic effects are used to make images more visually appealing, to add special effects and to make composite images.

Application: HCI Systems

Human-Computer-Interaction (HCI)
- Try to make computer interface more natural
  - Face Recognition
  - Gesture Recognition
Homework Exercise

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3D Volume as 2D Image Stack
DICOM Format and Information

- **DICOM**: Digital Imaging and Communication in Medicine
  - Store 3D Volumes as a stack of 2D images
  - One of the Major Medical Image Format Standard
  - DICOM image: a single slice scan with tag information
  - Geometrical and other information stored in the tag
    - Slice location (Z coordinate)
    - Slice thickness (Z interval)
    - Voxel size (X-Y resolution)
  - Pseudo Standard: each scanner manufacturer revised
    - [http://medical.nema.org/](http://medical.nema.org/)

NIH NBIA Database

- National Cancer Institute (NCI) in National Institute of Health (NIH) offer this massive anonymatized clinical medical image database
  - [https://imaging.nci.nih.gov/ncia/login.jsf](https://imaging.nci.nih.gov/ncia/login.jsf)
- Free download. Need registration for >3GB
  - Collection(s): Head-Neck Cetuximab-Demo
  - Image Modality(ies): CT
  - Add a couple of subjects to the basket and download DICOM data via "Manage Data Basket".
# Dicom Viewer: ImageJ

- Java-based general biomedical image viewer, Freeware
- **Homework Exercise:**
  - Download data from NBIA
  - Download/Install ImageJ to your computer
  - Load and View the data in ImageJ. Explore!
    - File>Import>ImageSequence
    - PlugIns>3D

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# Summary

- Course Overview
- Imaging Framework
- History and Application
- NBIA Database & ImageJ
- Next Week:
  - Imaging Methods and Physics #1
- Homework Exercise/Project
  - ImageJ to see the CT data
  - Read project assignment thoroughly
  - Start to play with ITK/VTK in you can