Medical Imaging and Beyond

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Schedule

- Today:
  - Lecture: Medical Imaging and Beyond
- Wednesday:
  - No Class (Thanksgiving Eve)
- Final presentations:
  - Nov 29th: W. Griffin, F. Zafar — **+5 bonus points**
  - Dec 1st: Y. Wang, N. Chhaya — **+3 bonus points**
  - Dec 6th: J. Dandois, T. Shin, H. Jean — **+2 bonus points**
  - Dec 8th: M. Lombard, J. Rosebrock, R. Dighade — **+1 bonus points**
  - Dec 13th: D. Mann, E. Baumel, P. Bindu — **+0 bonus points**
  - Dec 20th: K. Martinez, A. Campbell, N. Serova — **+0 bonus points**

20 mins talk + 5 mins Q/A

Final Paper

- Due: Dec 13th, 2010
- At least four pages
- Two columns

- It should have (at least) the following sections:
  1. Abstract
  2. Introduction
  3. Previous Work
  4. Approach
  5. Results
  6. Conclusion

MONITORING PULMONARY DISEASES BY PREDICTING IMAGE FEATURES FROM PHYSIOLOGICAL VALUES

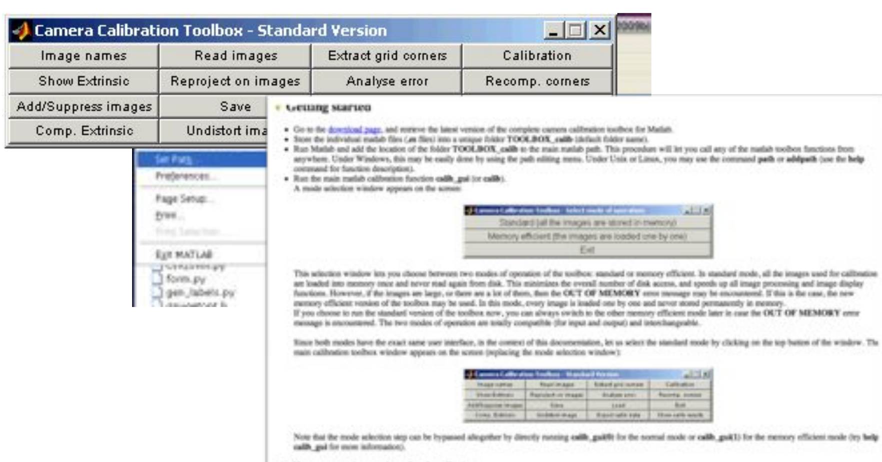
Need a template?
http://www.biomedicalimaging.org/

Assignment #4

1) ssh to linuxserver1 or linuxserver2 (use the –X option)

2) wget http://www.vision.caltech.edu/bouguetj/calib_doc/download/toolbox_calib.zip

3) /usr/local/matlab/bin/matlab



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NIH Summer Internship

- http://training.nih.gov
- Open from today until March 1st

SUMMER INTERNSHIP
for high school, college, and graduate students

Spend your summer at the National Institutes of Health working side-by-side with some of the leading scientists and clinical investigators in the world in a mentored research program of over 1000 students from across the country. As a summer intern you will:

- ✓ Experience the NIH – the largest biomedical research institution in the nation
- ✓ Carry out a research project with guidance from NIH investigators
- ✓ Learn the latest methodologies in basic, translational, and clinical science
- ✓ Improve your problem solving, observation, and communication skills
- ✓ Learn about career opportunities in biomedical research
- ✓ Experience the rich history, culture and diversity of the Washington D.C. metropolitan area

CAREER & PROFESSIONAL DEVELOPMENT ACTIVITIES FOR SUMMER INTERNS

- Orientation programs to help you make the most of your summer internship
- Lectures by NIH investigators working at the forefront of basic, translational and clinical research
- Individual advising and workshops on the graduate/medical school application process
- Workshops on scientific communication, reading scientific literature, succeeding in a lab environment, and more
- A graduate and professional school fair featuring information on programs across the country
- End-of-summer poster session

PROGRAM DETAILS AND ELIGIBILITY

- All interns receive a monthly stipend for an eight – ten week program

Our program is flexible – start anytime from May to July

You are eligible to apply if you:

1. are a US citizen or permanent resident;
2. will be 16 years of age or older at the start of the program, and
3. are enrolled at least half-time in a U.S. high school or accredited college or university; or
4. will enroll at least half-time in a U.S. high school or accredited college or university in the fall

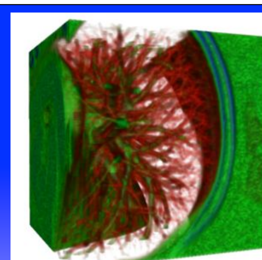
Why Medical Imaging?

- One of the primary applications of image processing
  - Medical images are widely available
  - Everyone understands the need for computational techniques to enhance medical images
  - Easy to establish collaborations (somewhat easier to get funding)
- University of Maryland Medical Center (2007)
  - 50 GB of 3D images a day
  - 15 TB last year
- Challenges
  - Image Diagnosis / Detection
  - Registration
  - Segmentation

Outline

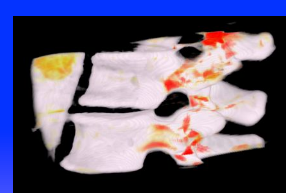
Fundamentals of Medical Imaging
- Acquisition
- CT
- MRI

1



Fundamentals of Visualization
- Volume Rendering
- Transfer Functions
- Display Systems

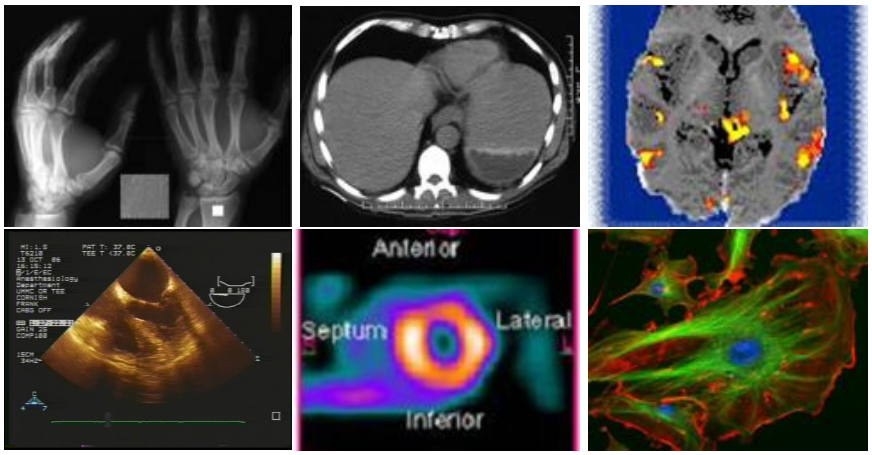
2



Analyzing and Processing Volumes
- Image Processing
- Statistical Volumes

3

Examples of Medical Images

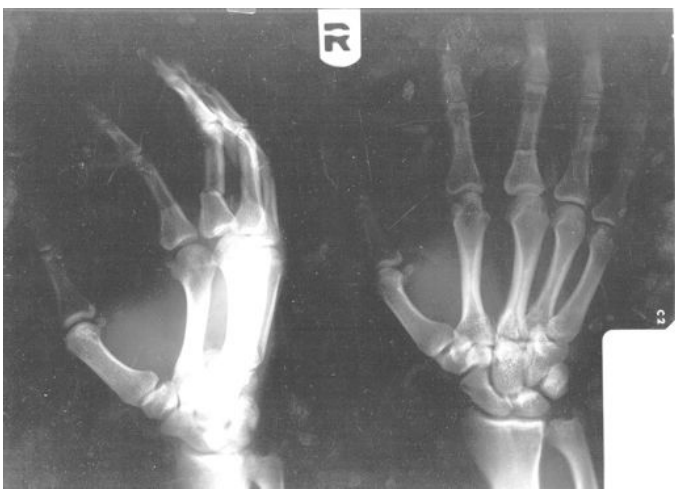


Medical Imaging - Acquisition

- Different devices are used for image acquisition
  - X-Ray, CT, MRI, PET, etc..
  - **Protocols:** With / without contrast
  - **Method:** Real-time or offline
- When are they used?
  - Purpose
    - X-Ray: Overview images
    - CT: Bone
    - MRI: tissue, muscles
  - Budget

X-Ray

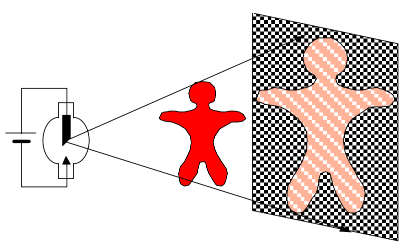
X-Ray Images



X-ray Imaging: How it works

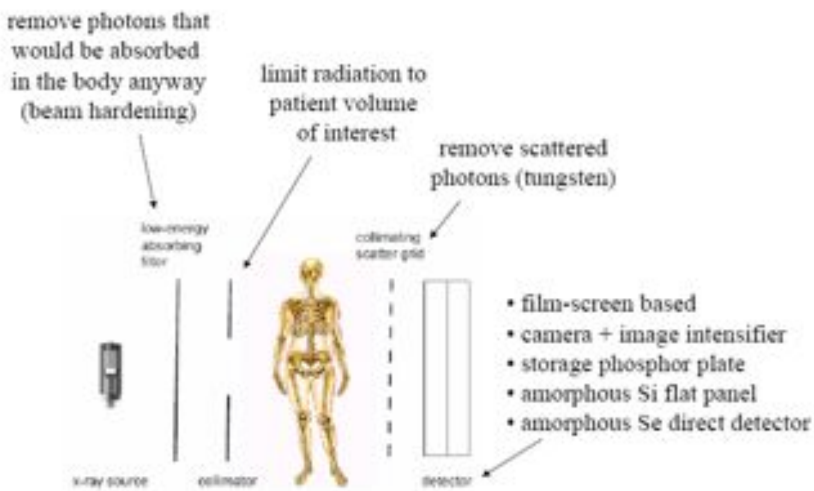
- Simplest imaging technique
- Wilhelm Röntgen in 1895
- Accidentally discovered
  - Accelerated electrons
  - Cathode tubes and fluorescent screens
  - The "light" evenly illuminated
  - Even when tube was placed
  - *X-rays* (*X* for unknown)

X-ray Imaging: How it works



X-ray shadow cast by an object

X-ray Imaging: How it works



X-ray uses

- Radiographic images are made for all parts of the body
  - skeletal, chest (thorax, heart), mammography (breast), dental
- Mammography is somewhat behind because it requires resolutions that exceed that of storage phosphors
- X-ray images can be static or dynamic

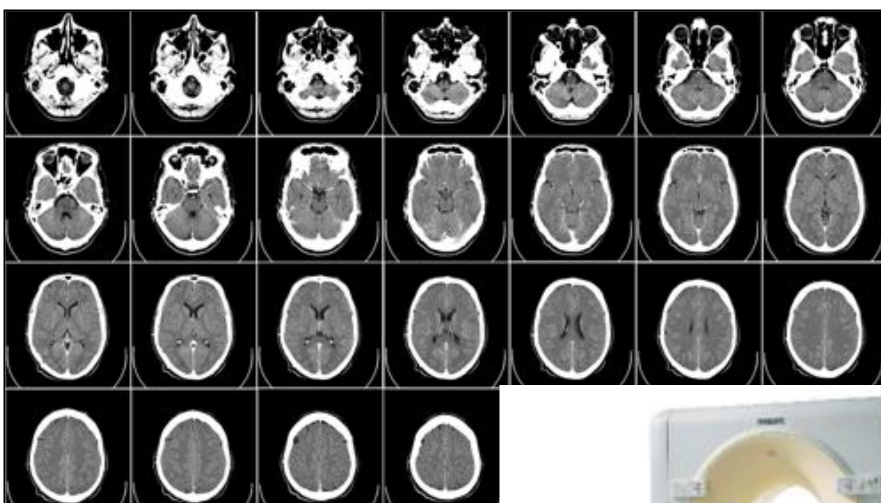
Fluoroscopy –- X-ray

- X-ray image sequences are produced in real time
  - applications where motion is the subject of investigation
  - guidance for minimally invasive procedures
  - angiography (coronary imaging, vessels)
  - instrument tracking

Summary: X-ray Imaging

- Oldest non-invasive imaging of internal structures
- Rapid, short exposure time, inexpensive
- Unable to distinguish between soft tissues in head, abdomen
- Real time X-ray imaging is possible and used during interventional procedures.
- Ionizing radiation: risk of cancer.

Computed Tomography (CT)



CT Images

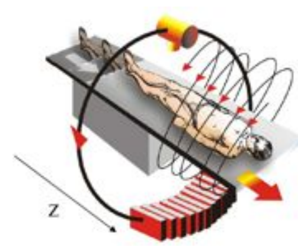
CT Scanner

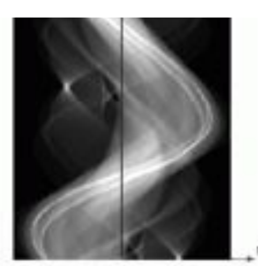
Computed Tomography

- Advance table with patient after each slice acquisition has been completed
- Rotate source detector pair around the patient

CT – How it works?

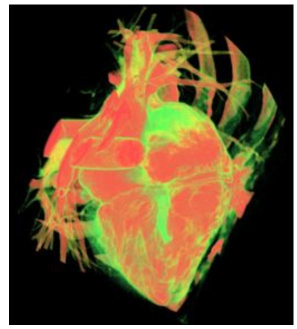
- Rotate source detector pair around the patient
- For each angle
  - Get a sinogram
  - Back-project data
  - Construct slice
- Math and physics more complicated than X-ray





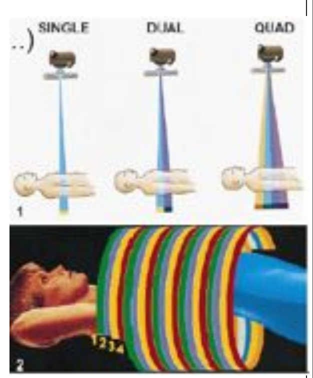
CT - Applications

- Applications of CT
  - head/neck (brain, maxillofacial, inner ear, soft tissues of the neck)
  - thorax (lungs, chest wall, heart and great vessels)
  - urogenital tract (kidneys, adrenals, bladder, prostate, female genitals)
  - abdomen(gastrointestinal tract, liver, pancreas, spleen)
  - musceloskeletal system

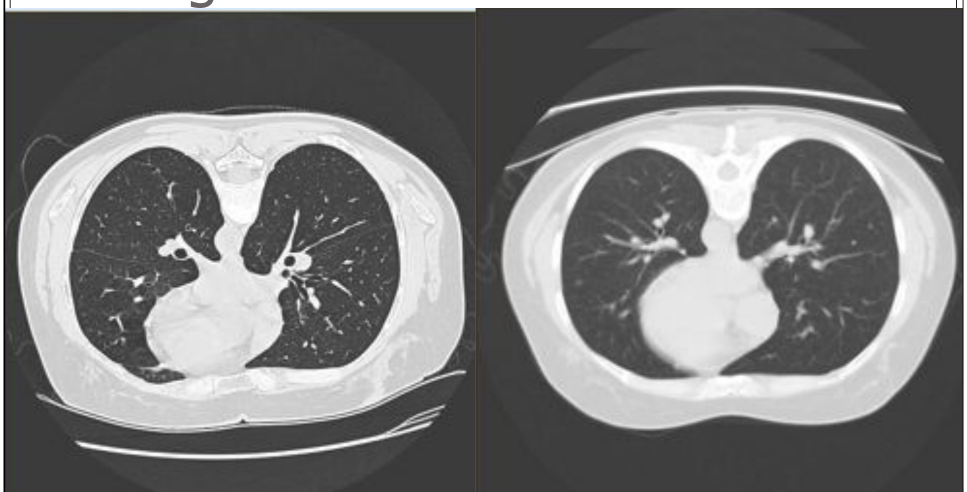


What’s new?

- Nowadays (spiral) scanners are available that take up to 64 simultaneous slices
- Much More…
  - High-resolution CT
  - Low-dose CT



High-Resolution CT



High-Resolution CT   Regular CT

Summary of CT

- Images of sectional planes (tomography) are harder to interpret
- CT can visualize small density differences, e.g. grey matter, white matter, and CSF.
- CT can detect and diagnose disease that cannot be seen with X-ray.
- More expensive than X-ray.
- Ionizing radiation (can cause cancer).

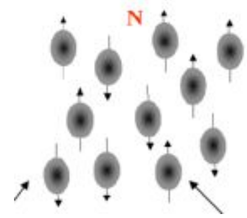
MRI

Magnetic Resonance Imaging/ Tomography

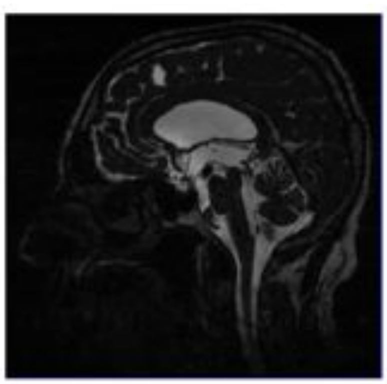
- MRI measures magnetic field
- 3D volume is reconstructed from measured proton
- Relatively slow image acquisition
- Noisy
- First human study published in 1977

MRI Image Formation

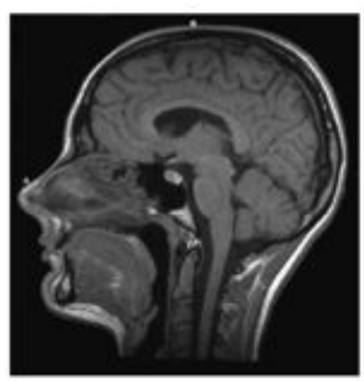
- The hydrogen atom has only one proton
- Protons are magnetic
- In a magnetic field, spin-up and spin-down protons have different energies
- Radio wave photons can flip the proton spins
- By controlling the energy differences between spin-up and spin-down and adjusting the radio waves, you can locate hydrogen in a person



Example – MRI Images



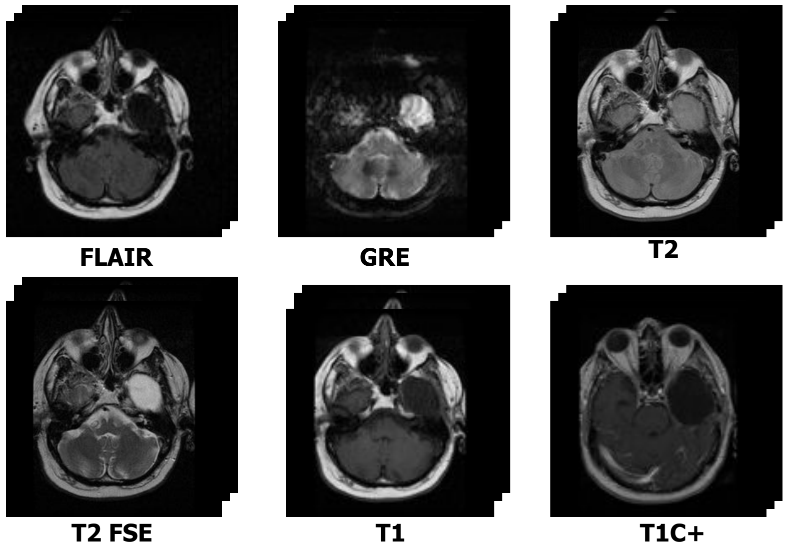
T2-weighted MRI-Image
(3D-CISS)



T1-weighted MRI-Image
(MR-Flash)

Sagittal Orientation

Multimodal Images



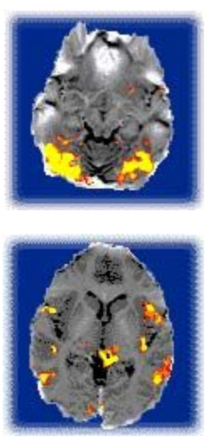
Features of MRI

- No ionizing radiation – expected to not have any long-term or short-term harmful effects
- Many contrast mechanisms: contrast between tissues is determined by pulse sequences
- Can produce sectional as well as projection images.
- Slower and more expensive than X-ray
- Many imaging modes (water, T1, T2, flow, neural activity)
- Tomography at arbitrary angle

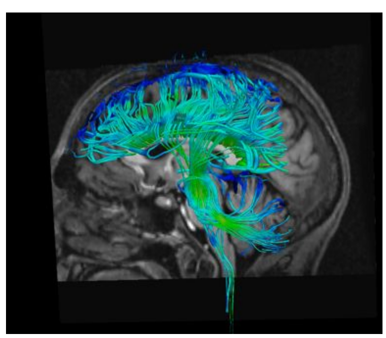
Others Imaging Techniques

- fMRI: displays neural activity in the brain
- Dynamic MRI: good for mammography
- DT-MRI
- Multi-slice CT
- Low-dose CT
- Nuclear Imaging
- PET

Example of Other Imaging Techniques



fMRI



DT-MRI

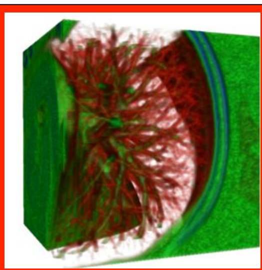
Low-dose CT

Conclusion: Medical Imaging

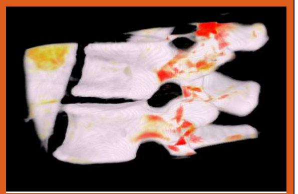
- Acquisition
  - CT
  - MRI
  - X-Ray
- Image/Volume formation

Outline

Fundamentals of Medical Imaging
•Acquisition
•CT
•MRI



Fundamentals of Visualization
•Volume Rendering
•Transfer Functions
•Display Systems



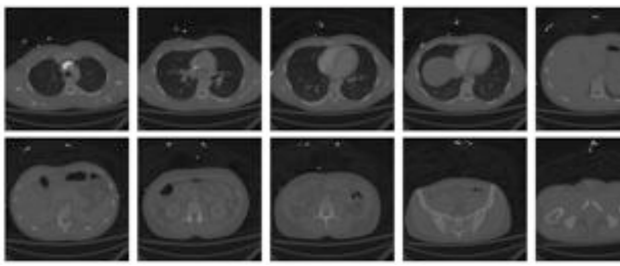
Analyzing and Processing Volumes
•Image Processing
•Statistical Volumes

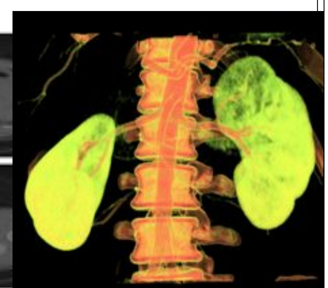
1 2 3

Why 3D Visualization?

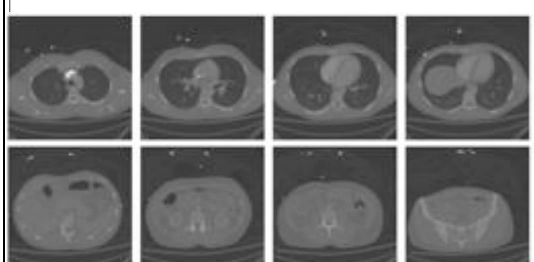
- Advances in 3D acquisition devices have created
  - Challenging task of analyzing large set of images
- Can we use volume visualization as a technique to quickly explore large datasets?

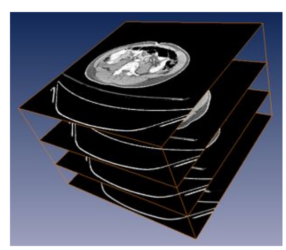
Siemens, 2007

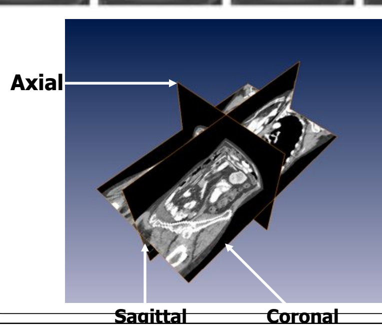


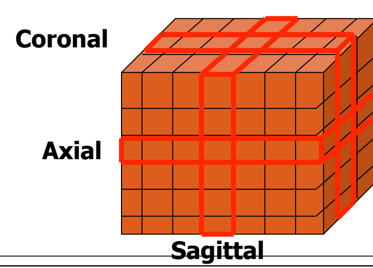


What's a volume?



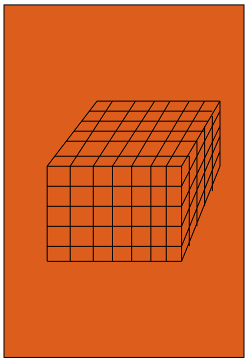


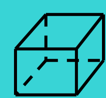




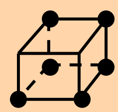
Data Representation (2)

What is a Voxel? – Two definitions



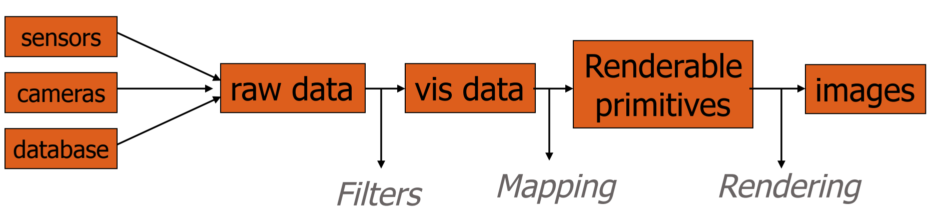


A voxel is a cubic cell, which has a single value or density



A voxel is a data point at a corner of the cubic cell
The value of a point inside the cell is determined by interpolation

Visualization Pipeline



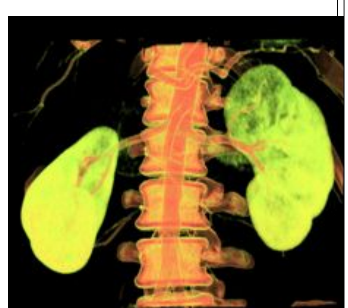
Filters	Mapping	Rendering
• Denoising • Raw Data • Decimation • Multiresolution • etc	Geometry: • Line • Surface • **Voxel** Attributes: • Color • Opacity • Texture	• Surface rendering • **Volume rendering** • Point based rendering • Image based rendering • NPR

Rendering Techniques

- Primary Rendering Techniques
  1. Direct Volume Rendering (DVR)
  2. Iso-surfaces
  3. Maximum-Intensity Projection (MIP)
  4. X-Ray Rendering
  5. Non-photorealistic rendering (NPR)

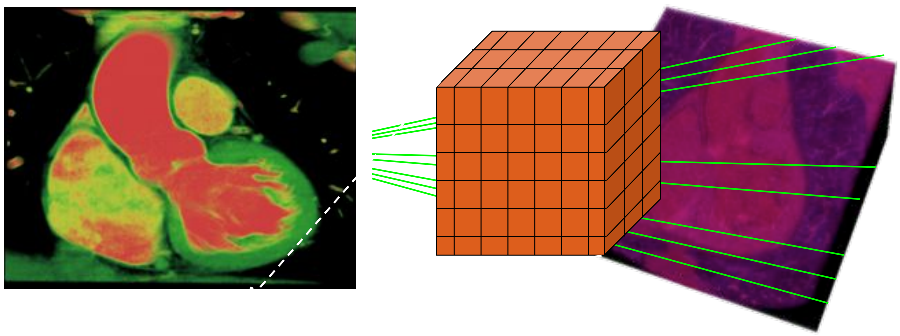
1. Direct Volume Rendering (DVR)

- Direct Volume Rendering
  - Technique used to display a 2D projection/image of a 3D image
  - Effective method to render different materials



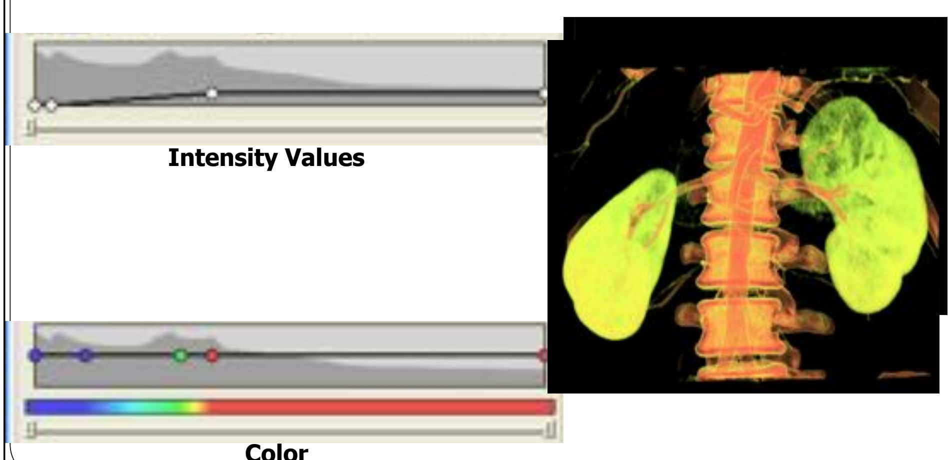
Raycast Function

- Integration process to simulate the light transport within a volumetric medium



Transfer Functions

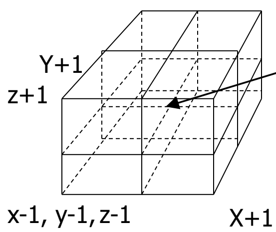
- How do we assign rendering properties?



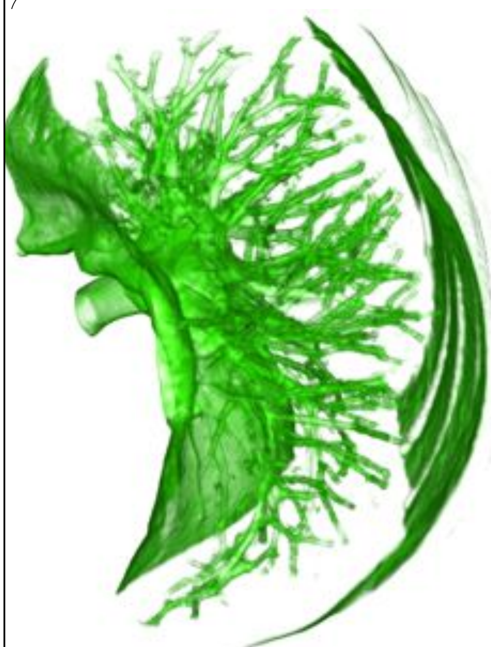
Gradient-based TF

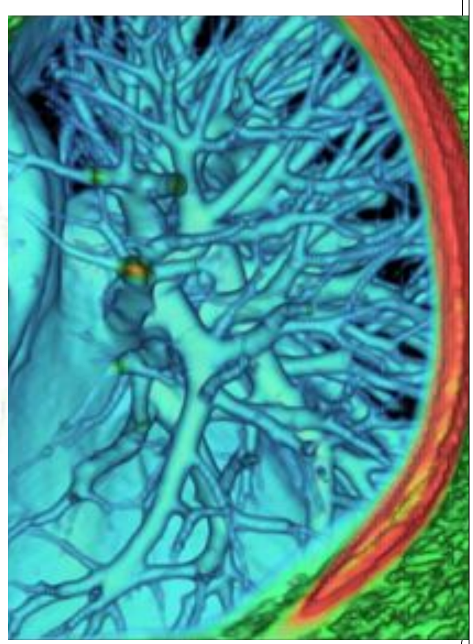
How to compute N(x)?

1. Compute the gradient at each corner
2. Interpolate the normal using central difference



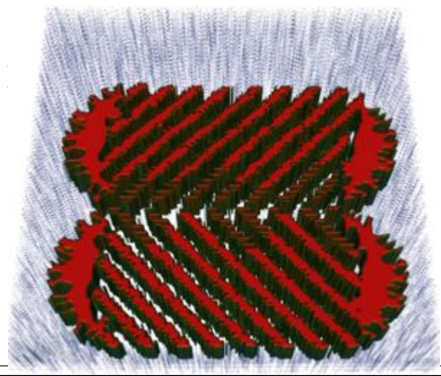
$$N(x,y,z) = [\ (f(x+1)-f(x-1))/2,\ (f(y+1)-f(y-1))/2,\ (f(z+1)-f(z-1))/2\ ]$$





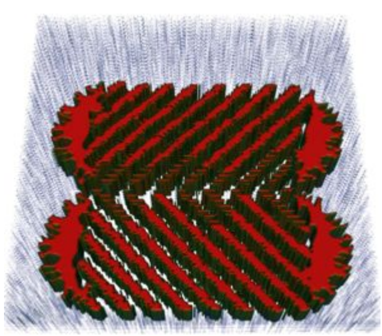
Problem with 1D TF

- What about when data has similar intensity and gradient values?



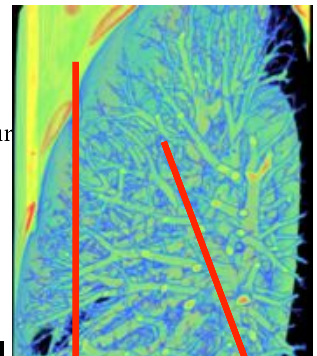
Texture-based TF

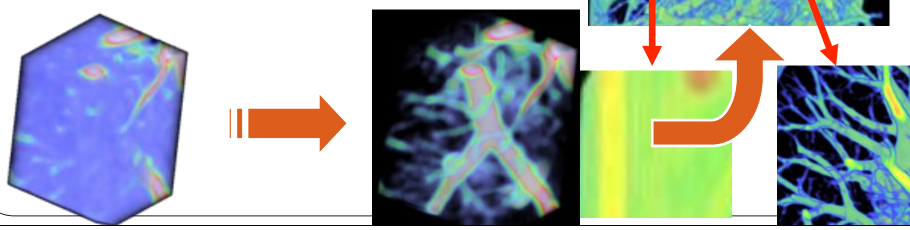
- Volumes present textural patterns
- Analyze textural properties, then classify



Observation: Textures

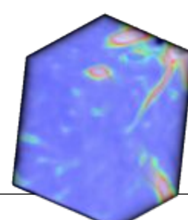
- Observations:
  - Like images, volumes contain characteristic patterns and small textures – textons - that our visual system can clearly identify
    - Combination of those *textons* create different structures and characteristic regions





First-Order Statistics

- The simplest textural measurements that can be obtained from 2D/3D images
  - Metrics estimated from a histogram



- Histogram Statistics:

- Variance:

$$\vartheta^2 = \frac{1}{(XY-1)} \sum_{x=1}^{X} \sum_{y=1}^{Y} [I(xy) - \mu]^2$$

- Standard Deviation:

$$\sigma = \sqrt{\frac{1}{N-1} \sum_{i=1}^{N} (x_i - \overline{x})^2}.$$

- Skewness:

$$\frac{1}{XY} \sum_{x=1}^{X} \sum_{y=1}^{Y} \left[\frac{I(xy) - \mu}{\vartheta} \right]^3$$

- Kurtosis:

$$\left\{ \frac{1}{XY} \sum_{x=1}^{X} \sum_{y=1}^{Y} \left[\frac{I(xy) - \mu}{\vartheta} \right]^4 \right\} - 3$$

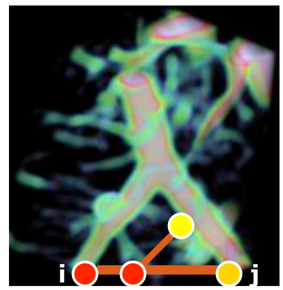
Second-Order Statistics

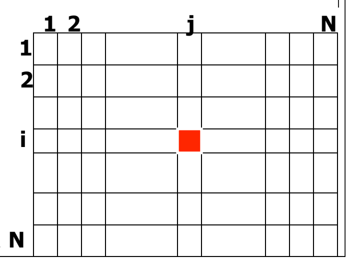
- Second-order statistics
  - Measure the likelihood of observing an intensity value *i* and *j* at an average distance
    $\Delta = (\zeta x, \zeta y, \zeta z)$

Energy: $$\sum_{i=1}^{N_g}\sum_{j=1}^{N_g} p(i,j)^2$$

Entropy: $$\sum_{i=1}^{N_g}\sum_{j=1}^{N_g} [p(i,j) log(p(i,j))]$$

Contrast: $$\sum_{n=0}^{N_g-1} n^2 \left\{ \sum_{i=1}^{N_g}\sum_{j=1}^{N_g} p(i,j) \right\}$$





Higher-Order Statistics

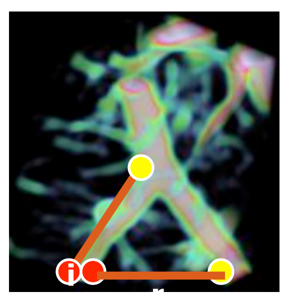
- Run-length matrices
  - Finds gray-level runs within the volume

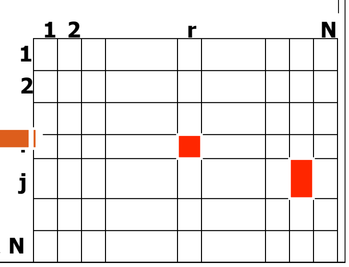
Short Run:

$$SRE = \frac{\sum_{i=1}^{N_g}\sum_{j=1}^{N_r} \frac{p(i,j)}{j^2}}{\sum_{i=1}^{N_g}\sum_{j=1}^{N_r} p(i,j)}$$

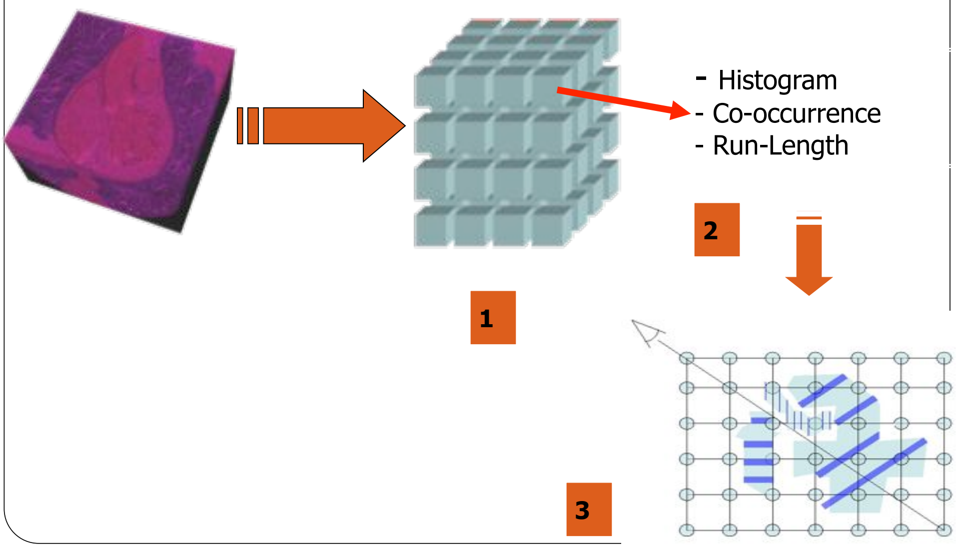
Long Runs:

$$LRE = \frac{\sum_{i=1}^{N_g}\sum_{j=1}^{N_r} j^2 p(i,j)}{\sum_{i=1}^{N_g}\sum_{j=1}^{N_r} p(i,j)}$$

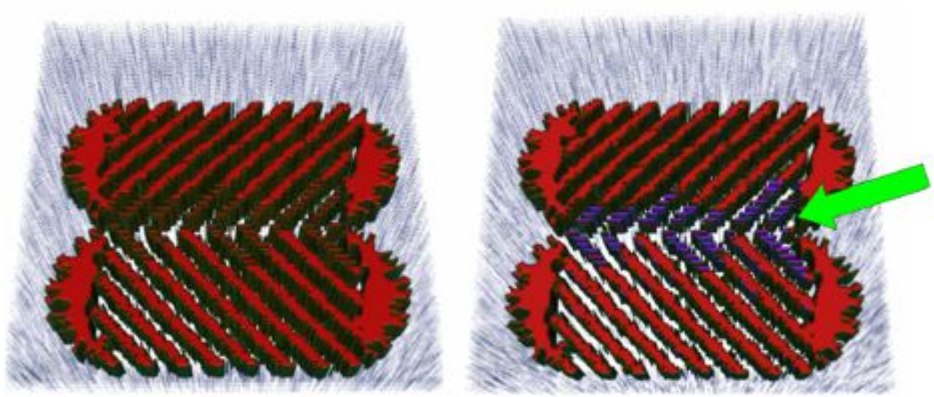




Approach – General Idea

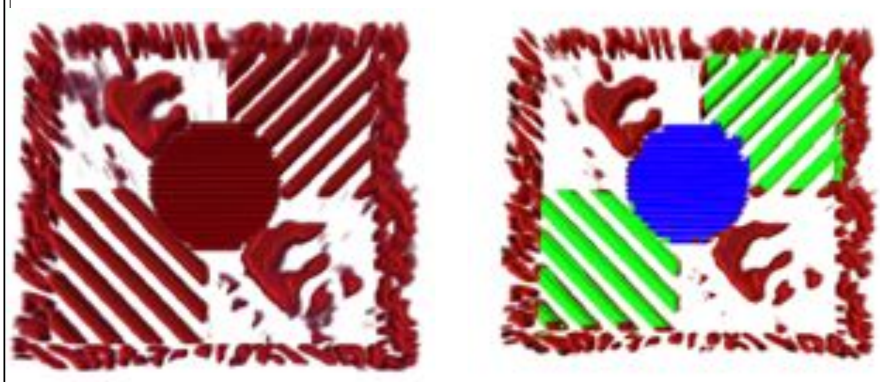


Results - Synthetic Data



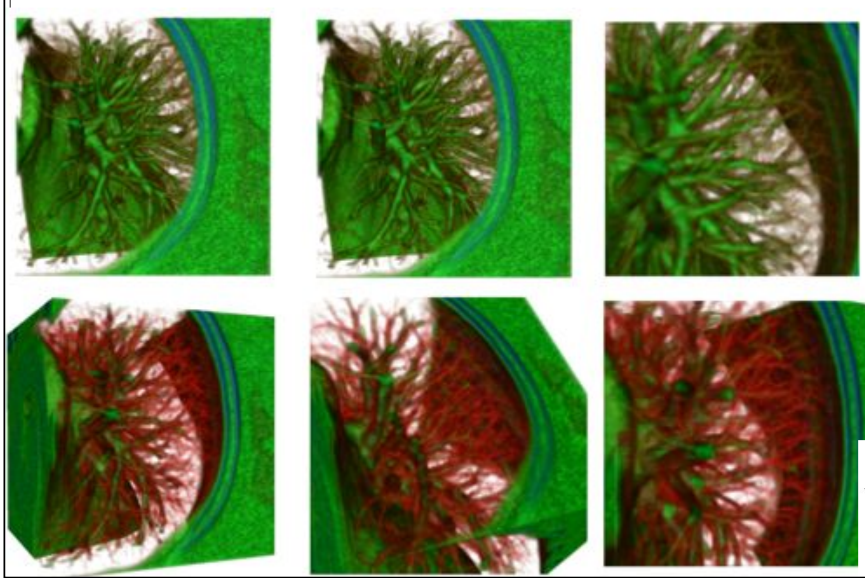
$p = 4$ $o = 0$ $k = 3$

Results - Synthetic Data



$p = 2$ $o = 2$ $k = 4$

Results – Lung Dataset



$p = 2$
$o = 2$
$k = 3$

Transfer Functions

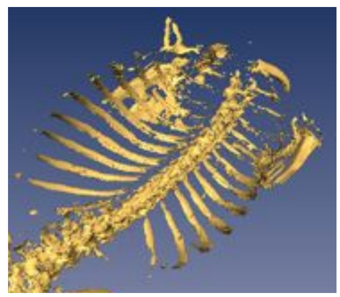
- A number of transfer functions have been proposed
  - Opacity Transfer Functions
  - Color Transfer Functions
  - Gradient Transfer Functions
  - Curvature Transfer Functions
  - Multi-dimensional Transfer Functions
  - Texture-based Transfer Functions

Software Applications

MeVisLab

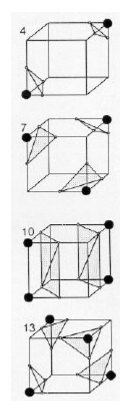
2. Iso-surfaces

- Approximate the data to polygonal primitives
- Use contours/boundaries of the volume to generate polygonal structures/“surfaces”

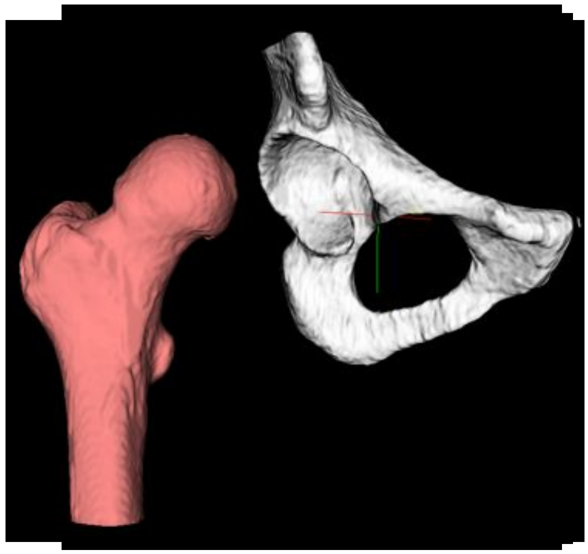


Marching Cubes

- Most common way to generate iso-surfaces
- Algorithm:
  - Select a cell
  - Calculate inside/outside of each vertex
  - Create binary index
  - Search LUT
  - Calculate contours location using interpolation



Iso-surfaces - Example



3. Maximum Intensity Projection

- Maximum Intensity Projection (MIP)
  - The interpolated sample with the largest value is written to the pixel
  - Often used to enhance vascular structures

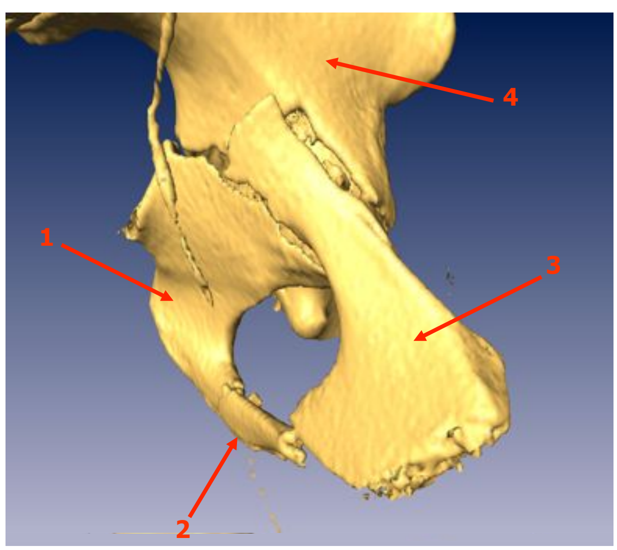
Source: Philips, Inc

4. X-ray Rendering

- X-ray rendering
  - Overview image
  - The interpolated samples are simply summed

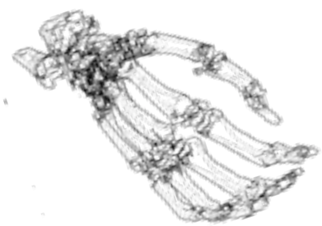
X-ray images

X-Ray Rendering



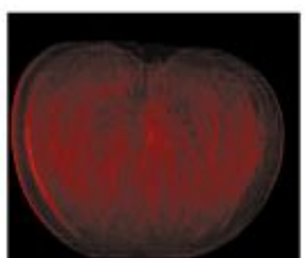
5. Non-Photorealistic Rendering

- The use of local image processing to produce artistic and illustrative effects
  - Pen-and-ink drawing
  - Silhouettes
  - Stippling
  - etc…

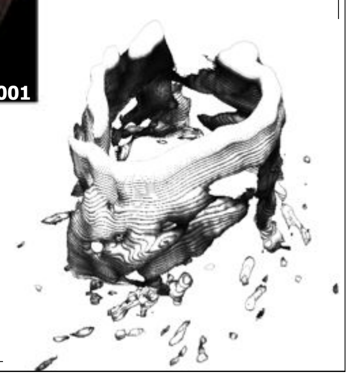


Burns et al., 2005

Non-photorealistic Volume Rendering



Rheingans et al, 2001

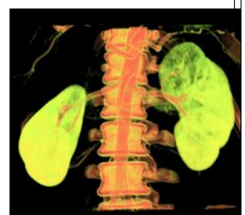


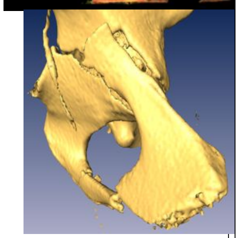
Burns et al., 2005

Limitations

- What's the most effective volume rendering techniques?

  1. Direct Volume Rendering (DVR)
  2. Iso-surfaces
  3. Maximum-Intensity Projection (MIP)
  4. X-Ray Rendering
  5. Non-photorealistic rendering (NPR)



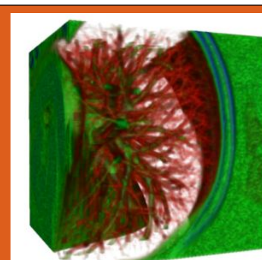


- What about a combination?

Outline

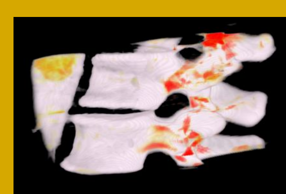
Fundamentals of Medical Imaging
- Acquisition
- CT
- MRI

1



Fundamentals of Visualization
- Volume Rendering
- Transfer Functions
- Display Systems

2

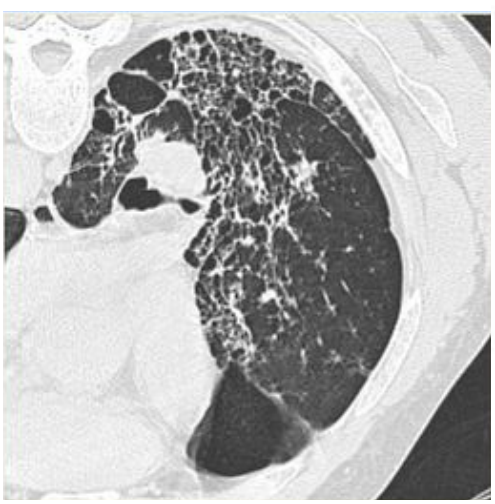


Analyzing and Processing Volumes
- Image Processing
- Statistical Volumes

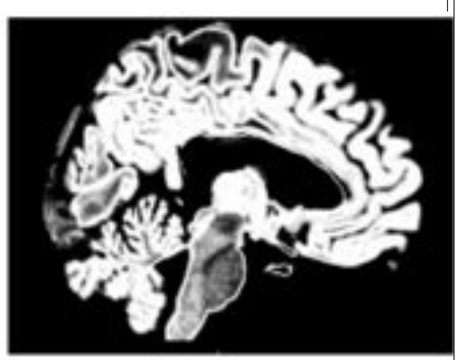
3

Processing
Image Processing
Lung Fibrosis

Processing and Analysis



Lung Fibrosis



White Matter + Cerebellum

Texture Analysis

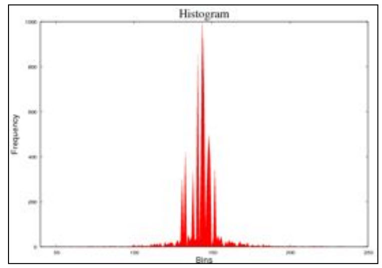
- Observation:
  - Medical images and volumetric data presents specific pattern and textural features
  - patterns can be described as textures
- Why Textures?
  - Intensity patterns characteristics of specific objects
  - One of the most important properties used in image processing, computer vision, and medical imaging

Approach

- Approach: Texture-based CAD system
  1. Determine regions of interest
  2. Compute advanced textural properties for each feature
  3. Train and learn an statistical model
  4. Test new data
- Which texture analysis techniques?
  - Combination:
    - First-order statistics
    - Second-order statistics
    - Run-length matrices

Feature of interest

First-Order Statistics



- The likelihood of observing a intensity value at a random location in the subvolume.
- Done by computing a frequency distribution or histogram for the subvolume under consideration
- A histogram contributes six different metrics

1) Mean: $\bar{x} = \frac{1}{n} \cdot \sum_{i=1}^{n} x_i$

2) Variance: $\sigma^2 = \frac{1}{N} \sum_{i=1}^{N} (x_i - \overline{x})^2$

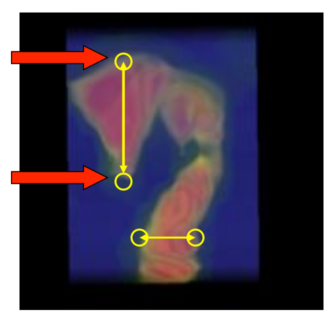
3) Absolute Deviation:
$$\frac{1}{n} \sum_{i=1}^{n} |x_i - \overline{x}|$$

4) Standard Deviation:
$$\sigma = \sqrt{\frac{1}{N-1} \sum_{i=1}^{N} (x_i - \overline{x})^2}.$$

5) Skewness

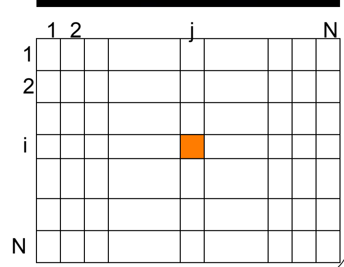
6) Kurtosis

Second-Order Statistics



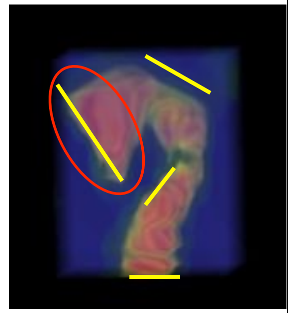
- The probability of a pair of voxels v_1 and v_2 with intensities i and j occurring at some distance d.
  - frequency that a grayscale value appears in relation to another grayscale value on the image
- To compute the second-order statistics we use co-occurrence matrices.

1) Energy
2) Inertia
3) Entropy
4) Correlation
5) Average Difference
6) Entropy Difference
7) Average Sum
8) Entropy Sum
9) Inertia Difference



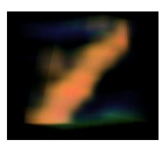
Run-Length Matrices

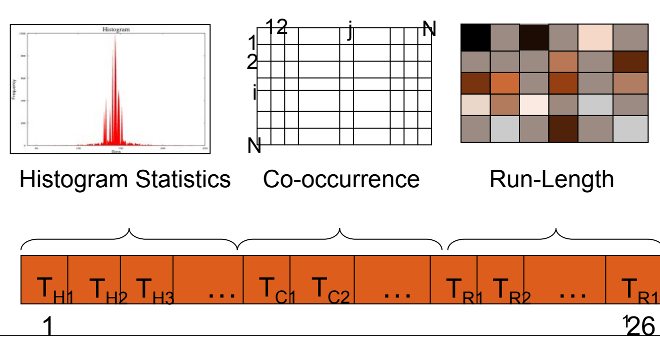
- General idea:
  - find strings of consecutive pixels that have the same gray level intensity along a specific linear orientation
  - Run-length matrix $p(i, j)$ is defined as the number of pixels of gray level i and run length j along a direction d.



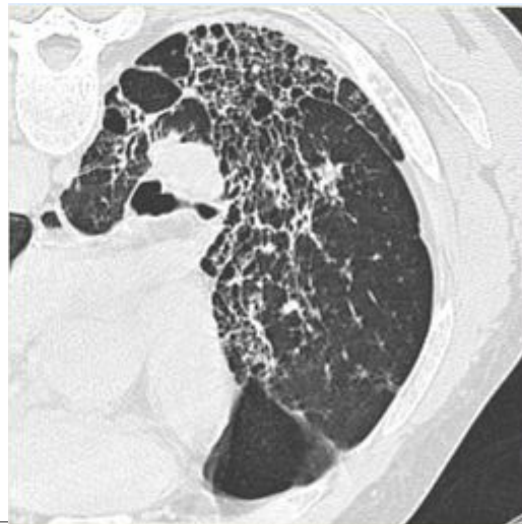
1. Long run emphasis
2. Run length non-uniformity
3. Low gray-level run emphasis
4. Short run low gray-level emphasis
5. Long run low gray-level emphasis
6. Short run high gray-level emphasis
7. Long run high gray-level emphasis
8. Short run emphasis
9. Run gray-level non-uniformity
10. Run percentage
11. High gray-level run emphasis

Multi-dimensional Descriptor

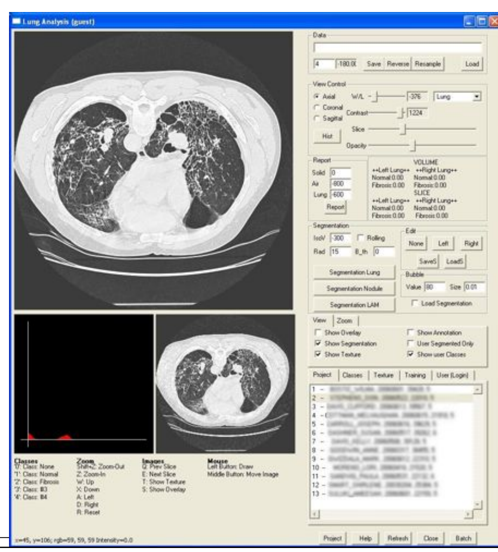




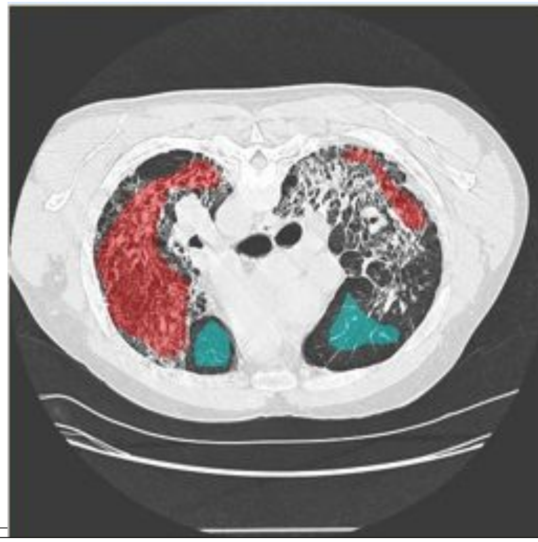
Pulmonary Fibrosis



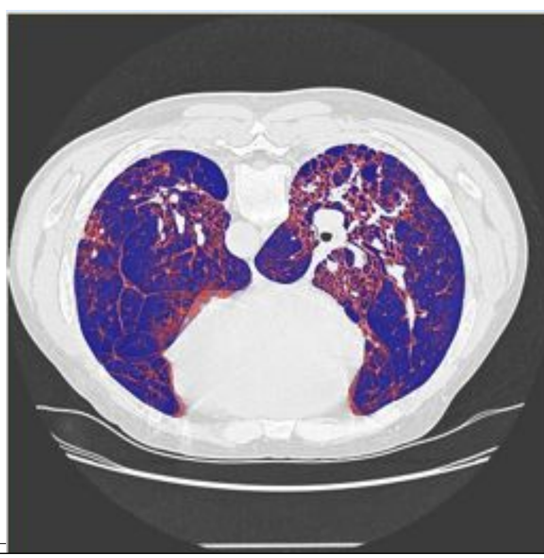
Texture-Based CAD System



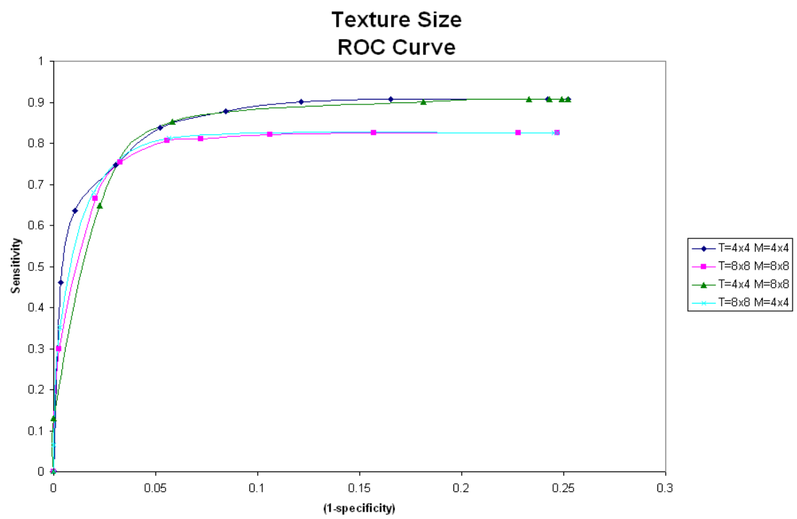
Expert Selection



Results



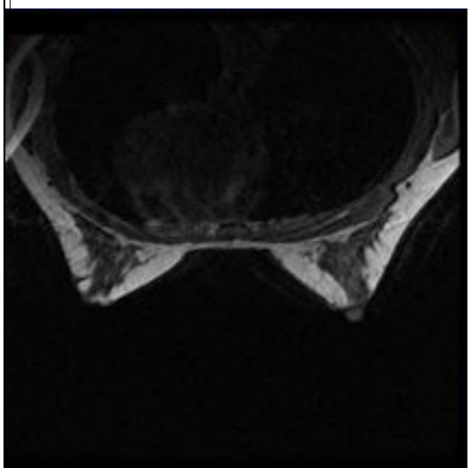
Results

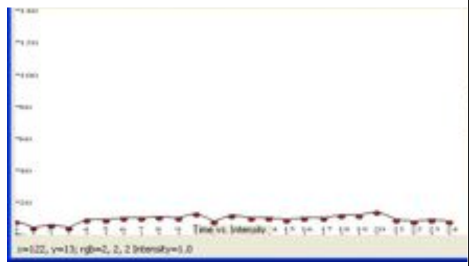


Processing

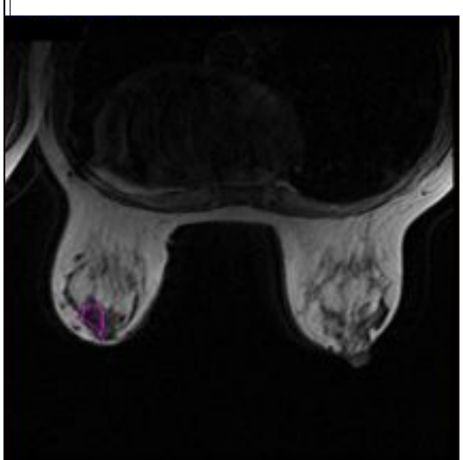
Image Processing
Breast Cancer

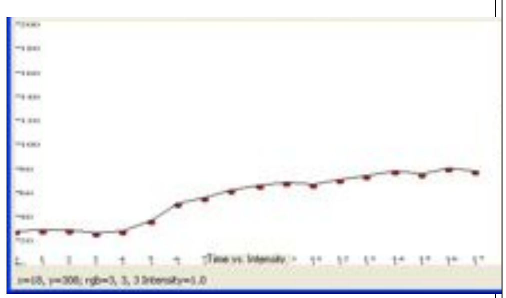
Dynamic MRI





Cancer





Conclusion

- There's a significant need to apply more and better computational techniques to medical imaging.