Computational Medical Imaging Analysis
Chapter 6: Image Measurement and Meaning

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6.1a: Introduction

- Digital images are inherently measurable
- Suitable measurements provide insights, understanding, and meaning of the images
- Usefulness of image measurements depends on the accuracy and reproducibility of the measurements
- Factors such as image type, fidelity, “realness”, and method and/or algorithm used for measurement, may affect the measurement usefulness

6.1b: Image Attributes

- Many attributes that may be measured to quantify the properties and features of the imaged objects
- Spatial extent (length, area, volume) of imaged objects is easy to measure
- It can be used to calculate the surface area of skin needed in plastic surgery, or
- To estimate the change in volume of brain tumors in response to radiation therapy treatment

6.1c: Measurements

- Measure of imaged shape and fractal signature may hold promise for automated image segmentation and understanding
- Measure of image gray scale statistics within selected object regions can be used to estimate blood volume and blood flow from dynamic CT contrast scans
- It can be used to quantify regional brain pathology using functional imaging modalities, and brain function mapping from MRI neurofunctional studies

6.1d: Statistical Approach

- Measurements are most commonly made after manual or automated segmentation of an image or group of images into specific sets of substructures
- Accurate automated segmentation may be impossible in some cases due to image quality
- Manual segmentation may be prohibitively expensive
- It is possible to use statistical sampling, which may offer higher accuracy and reproducibility in measurements
- Errors in measurements must be quantified

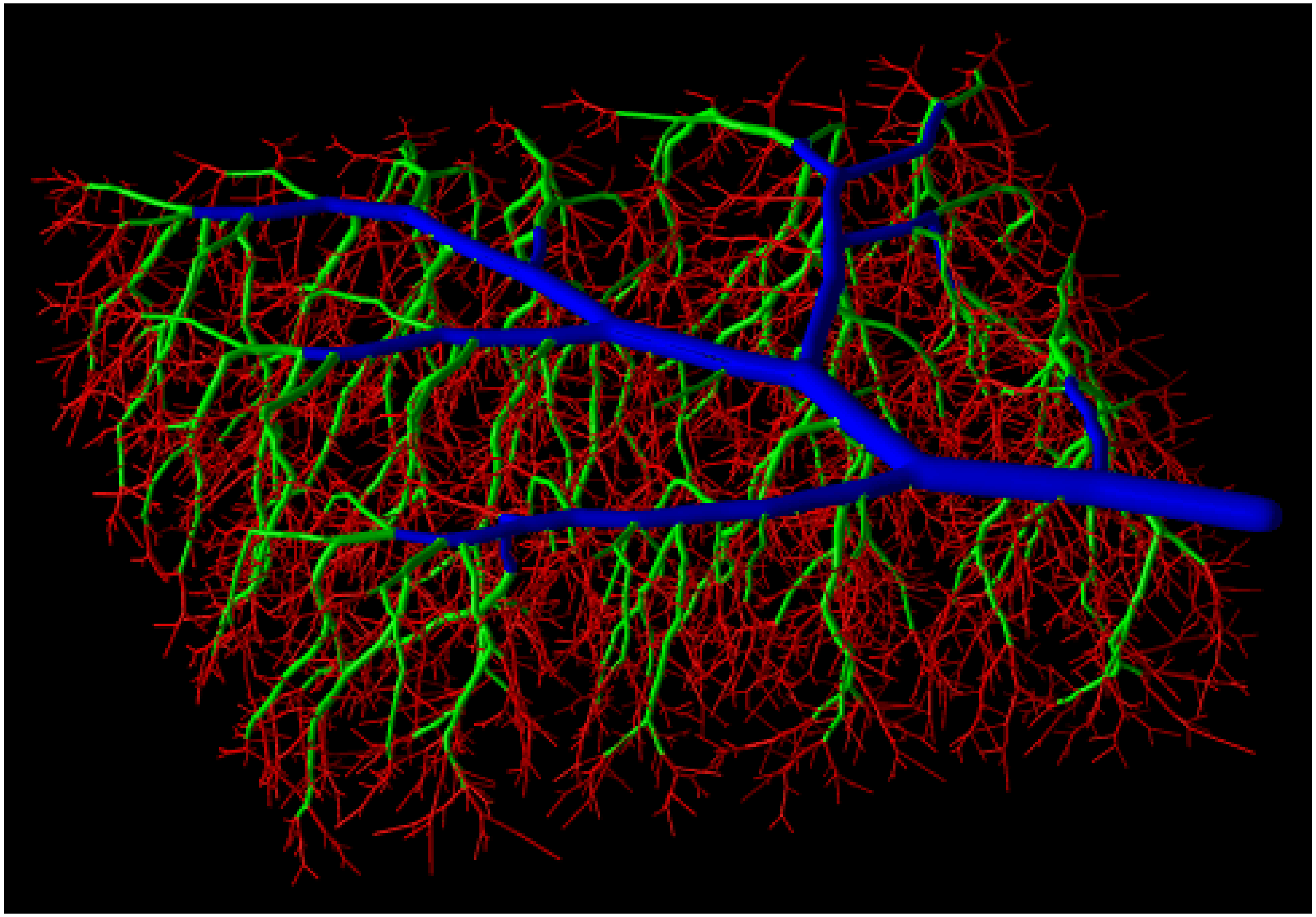
6.2a: Region of Interest Measurements

- The most basic measurements are simply computing 3D coordinate locations
- These might be made interactively by scanning through a stack of sections to find a certain structure,
- then pointing to a feature on that structure in the desired section
- These positions may be automatically computed following a segmentation process

6.2b: MRI Head Measurements

- MR volumes of the head are commonly reformulated along a line that joins selected points on the anterior and posterior commisure
- Arterial tree analysis may use the segmented medial axis skeleton of the artery to compute the center and orientation of oblique sections that are perpendicular to the section
- 3D point locations may be selected directly on 3D renderings of a volume, such locations can be used to compute and display the three orthogonal planes that intersect at the selected point

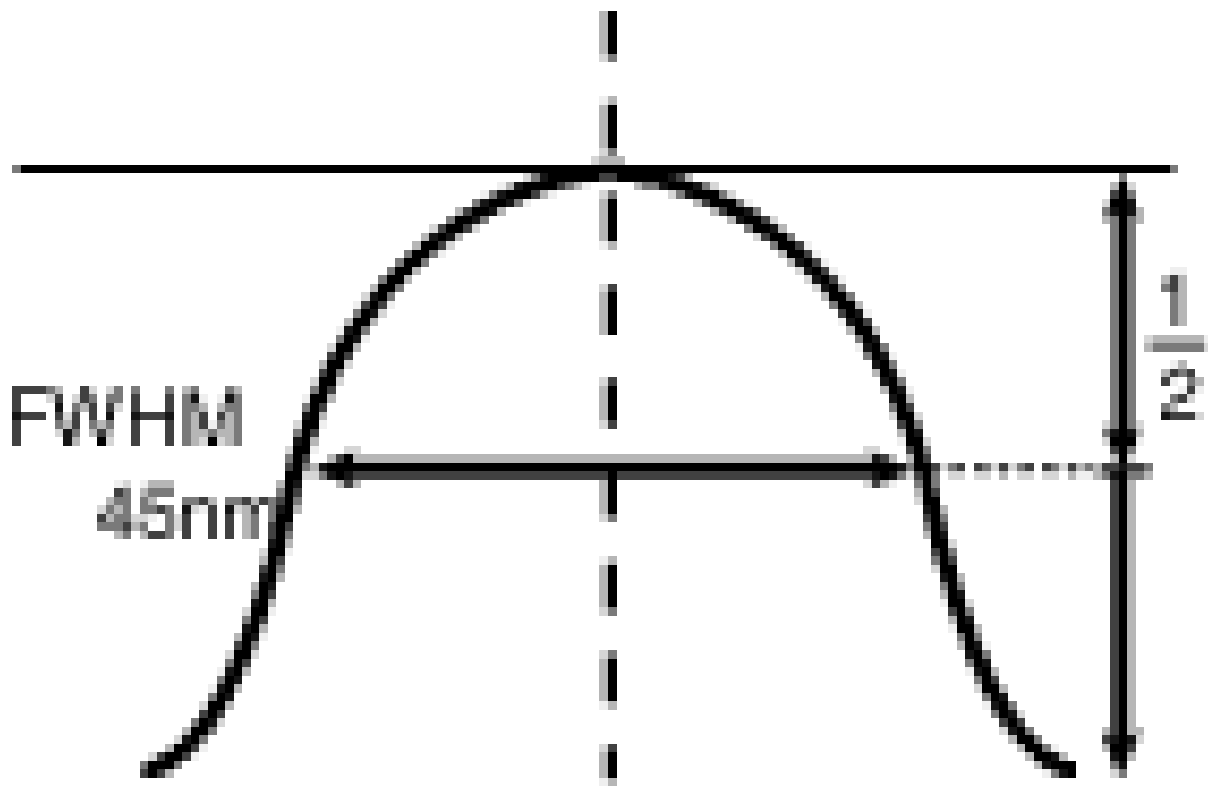
6.2b*: Arterial Tree



6.2c: Distance Measurements

- Measurements of “line profiles” reveals the progression of image gray scale values along any **traced line**
- Straight and curvilinear traces can be profiles, provided both local distance and intensity information
- The *full-width half-maximum* technique: two successive points where the line profile is at one-half of its maximum value are detected and used as the end points of a segment across the object
- The distance between these points is used as a measure of object size or diameter

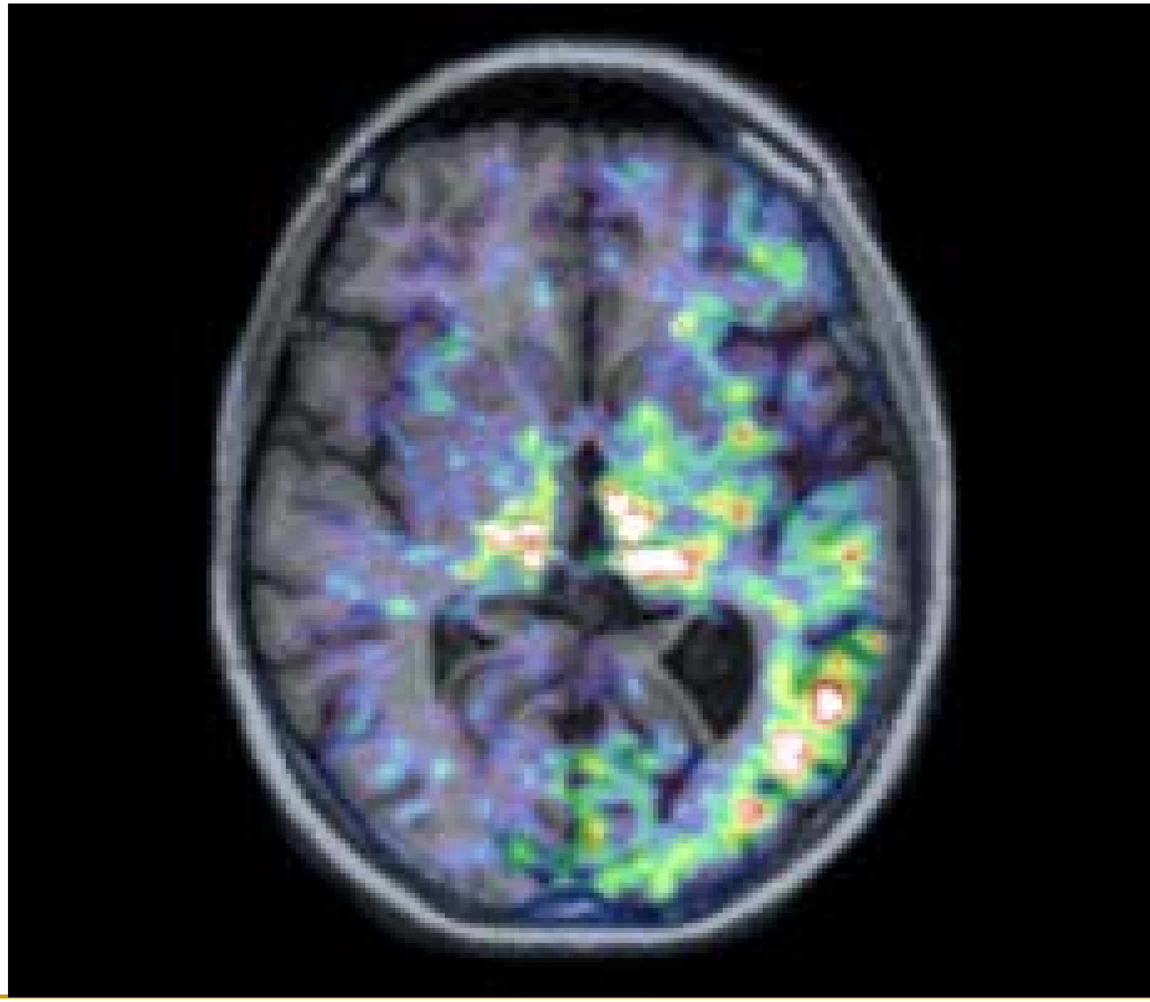
6.2c*: Full-Length Half-Maximum Technique



6.2d: Coregistered Data

- The use of coregistered data from different imaging modalities often makes region definition and measurement more precise
- To measure the functional activity within a specific anatomical region of the brain, MR images are often used to precisely define the locations to be measured
- The actual measurements are made on the corresponding regions of the coregistered PET data

6.2d*: Co-registered MRI and PET Data in Studies of Neuroinflammation



6.2e: Measurements in 2D regions

- A straightforward way is to count all pixels included in the region and scale (multiple) the results by the known area of a pixel
- It assumes the border lies exactly along the edges of the boundary pixels in the region and the region was segmented to contain all pixels known to be entirely part of the object
- Such pixel counting gives highly reproducible results, but is likely to consistently overestimate the area and perimeter of the actual object

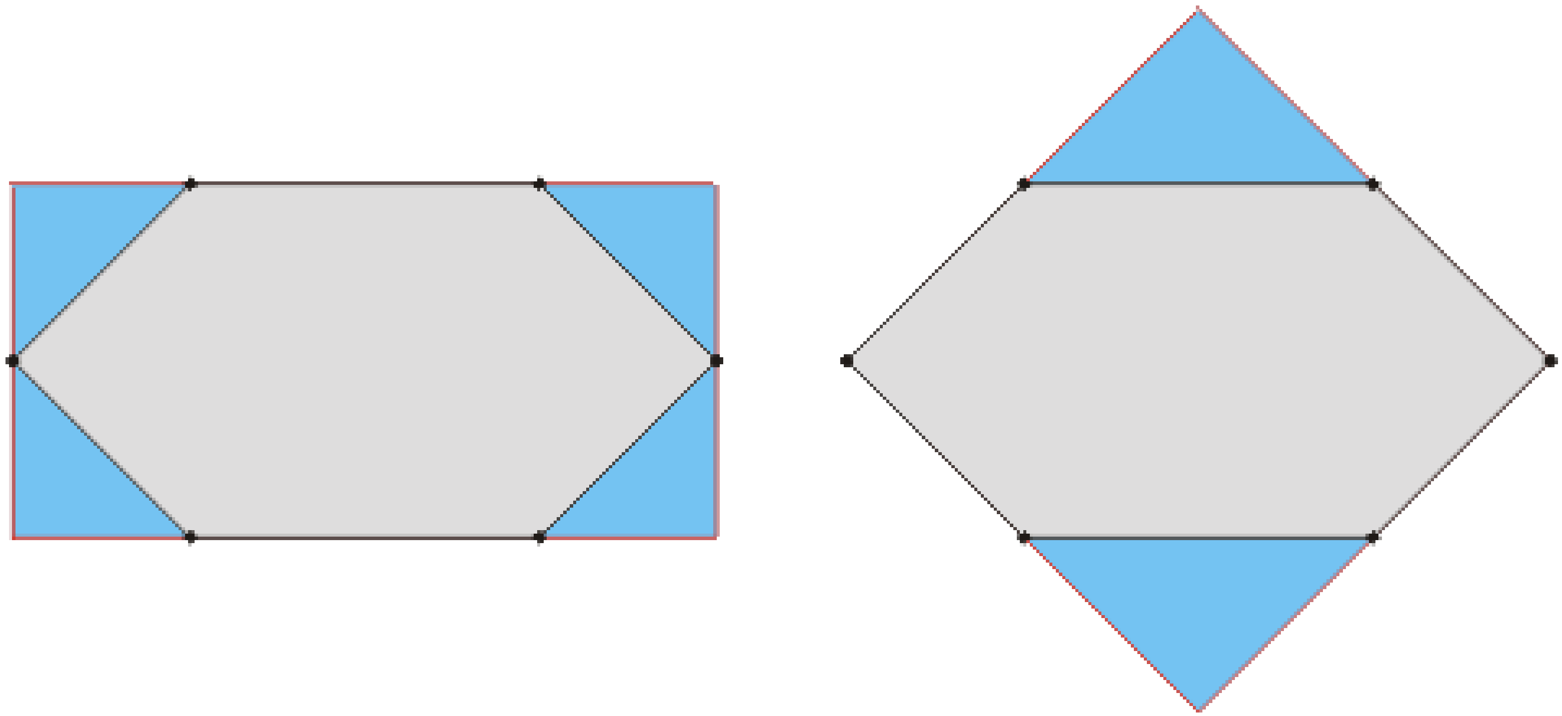
6.2f: Measurements in 2D Regions (II)

- If the image region was segmented to contain all pixels thought to be even partially in the object of interest
- The area may be more accurately estimated by considering the region boundary as a curve connecting the centers of the edge pixels and calculate the area bounded by the curve
- Simple line segment boundaries provide useful estimate, but detailed boundary formed by analytical curves is more accurate when knowledge about the anatomy and imaging modality can be included

6.2g: Shape-Descriptive Measurements

- The area and aspect ratio of the minimum enclosing rectangle (MER) give some indication of the orientation and compactness of a region
- The ratio of the area if the region to the area of the MER, known as the rectangular fit factor (RFF), indicates how well the region fill its MER
- Circularity indicates how efficiently the shape encloses space ($C = P^2/A$)
- (P = perimeter, A = area)

6.2g*: Minimum Enclosing Rectangle



6.2h: Statistical Distribution

- Statistical distribution of gray scale values within the region may be of interest
- This is the basis of measurement of blood flow and perfusion from change in dye concentration, of average metabolism rate in PET
- The maximum, minimum, mean, and standard deviation are the most commonly derived statistical measures
- The gray scale histogram of an image region contains the entire statistical distribution

6.2i: Statistical Distributions (II)

- The properly scaled sum of all pixel values in the region of interest is known as the integrated optical density (IOD)
- If the image is thresholded, the sum of pixel values above the threshold in the region is known as the brightness area product (BAP)
- The BAP is useful for estimating the amount of high-contrast material in a region, such as radiopague dye injected into the bloodstream

6.2j: 3D Volume of Interest (VOI)

- Regions of interest can be uniquely defined or extruded through a defined number of successive sectional images in a volume to facilitate measurements in 3D
- Tomographic sections contain unambiguous information about the interior of objects in a basically unintuitive and difficult to analyze form
- 3D renderings of objects are intuitively natural, familiar forms that contain no direct information about their interiors
- They are complementary in analysis

3.2k: Volume of 3D Solid Objects

- This is easily estimated by voxel counting
- The precision of the measurements is inversely proportional to the number of voxels in the object
- The count of the surface voxels scaled by the squared voxel dimension may be a good estimate of surface area for large objects
- This generally produces an underestimation of the true surface area

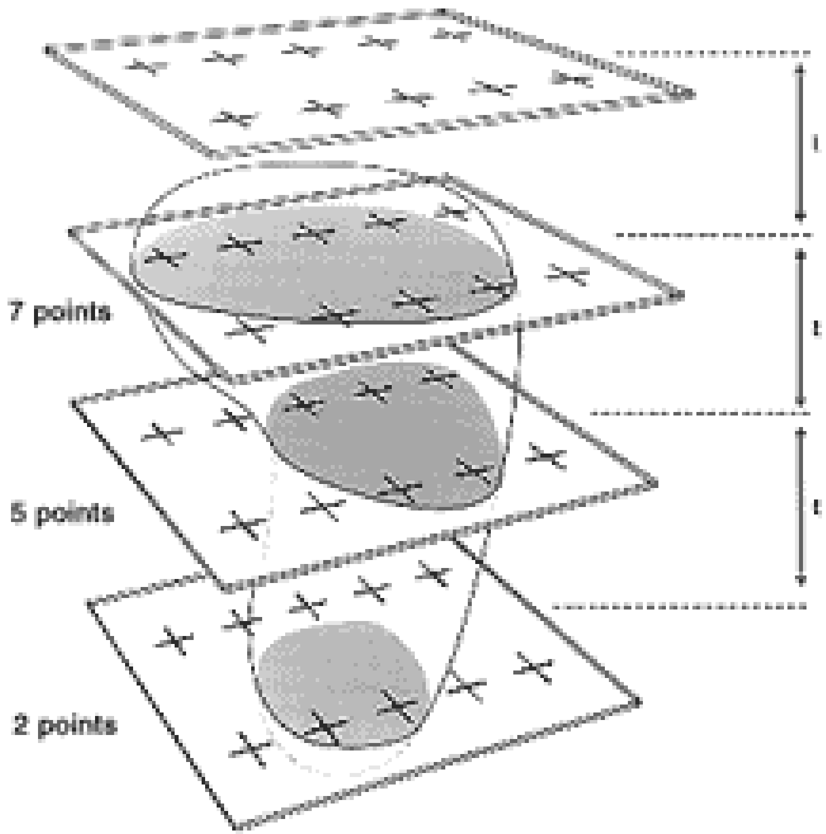
6.3a: Stereological Measurement Techniques

- This process involves the simple and fast method of segmenting an object by counting the number of intersections a randomly oriented and positioned grid makes with the object being measured
- It is based on the Cavalieri principle, which states that the volume of an object can be estimated by cutting the object into *N* equally spaced sections and finding the area of the object on each section

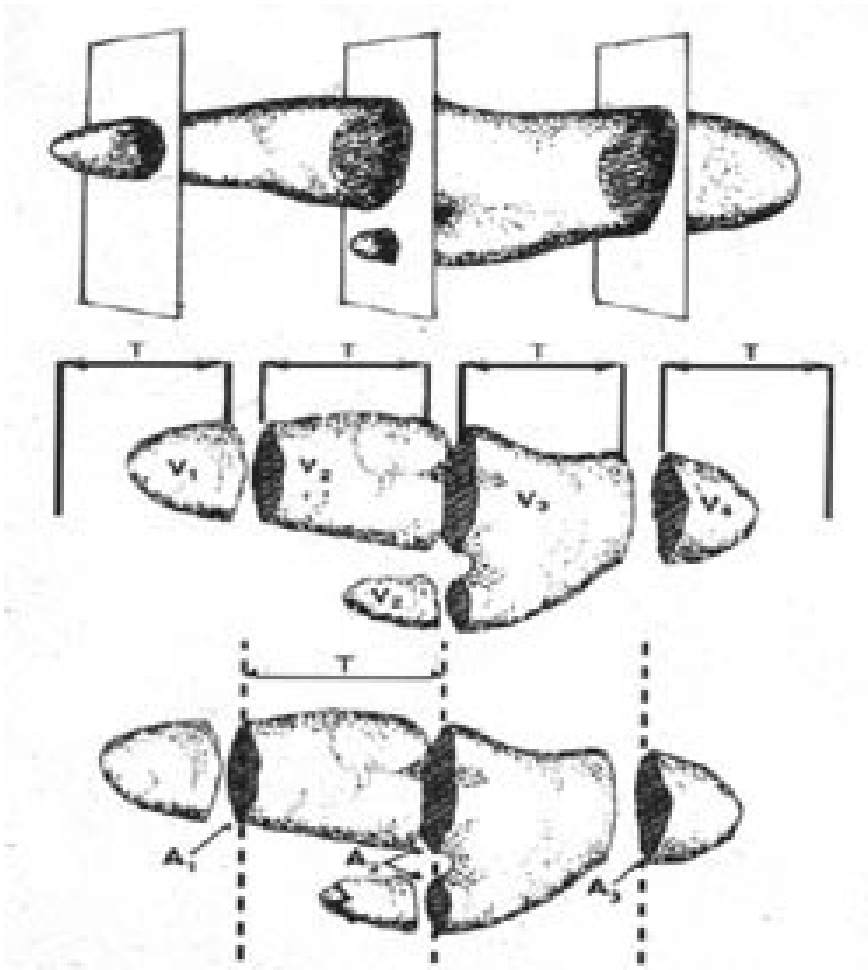
6.3b: Calvalieri Principle

- With appropriately weighting the sum of all sectioned areas, the estimated volume is
- $$V_{est} = T^*(A_1 + A_2 + \ldots + A_N)$$
- Where *T* is the thickness of each object slice
- A_i us the area of the object on slice *i*
- The error in using this type of measuring scheme is based on how the measured area changes from slice to slice

6.3b*: Cavalieri Principle for Shape Volume Estimate



6.3b**: Volume Measurement



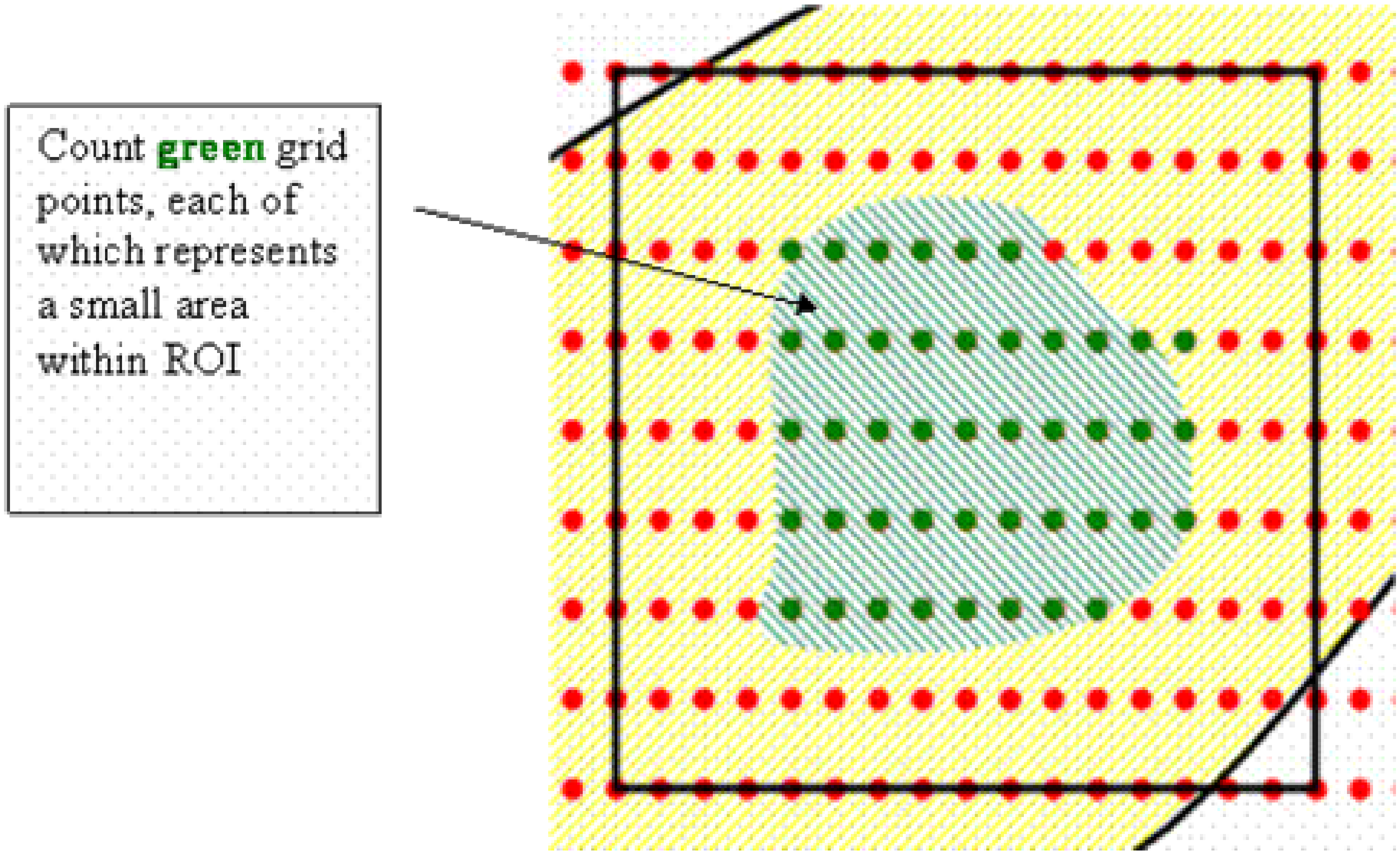
6.3c: Voxel Counting

- Voxel counting on each slice is one variant of the Cavalieri principle
- The subdivision of the objects are the voxels themselves
- An explicit voxel-by-voxel segmentation of the object is required

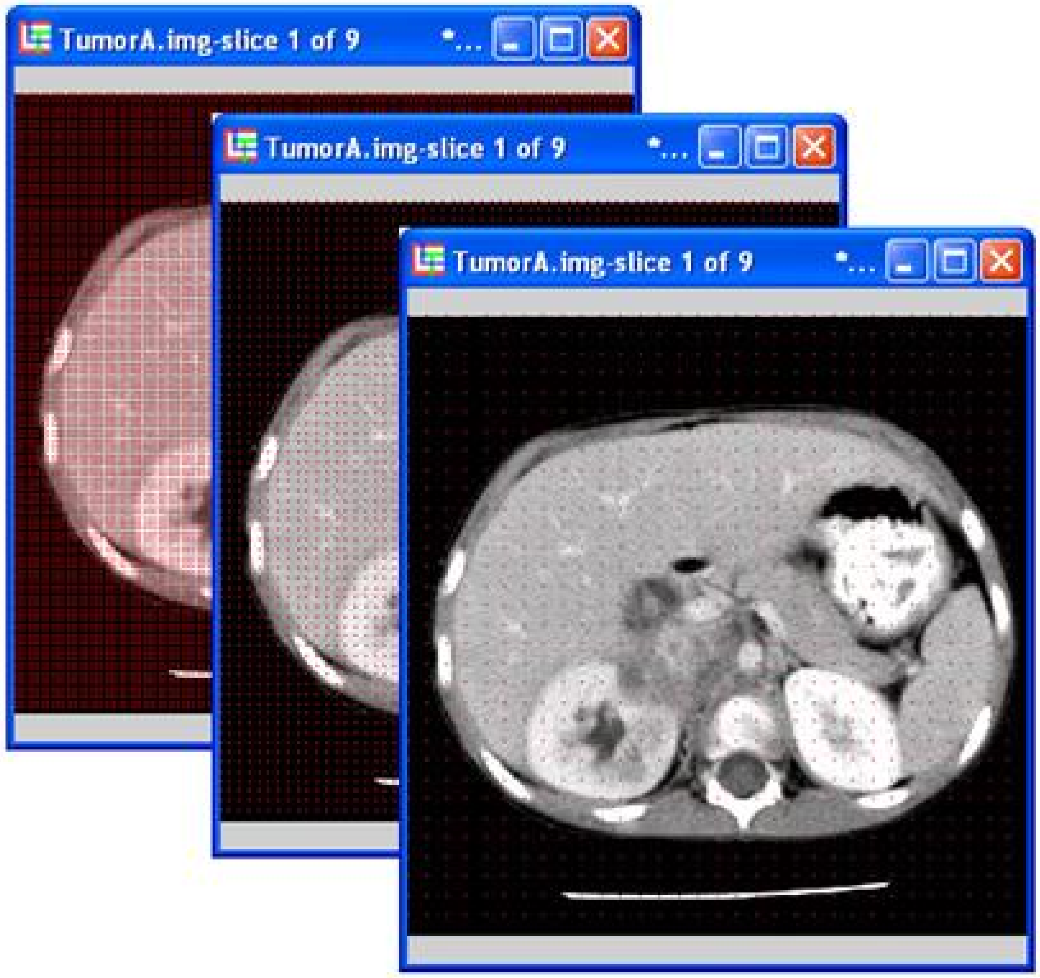
6.3d: Grid Measurement

- Placement of a systematic grid of points over each section and counting the number of intersections between the points and the object
- The spacing of the points determines the area contributed by each point that intersects the object
- Fewer border decisions are needed as many of them points will be either clearly on or off the object of interest

6.3d*: Point Counting in a Grid



6.3d**: Grid Image Volume



6.4a Measurement in the Frequency Domain

- Certain types of image features (such as patterns) are best measured in the frequency domain
- Image contamination in the form of defocus or motion blur can be detected in the Fourier domain
- Blur will always destroy high-frequency information in the image
- Metrics such as the sum of high frequency Fourier components, or a ratio of high- to low-frequency values, allow the detection and quantitative evaluation of image blur

6.5a: Meaning of Measurements

- Measurement is both the process and purpose of imaging
- Meaning is the purpose of measurement
- The advantage is the significant potential for obtaining meaning from measurements of the numbers comprising the images
- If these numbers are robust, then accurate, reproducible, quantitative assessments of anatomy and function of organs can be made

6.5b: Shortcomings

- Imaging systems and methodologies for image processing and analysis, as advanced as they are, are still imperfect and finite
- In the infinite perspective, digital images remains relatively coarse samples of real-world objects and their properties
- Measuration on images must be carefully done, accounting for a variety of linear and nonlinear, systematic, and random sources of errors