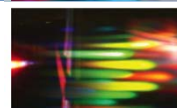




Imperial College
London



Cardiovascular Image Processing

Dr Daniel Elson
Reader in Surgical Imaging
Friday 4th January 2013



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Summary

Imperial College
London

- Properties of digital images
- Methods of enhancing digital images
 - Pixel and local operators, frequency domain methods
- Image segmentation
 - Thresholding and edge detection methods
- Quantification and analysis in cardiovascular applications
 - Myocardial wall motion and blood flow
- Visualisation methods
 - Display of 3D data, projections



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Why learn about image processing techniques?



- Medical imaging technologies are able to probe structure, function and pathology of human body, tissues and cells
- Used for planning treatment and surgery
- Data sets in 2, 3 and more dimensions and vast amount of information
- Some analysis may be automated, but others require human input
- Clinical interpretation of data important to remain at the forefront of medicine research

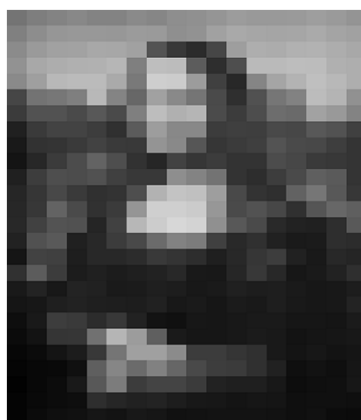


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Human vision (1)



- Excellent at qualitative tasks...



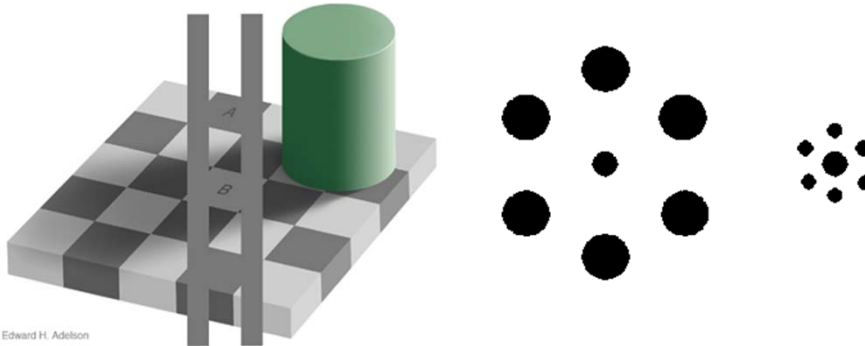
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Glasbey and Horgan, "Image analysis for the biological sciences"

Human vision (2)



- ...but not so good at quantitative ones



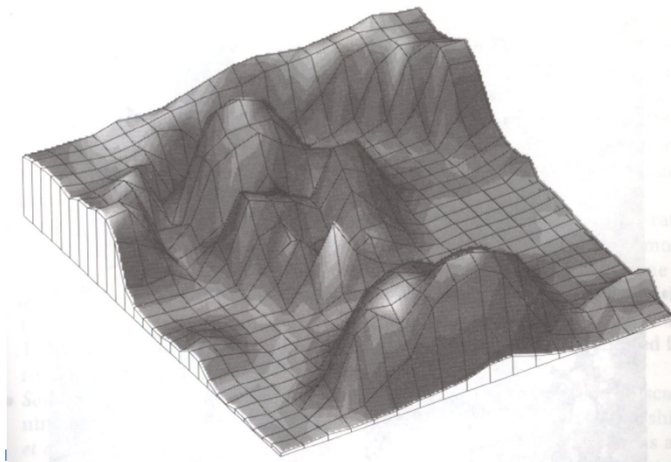
Edward H. Adelson



Human vision (3)



85	324	236	162	36	186	173	165	164	63
26	42	52	162	157	198	175	136	165	85
235	5	25	162	164	198	127	125	163	64
23	216	63
23	124	63							
52	126	23							
51	152	164							
54	146	187							



Human-computer interaction



- Need to divide image interpretation and quantification tasks between the computer and the human
- Automate as much as possible, but allow human correction of results



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What is a digital image? (1)



- Collection of 'pixels' on a rectangular grid
- Each pixel contains a number or a collection of numbers that represent the real continuous signal

'Greyscale'
e.g. whole numbers from 0-255

15	37	38	
13	28	71	12
39	63	19	63
26	32	17	35




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What is a digital image? (2)

'Binary'
i.e. 1s and 0s

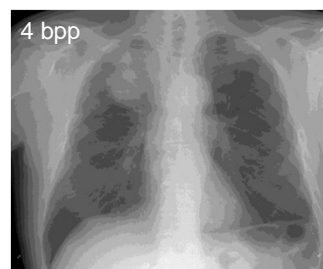
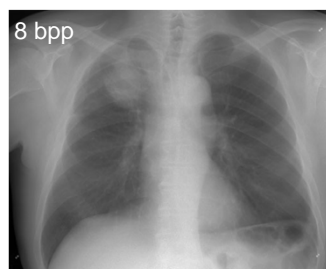
0	1	1	
0	0	1	0
1	1	1	0
0	0	1	0



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What is a digital image? (2)

- Different number of *bits per pixel (BPP)* results in images of varying quality
- The number of possible grey levels is called the dynamic range
- Too few BPP results in *contouring* of the image
- Most medical images use 12 or more bpp



From Suetens

What is a digital image? (3)



'Colour' (RGB)
3 values per pixel

75	72	25
15	35	95
23	61	83
35	52	57
61	85	27
83	46	46
49	57	26
27	27	85
46	83	87
57	49	13
85	93	35



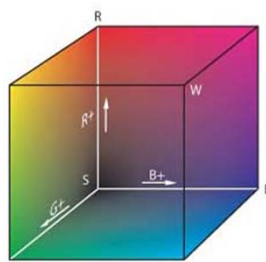
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Colour models

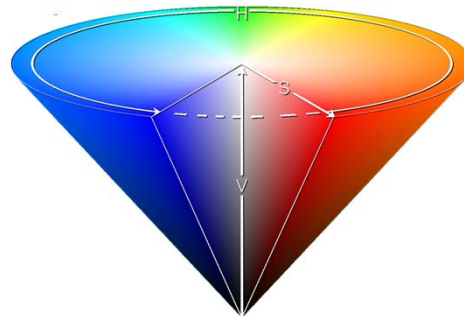


'Colour' (RGB)
3 values per pixel

75	72	25
15	35	95
23	61	83
35	52	57
61	85	27
83	46	46
49	57	26
27	27	85
46	83	87
57	49	13
85	93	35



Alternative: Hue, saturation, value model



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What is a digital image? (4)

1	0 0 1
2	0 1 1
3	0 0 2
4	0 1 2

'Colour' (RGB)

1 value per pixel + look up table

15	37	38	
13	28	71	12
39	63	19	63
26	32	17	35

etc



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Image enhancement



- Refine images so that desirable attributes are emphasised and undesirable attributes are suppressed.
 - **Pixel operations** – transformation based only on the intensity level of each pixel.
 - **Local operations** – depend on the intensity of each pixel and those in its neighbourhood.
 - **Operations with multiple images** – examples include averaging using multiple input images. Images have to be registered, i.e. pixels in each image have to be measurements of the same spatial region.
 - **Frequency domain techniques** – these involve performing a Fourier transform on the image data. Common uses include noise suppression, image smoothing or edge enhancement.



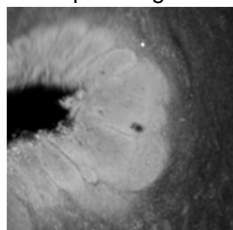
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Intensity histograms

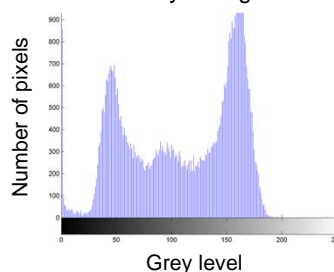


- Shows the number of pixels in the image at each different grey level

Input image



Intensity histogram



- Useful for manipulating images in order to improve the visibility of different features.
- Also used for some image segmentation methods

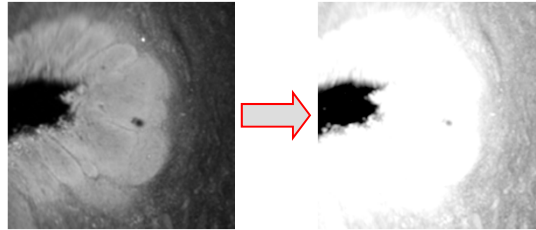


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Pixel operations

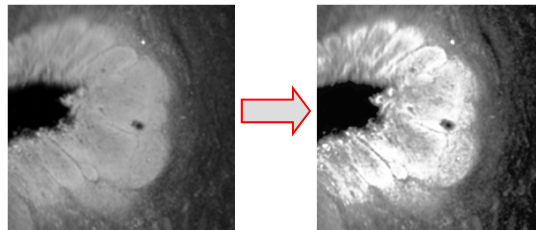


- Intensity scaling
 - Use a user-defined numerical operation to emphasise specific intensities



- Histogram equalisation

- Automated method to spread the intensities smoothly across full range of values



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Local operations (1)



- Enhance image using the value of each pixel and its nearest neighbours (*convolution*)

Step 1: Define a 'Kernel' or 'operator' consisting of a matrix of numbers

e.g.

1	2	1
2	3	2
1	2	1

Step 2: Line the centre of the Kernel with one of the pixels in the image

15	37	38	
13	28	71	12
39	63	19	63
26	32	17	35

Step 3: Multiply together the corresponding numbers and add them up, i.e.

$$(1 \times 13) + (2 \times 28) + (1 \times 71) + (2 \times 39) + (3 \times 63) + (2 \times 19) + (1 \times 26) + (2 \times 32) + (1 \times 17) = 552$$

Step 4: Place the calculated value of 552 in the corresponding position in the output image

	552		

Step 5: Repeat for all pixels in the input image



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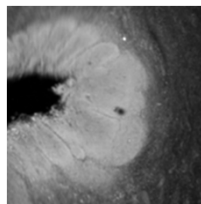
Local operations (2)

- Example 1: smoothing Kernel, for instance:

1/9	1/9	1/9
1/9	1/9	1/9
1/9	1/9	1/9

1/12	1/6	1/12
1/6	1	1/6
1/12	1/6	1/12

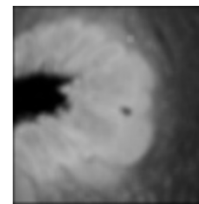
This is called noise suppression by mean filtering, or smoothing



⊗
convolved
with

1/9	1/9	1/9
1/9	1/9	1/9
1/9	1/9	1/9

smoothing
kernel



Input image

Output image

Edge detection (Sobel)

- Example 2: edge detection Kernel, for instance:

-1	-2	-1
0	0	0
1	2	1

Enhances
horizontal edges

-1	0	1
-2	0	2
-1	0	1

Enhances
vertical edges

This is called a Sobel
filter – useful for
segmentation



⊗
convolved
with

-1	-2	-1
0	0	0
1	2	1

Horizontal edge
enhancement
kernel

+ further
pixel
intensity
scaling
→



Input image

Output image

Operations on Multiple Images

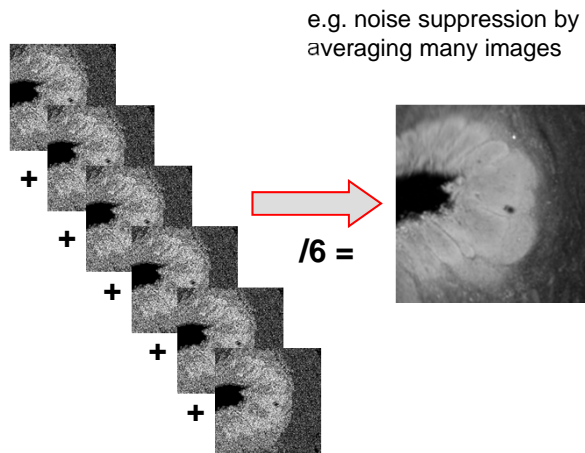
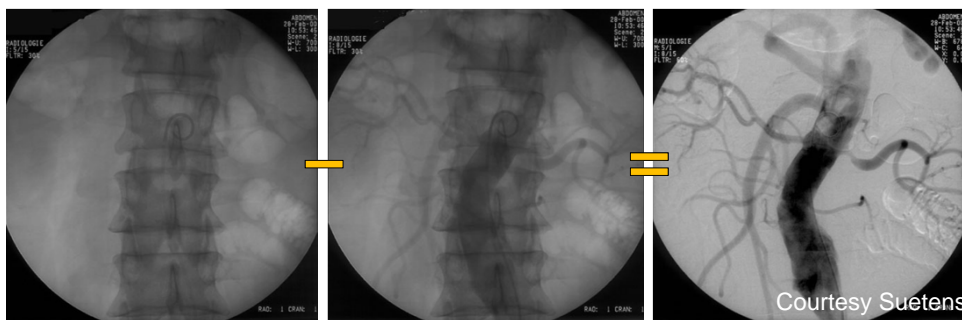


Image subtraction



Before contrast agent

After contrast agent

Can also look at the differences between two images by subtracting one from the other - enhances the difference between them

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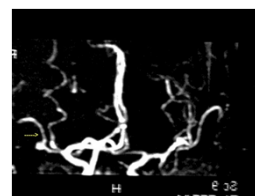


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Introduction to segmentation



- The goal of segmentation is to divide an image into **regions** or **categories** that have similar properties
- Used for feature extraction and display, or to delineate anatomical features, bones, muscles etc. or pathological regions, tumours
- Applications include:
 - detecting the coronary border in angiograms or MRI
 - detection of microcalcifications on mamograms
 - surgical planning
 - detecting borders between different cell types
 - separating objects that have been labelled differently, e.g. to locate regions that contain a contrast agent
- Many methods are used including thresholding, multivariate, edge based and region growing techniques

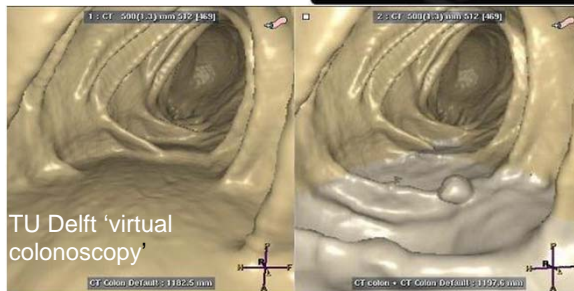
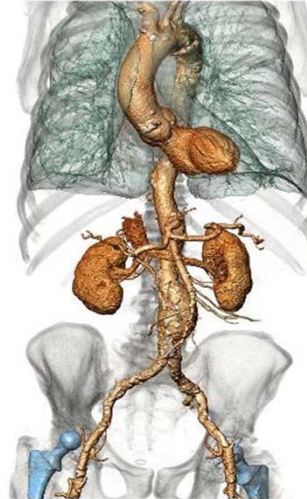
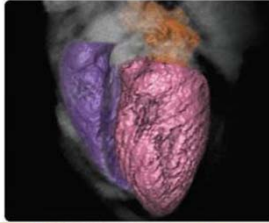


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Applications: image visualisation

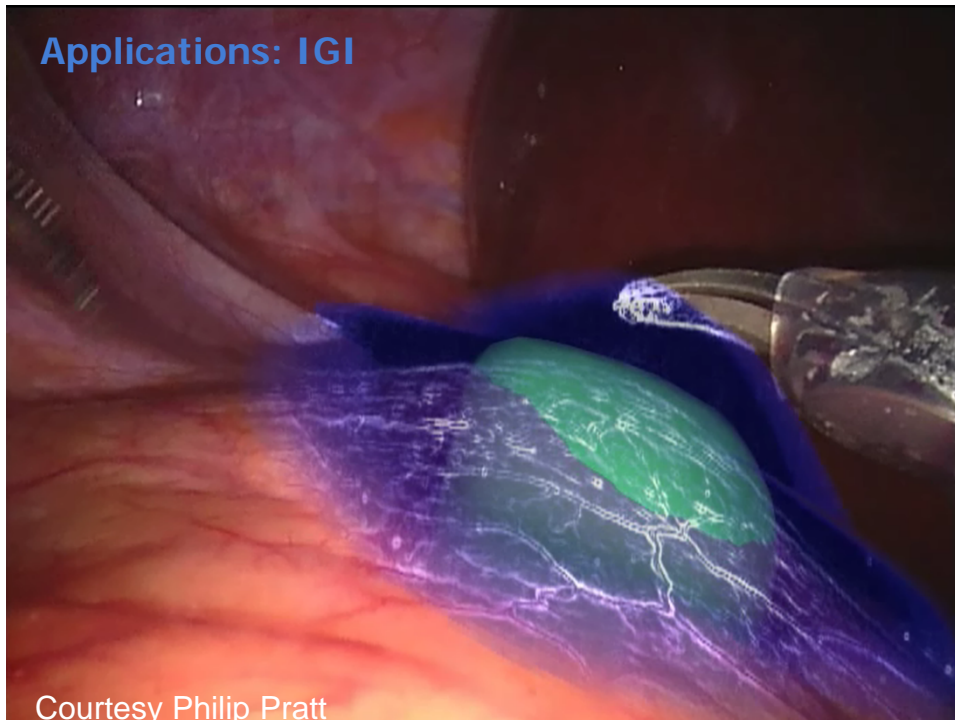


- Segmentation allows 3D surface models of the tissue to be constructed
- Typical algorithms include marching cubes



Birmingham Heartlands Hospital

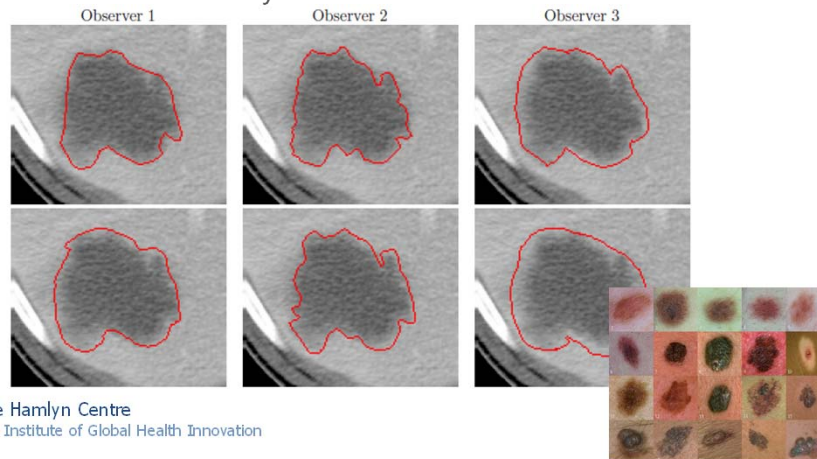
Applications: IGI



Courtesy Philip Pratt

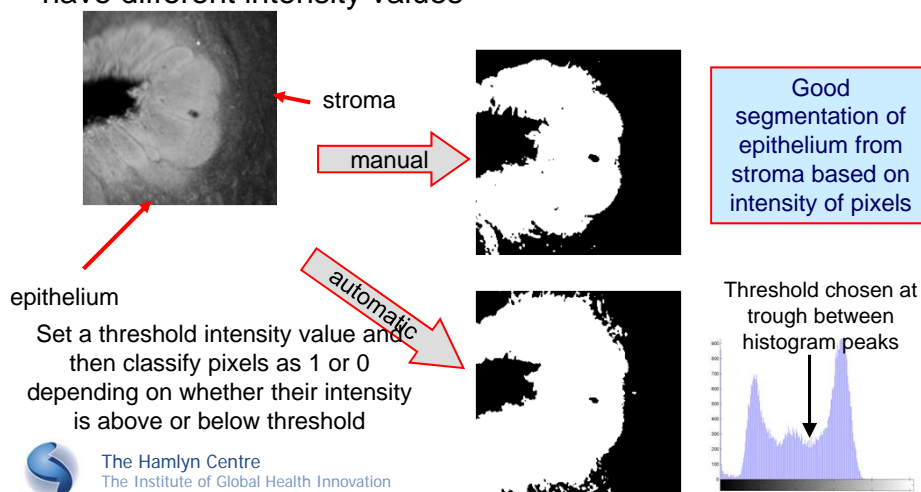
Manual segmentation

- Clinician manually draws a line around the area of interest
- Automated analysis is often very difficult or unreliable
- Manual analysis may be more reliable, but significant inter and intra observer errors may still occur



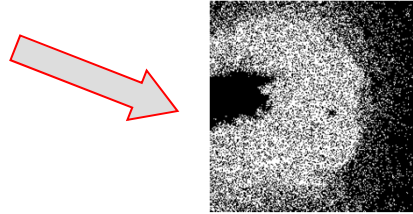
Pixel-based classification methods

- Assume that different anatomical / physiological regions have different intensity values



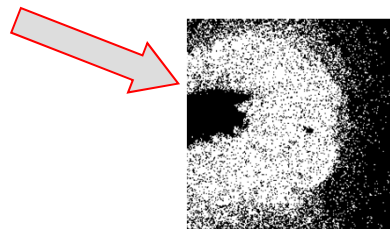
Problem: noise

- Thresholding may be sensitive to speckle or noise in the image



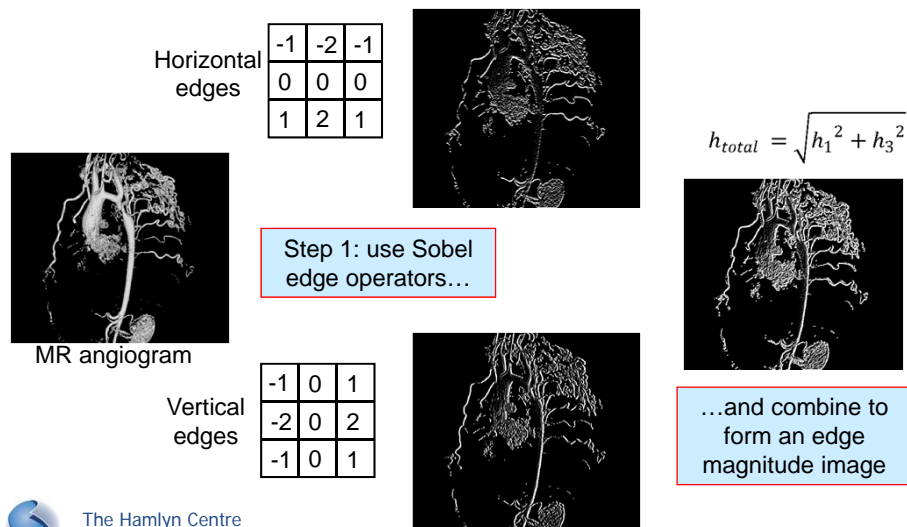
- Solution:** smooth the image before thresholding

This is univariate classification – using just one image parameter to determine segmentation thresholds



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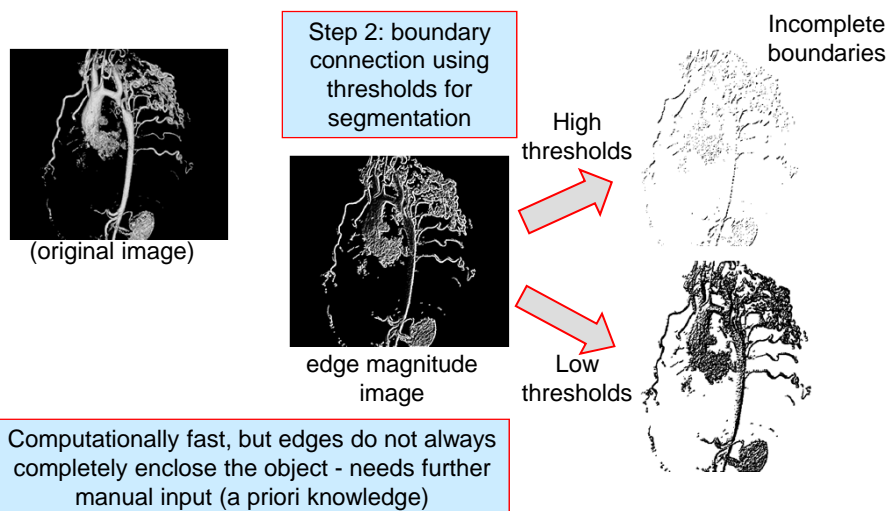
Edge-Based Segmentation Techniques



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Forming connected regions

- Edges must be linked to form fully enclosed regions of the image for segmentation, depending on $T_{1,2,3}$



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Cardiac Quantification Examples



- Uses:
 - Measure ventricular wall motion abnormalities
 - Measure myocardial perfusion
 - Visualise cardiac malformation
- Methods
 - Geometrical estimation of ventricular size and ejection fraction (US, MRI, cineangiogram, radionuclide ventriculogram)
 - Blood flow and coronary reserve (angiography, scintigraphy, PET)
 - Wall motion dynamics (cineangiography, radionuclide ventriculography, MRI)

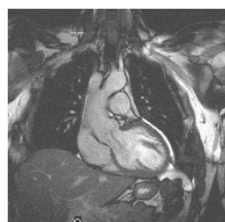


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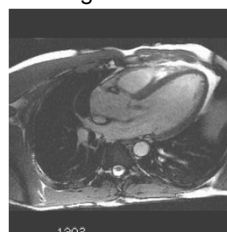
Dynamic Image Acquisition



- Limits of imaging hardware mean that a sequence of images may not be acquired over just one cardiac cycle.
- Instead, acquisition is synchronised to ECG signal and different phases of the cardiac cycle are recorded on different cardiac cycles.
- May also need to synchronise with respiratory cycle or record during breath hold.

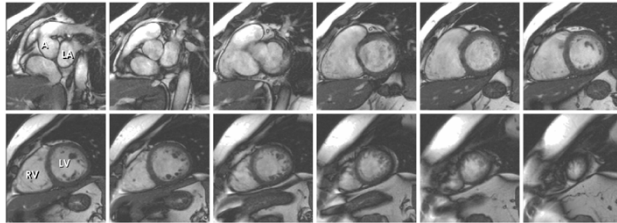


long axis view



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Image Stacks, Volumes and Plane Construction



Record MRI stack of 'short axis' images (~10 mm apart)
One set for each point of cardiac cycle

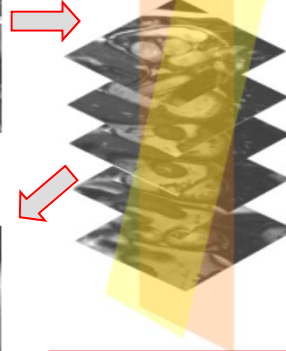


4 chamber view vertical long axis view oblique long axis view



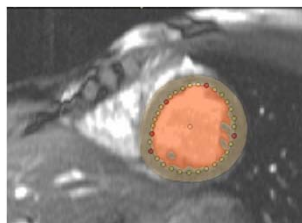
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Create 3D model consisting of 'voxels'

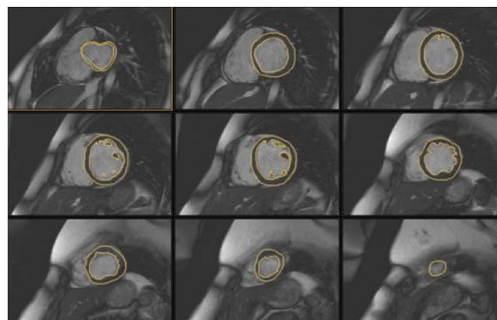


Reconstruct oblique diagnostic planes by interpolation through different voxels

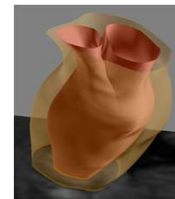
Myocardial Wall Motion Measurement (1)



Segmentation based on edge detection

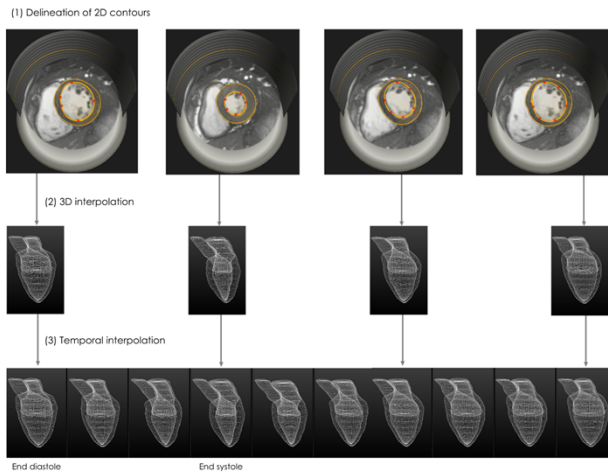


- May be totally automated, although in some cases human interaction is required to guide and correct the borders
- Some methods assume a particular heart geometry and radial edge detection from the centre of the ventricle to improve performance
- Construct a model of heart based on the segmentation results.



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Myocardial Wall Motion Measurement (2)



- NB many more simple methods measure the length and width of the left ventricle and calculate volume of three dimensional ellipsoid.

Reconstruct model of cardiac cycle

Can evaluate left ventricular volume to indicate cardiac performance

Can calculate ejection fraction of blood (should be > 50%)

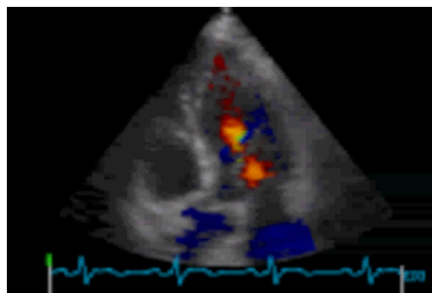
More diagnostic information can be found from the myocardial wall, including its thickness or presence of abnormalities

- Motion of wall may reveal regional asynchrony (techniques use Fourier analysis)

Evaluation of Flow Motion



- Two-dimensional colour Doppler ultrasound (echocardiography) reveals blood flows and wall motions
- Real-time two-dimensional Doppler flow mapping with real-time display (overlay a colour 'flow map' on top of black and white anatomical cardiac image)
- Used to diagnose various types of valvular disease



Shows blood motion from left atrium to left ventricle. Red is motion towards transducer (atrium to ventricle). Blue is motion away from transducer (ventricle to aorta)



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Visualisation



- Increasingly important role in biomedical applications
- Allow practitioners to 'see into' and comprehend living systems
- Display and analysis of medical image data
- Used for diagnosis, orientation of anatomy, surgical planning and navigation
- Computationally intensive – need seamless and intuitive human-visual interaction

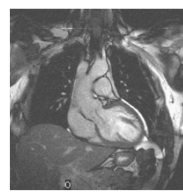
– Examples so far:



Oblique sections



Surface modelling



Dynamic

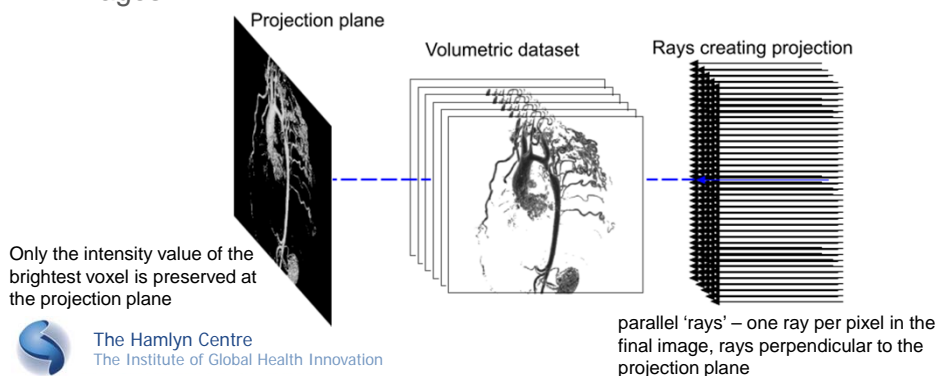


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Volume visualisation



- Maximum Intensity Projection is a volumetric visualisation method for 3D data
- Voxels are illuminated from behind by array of parallel rays and the brightest voxel is projected onto the output image plane
- Two MIP renderings from opposite viewpoints are symmetrical images.



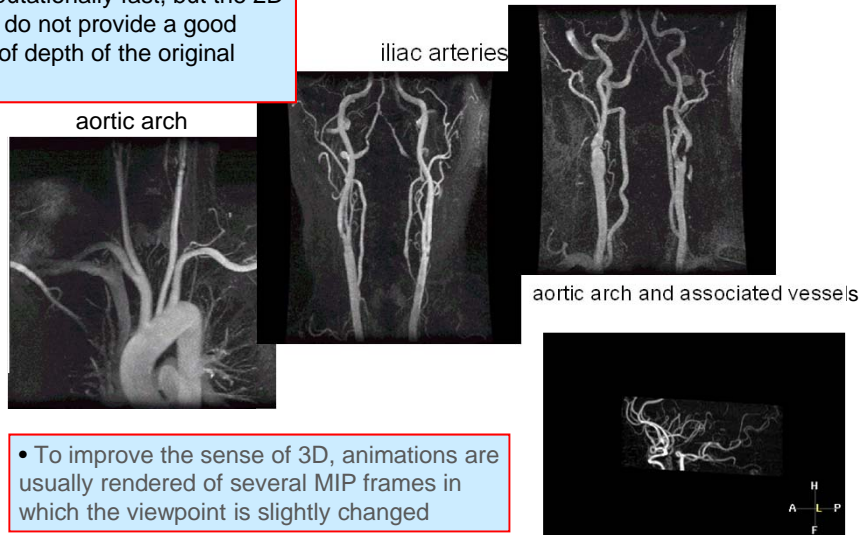
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Maximum Intensity Projections (1)



- Examples of MIP from angiography volumetric dataset

• Computationally fast, but the 2D results do not provide a good sense of depth of the original data.

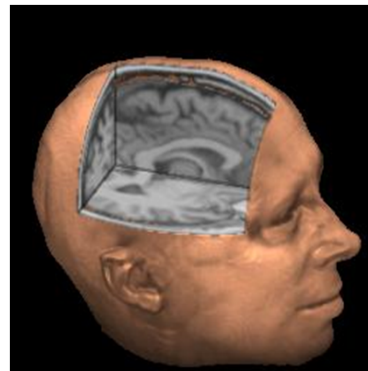


• To improve the sense of 3D, animations are usually rendered of several MIP frames in which the viewpoint is slightly changed

Multi-plane based volume rendering



- It is also common to display the three planes simultaneously
- User can move the planes individually to visualise the volume
- Requires image transformation to display data from a particular viewpoint

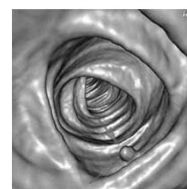
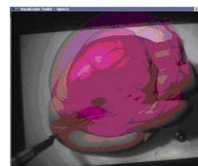


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Future visualisation methods



- Augmented reality
 - Enhance real-world image data with computer generated virtual enhancement
- Virtual reality environments
 - Use realistic real-time surgery planning and interactive computer guidance systems to enhance surgery
- Virtual endoscopy
 - Create a 'fly through' movie or environment from MRI data to perform endoscopic procedures. Can be used in endoscopically inaccessible areas, for instance arteries



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Further information



- Image Analysis for the Biological Sciences, Glasbey and Horgan (Wiley, 1995)
- Handbook of Medical Imaging Volume 2: Medical image processing and analysis, M. Sonka and J. M. Fitzpatrick (SPIE Press, Bellingham, Washington, 2000)
- Fundamentals of Medical Imaging, P. Suetens (Cambridge University Press, 2002)
- Handbook of Medical Imaging: Processing and Analysis, I. Bankman (Academic Press, 2000)
- <http://www.scmr.org/education/atlas/intro/index.html>



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Any questions?



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