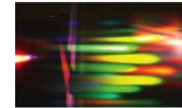# Cardiovascular Image Processing

Dr Daniel Elson
Senior Lecturer in Surgical Imaging
Friday 7th January 2012

The Hamlyn Centre
The Institute of Global Health Innovation

Summary

- 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

The Hamlyn Centre
The Institute of Global Health Innovation

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
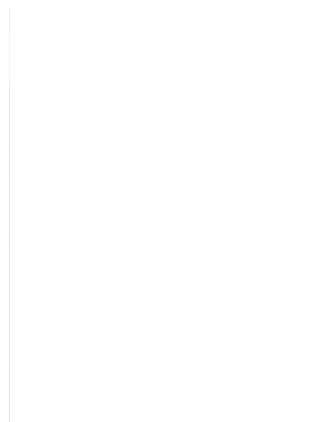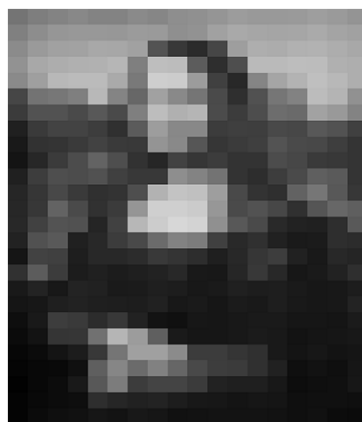- Clinical interpretation of data important to remain at the forefront of medicine research

The Hamlyn Centre
The Institute of Global Health Innovation

Human vision (1)

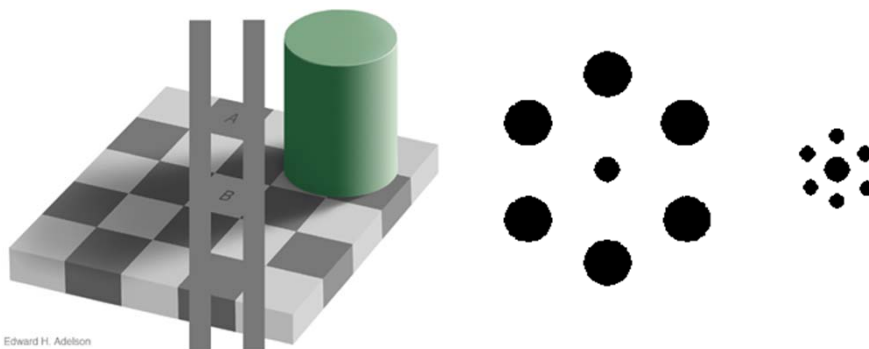- Excellent at qualitative tasks...

The Hamlyn Centre
The Institute of Global Health Innovation
Glasbey and Horgan, "Image analysis for the biological sciences"

Human vision (2)

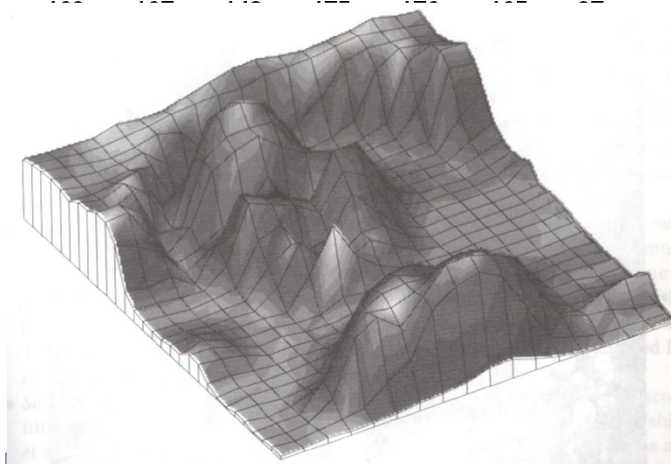- ...but not so good at quantitative ones

Edward H. Adelson

The Hamlyn Centre
The Institute of Global Health Innovation

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							

The Hamlyn Centre
The Institute of Global

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

The Hamlyn Centre
The Institute of Global Health Innovation

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

The Hamlyn Centre
The Institute of Global Health Innovation

What is a digital image? (2)

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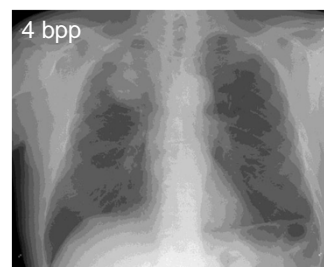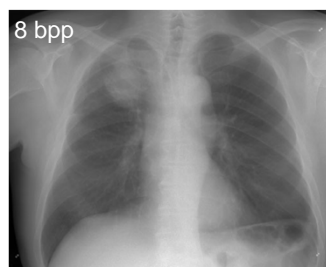

The Hamlyn Centre
The Institute of Global Health Innovation

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

8 bpp

4 bpp

From Suetens

The Hamlyn Centre
The Institute of Global Health Innovation

What is a digital image? (3)

Imperial College
London

'Colour' (RGB)
3 values per pixel

The Hamlyn Centre
The Institute of Global Health Innovation

Colour models

Imperial College
London

Alternative: Hue, saturation, value model

'Colour' (RGB)
3 values per pixel

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

The Hamlyn Centre
The Institute of Global Health Innovation

Imperial College London

Lecture contents

- 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

The Hamlyn Centre
The Institute of Global Health Innovation

Imperial College London

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.
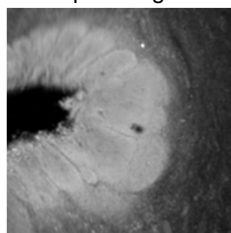
The Hamlyn Centre
The Institute of Global Health Innovation
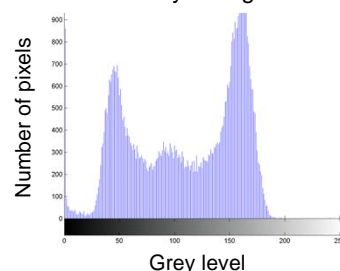
Intensity histograms

- 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.
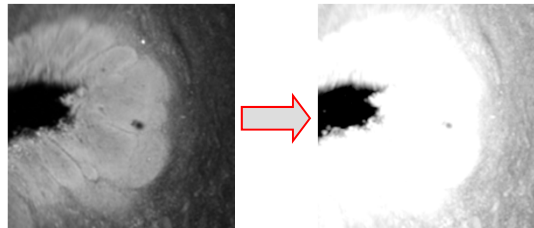- Also used for some image segmentation methods

The Hamlyn Centre
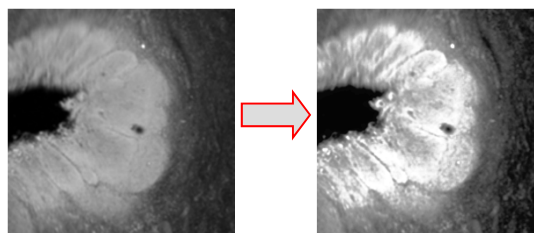The Institute of Global Health Innovation

8

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

The Hamlyn Centre
The Institute of Global Health Innovation

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. (1x13)+(2x28)+(1x71)+(2x39)+(3x63)+(1x19)+(1x26)+(2x32)+(1x17) = 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

The Hamlyn Centre
The Institute of Global Health Innovation

Local operations (2)

Imperial College
London

- Example 1: smoothing Kernel, for instance:

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

Alternative smoothing kernels

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
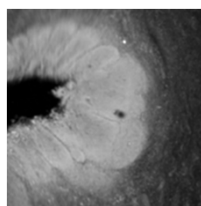
Input image $\otimes$ convolved with

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

smoothing kernel

Output image

The Hamlyn Centre
The Institute of Global Health Innovation

Edge detection (Sobel)

Imperial College
London
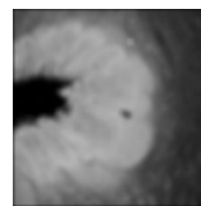
- Example 2: edge detection Kernel, for instance:

-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

Input image $\otimes$ convolved with

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

Horizontal edge enhancement kernel

+ further pixel intensity scaling

Output image

The Hamlyn Centre
The Institute of Global Health Innovation

Operations on Multiple Images

e.g. noise suppression by averaging many images

The Hamlyn Centre
The Institute of Global Health Innovation
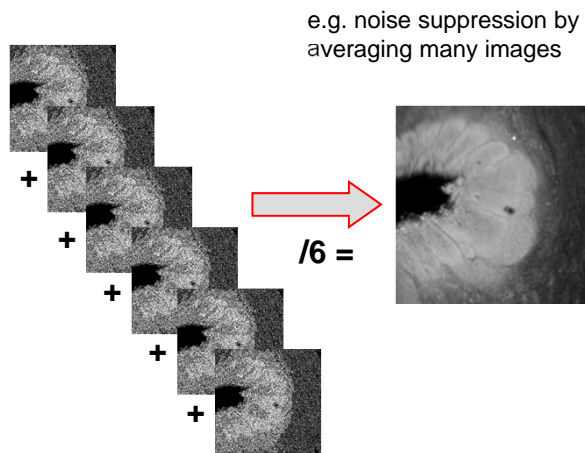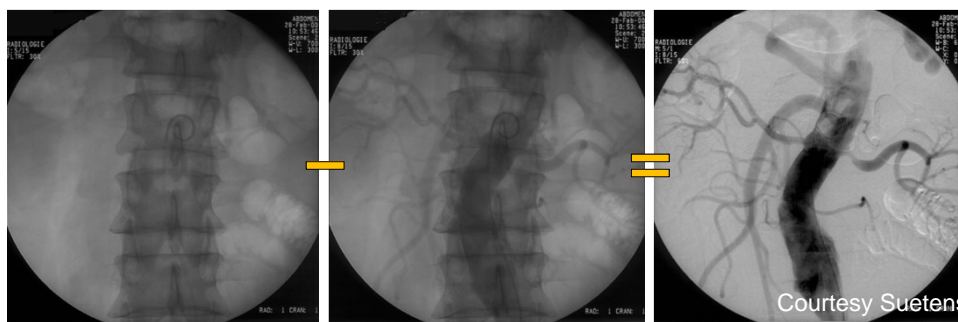
Image subtraction

Before contrast agent   After contrast agent

Courtesy Suetens

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

The Hamlyn Centre
The Institute of Global Health Innovation

Lecture contents

- 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

The Hamlyn Centre
The Institute of Global Health Innovation

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
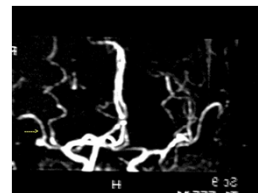
The Hamlyn Centre
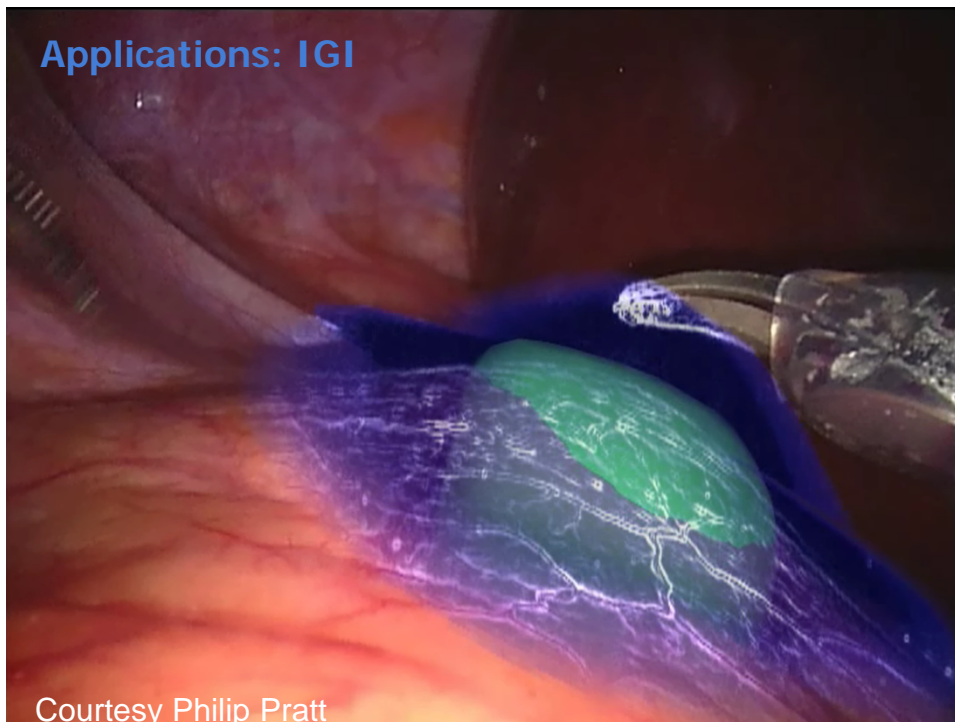The Institute of Global Health Innovation

Applications: image visualisation

- Segmentation allows 3D surface models of the tissue to be constructed
- Typical algorithms include marching cubes (see Merrifield lectures)

TU Delft 'virtual colonoscopy'
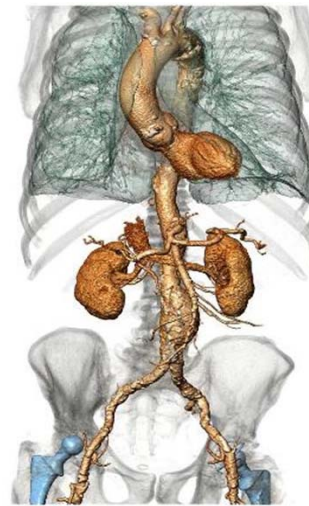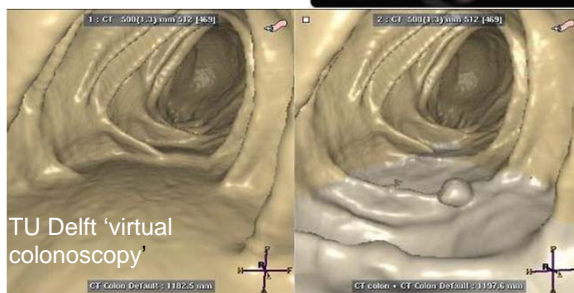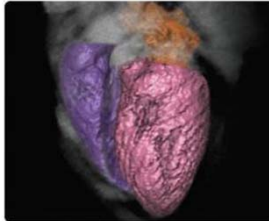
Birmingham Heartlands Hospital

Applications: IGI
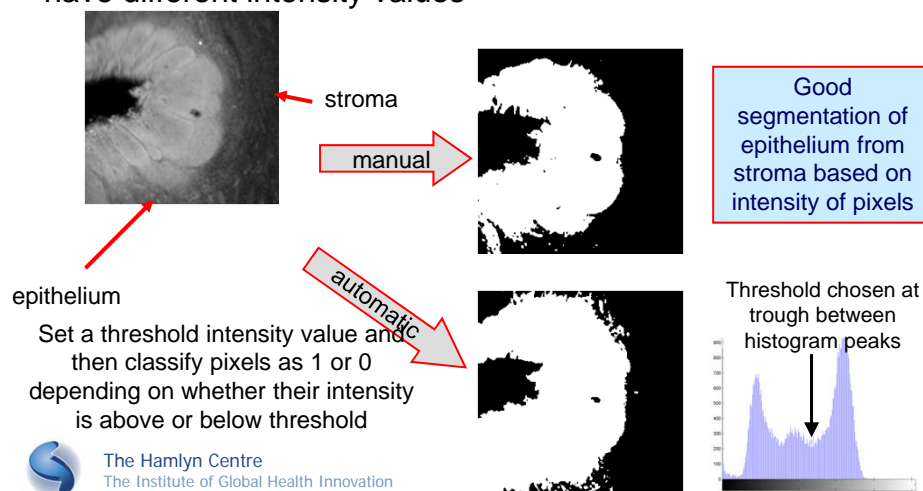
Courtesy Philip Pratt

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
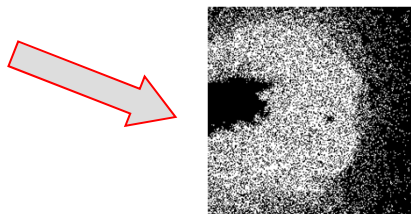

The Hamlyn Centre
The Institute of Global Health Innovation
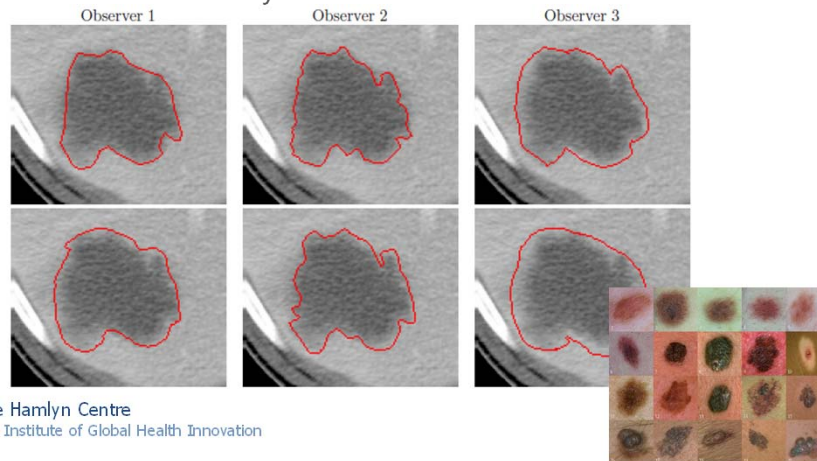
Pixel-based classification methods

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

stroma

manual

Good segmentation of epithelium from stroma based on intensity of pixels

epithelium

Set a threshold intensity value and then classify pixels as 1 or 0 depending on whether their intensity is above or below threshold

automatic

Threshold chosen at trough between histogram peaks

The Hamlyn Centre
The Institute of Global Health Innovation

14

Problem: noise

Imperial College London

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

- Solution: smooth the image before thresholding

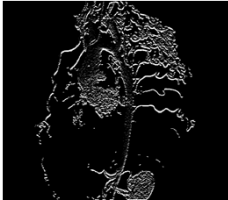This is univariate classification – using just one image parameter to determine segmentation thresholds

The Hamlyn Centre
The Institute of Global Health Innovation
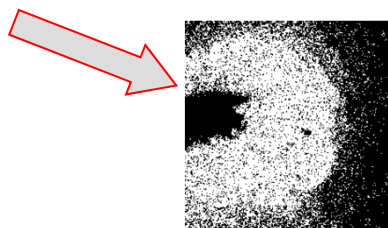
Edge-Based Segmentation Techniques

Imperial College London

Horizontal edges

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

Step 1: use Sobel edge operators…

$$h_{total} = \sqrt{h_1{}^2 + h_3{}^2}$$

MR angiogram
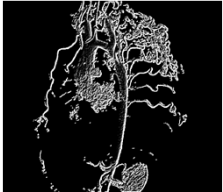
Vertical edges

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

…and combine to form an edge magnitude image

The Hamlyn Centre
The Institute of Global Health Innovation

15

Forming connected regions

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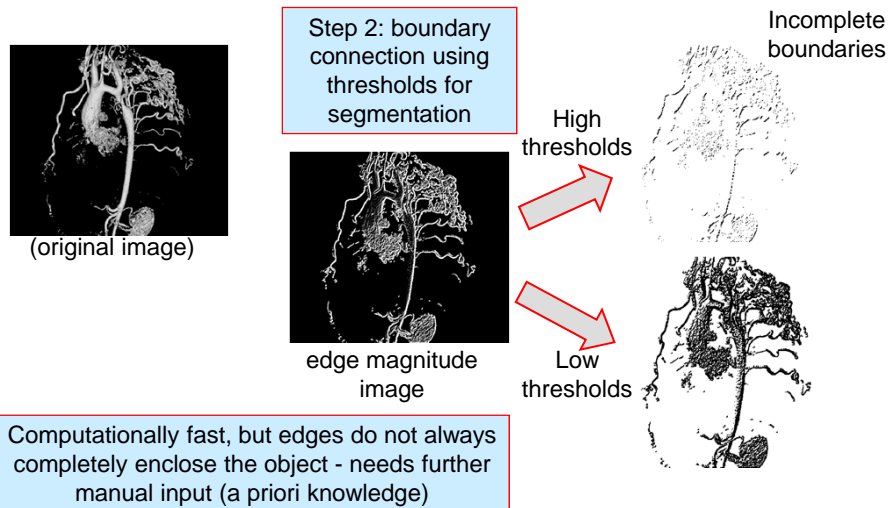
(original image)

Step 2: boundary connection using thresholds for segmentation

edge magnitude image

High thresholds

Low thresholds

Incomplete boundaries

Computationally fast, but edges do not always completely enclose the object - needs further manual input (a priori knowledge)

Lecture contents

- 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

The Hamlyn Centre
The Institute of Global Health Innovation

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)

The Hamlyn Centre
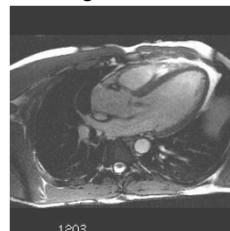The Institute of Global Health Innovation

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.
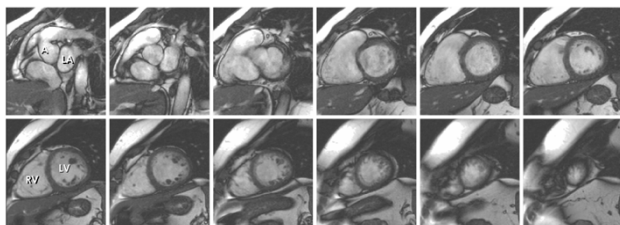- May also need to synchronise with respiratory cycle or record during breath hold.
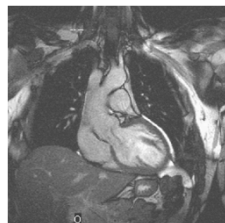
long axis view

The Hamlyn Centre
The Institute of Global Health Innovation

Image Stacks, Volumes and Plane Construction

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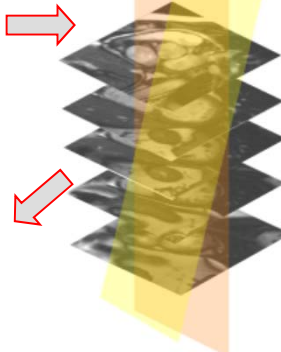One set for each point of cardiac cycle

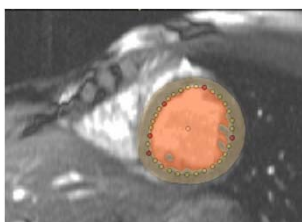4 chamber view   vertical long axis view   oblique long axis view

Create 3D model consisting of 'voxels'

Reconstruct oblique diagnostic planes by interpolation through different voxels

The Hamlyn Centre
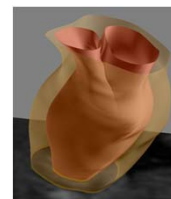The Institute of Global Health Innovation

Myocardial Wall Motion Measurement (1)

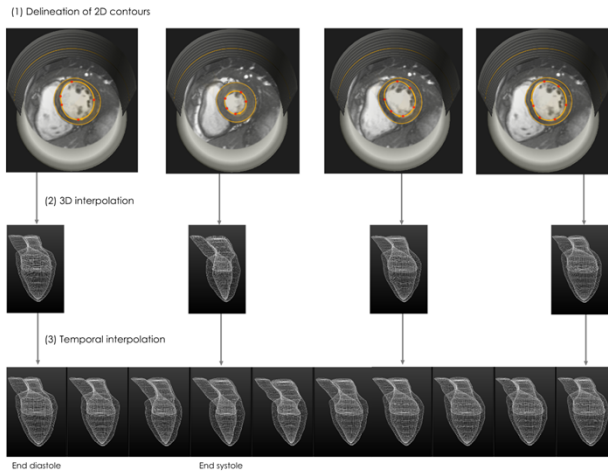

Segmentation based on edge detection
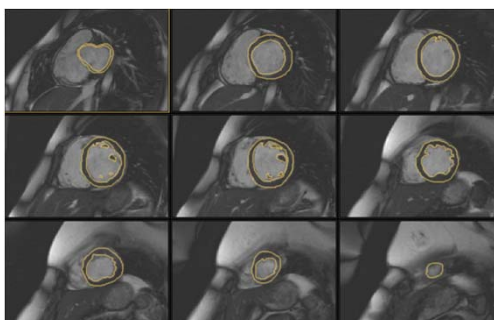
- May be totally automated, although in some cases human interaction is required to guide and correct the borders
- Some methods assume a particular heart geometry and radial edge detection from the centre of the ventricle to improve performance
- Construct a model of heart based on the segmentation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

The Hamlyn Centre
The Institute of Global Health Innovation

18

Myocardial Wall Motion Measurement (2)

(1) Delineation of 2D contours

(2) 3D interpolation

(3) Temporal interpolation

End diastole   End systole

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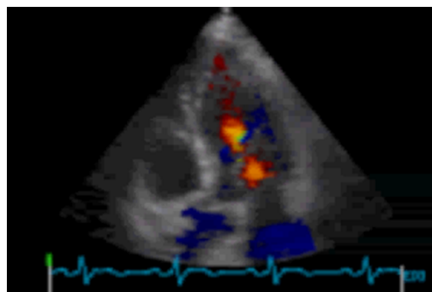
Shows blood motion from left atrium to left ventricle. Red is motion towards transducer (atrium to ventricle). Blue is motion away from transducer (ventricle to aorta)

The Hamlyn Centre
The Institute of Global Health Innovation

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
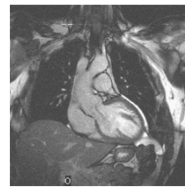- Computationally intensive – need seamless and intuitive human-visual interaction

  – Examples so far:

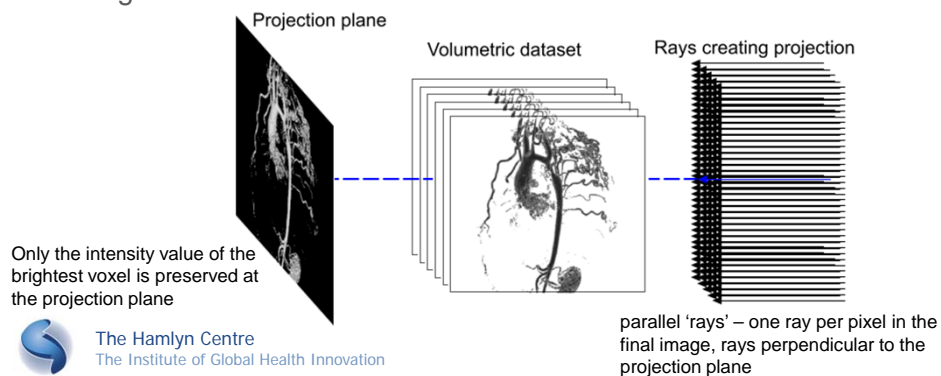Oblique sections   Surface modelling   Dynamic

The Hamlyn Centre
The Institute of Global Health Innovation

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.

Projection plane

Volumetric dataset

Rays creating projection

Only the intensity value of the brightest voxel is preserved at the projection plane

The Hamlyn Centre
The Institute of Global Health Innovation

parallel 'rays' – one ray per pixel in the final image, rays perpendicular to the projection plane

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.

iliac arteries
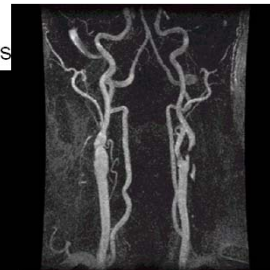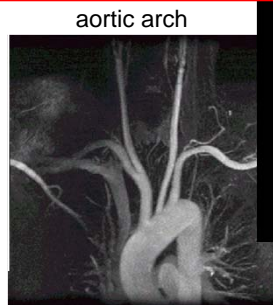
aortic arch

aortic arch and associated vessels

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

21
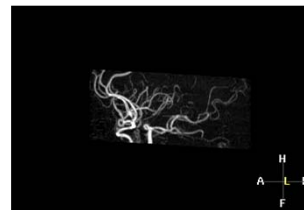
Multi-plane based volume rendering

- 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
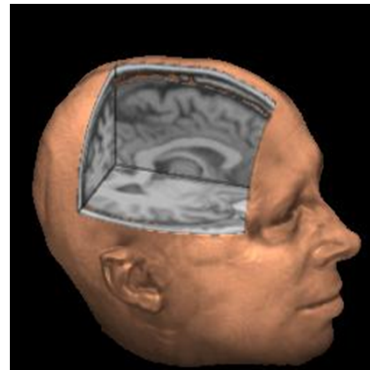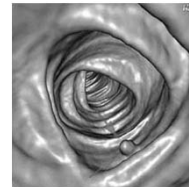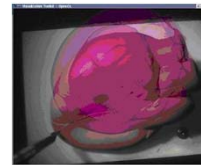
The Hamlyn Centre
The Institute of Global Health Innovation

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

The Hamlyn Centre
The Institute of Global Health Innovation

Summary

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

The Hamlyn Centre
The Institute of Global Health Innovation

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

The Hamlyn Centre
The Institute of Global Health Innovation

Any questions?

The Hamlyn Centre
The Institute of Global Health Innovation