# *Image Segmentation and Pre-processing*

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## *Goals*

- Understand the fundamentals of digital image processing.
- Define image enhancement and the different types commonly used in medical/surgical applications.
- Understand the process of image segmentation and its relevance in manipulation of medical images.
- Enumerate the most commonly used image segmentation techniques indicating their main characteristics and advantages/disadvantages.
- Mention some possible applications of image segmentation in surgery.

## *Manipulation*

- Selection of region of interest
- Image resampling
- Greyscale contrast enhancement
- Pre-processing
- Segmentation



## *Contents*

- Pre-processing
- Segmentation
- Applications
- Summary and Conclusion

## *Pre-processing*

- Goal:
  - Enhance the visual appearance of images.
  - Improve the manipulation of datasets.
- Caution: enhancement techniques can emphasize image artefacts, or even lead to a *loss* of information if not correctly used.



## *Pre-processing*

- Image resampling
- Greyscale contrast enhancement
- Noise removal
- Mathematical operations
- Manual correction

## *Pre-processing*

- Image resampling:
  - Reduce or increase the number of pixels of the dataset.
- Greyscale contrast enhancement:
  - Improve the visualisation by brightening the dataset.



## *Noise removal*

- Several techniques:
  - Low-pass, high-pass, band-pass spatial filtering
  - Mean filtering
  - Median filtering

## *Noise removal*

- Low-pass filtering replaces all pixels of intensity higher than a specified value.
- Example:

Noisy image

Mask

Low-pass filtered image



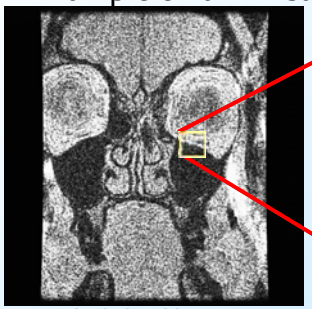
## *Noise removal*

- High-pass filtering replaces all pixels of intensity lower than a specified value.
- Band-pass filtering replaces all pixels of intensity lower than a specified value and higher than another one.

- Low, high-pass, band-pass spatial filtering are efficient only in specific cases.
- Most of the time, blur the image…

## *Noise removal*

- Mean filtering and median filtering work on a n x n sub-region of the image.
- n is usually 3 or 5.
- Example on a 4x4 sub-image:



| | | | |
|---|---|---|---|
| 121 | 118 | 124 | 127 |
| 81 | 113 | 109 | 126 |
| 90 | 88 | 87 | 84 |
| 83 | 80 | 81 | 79 |



## *Noise removal*

- Mean filtering:
  - The 3x3 sub-region is scanned over the entire image
  - At each position the centre pixel is replaced by the **average** value.

| | | | |
|---|---|---|---|
| 121 | 118 | 124 | 127 |
| 81 | 113 | 109 | 126 |
| 90 | 88 | 87 | 84 |
| 83 | 80 | 81 | 79 |

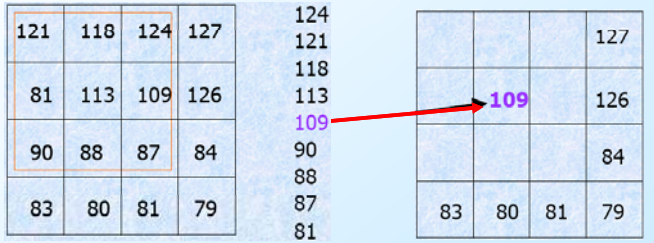
Raw sub-image

| | | | |
|---|---|---|---|
| | | | 127 |
| | 103 | | 126 |
| | | | 84 |
| 83 | 80 | 81 | 79 |

3x3 average value

## *Noise removal*

- Median filtering:
  - The 3x3 sub-region is scanned over the entire image
  - At each position the centre pixel is replaced by the **median** value.



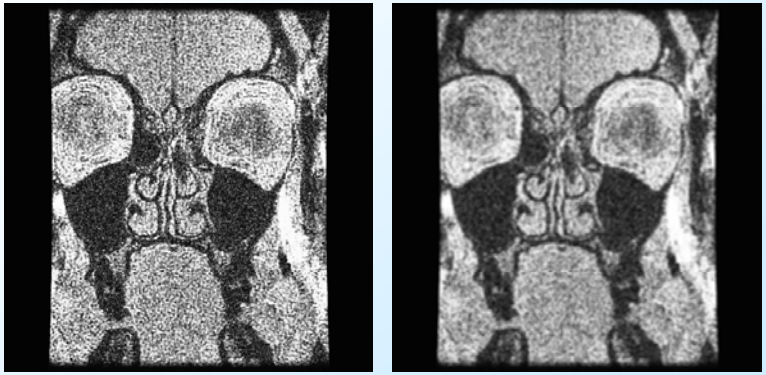

Raw sub-image

3x3 average value



## *Noise removal*

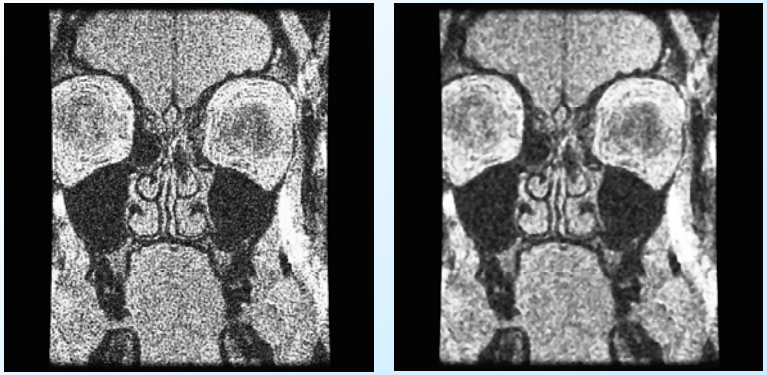
- Mean filtering applied to the image with a 3x3 sub-region:



Mean filtered

## *Noise removal*

- Median filtering applied to the image with a 3x3 sub-region:



Median filtered



## *Noise removal*

- Mean filtering:
  - Fast to compute.
  - Blurs edges.
  - Smears noise specks.

- Median filtering:
  - Slower to compute.
  - Preserves edges.
  - Can remove noise.

## *Mathematical operations*

- It is possible to apply to images:
  - Arithmetic operations (addition, subtraction…).
  - And morphological operations (dilation, erosion…).
- Goal: to enhance particular features

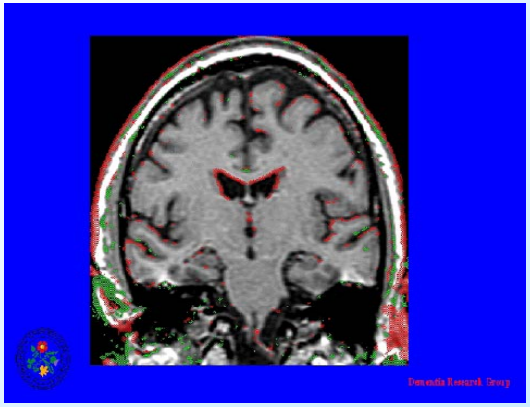


## *Mathematical operations*

- Addition is not very helpful
- Subtraction can be used to eliminate confusing background detail which has remained unchanged between the two images
- done pixel-by pixel
- Operations between two images are only useful if the images can be aligned closely enough
- Often used for x-ray contrast angiography to highlight occluded arteries
- Can also be used to show changes over time

## *Mathematical operations*

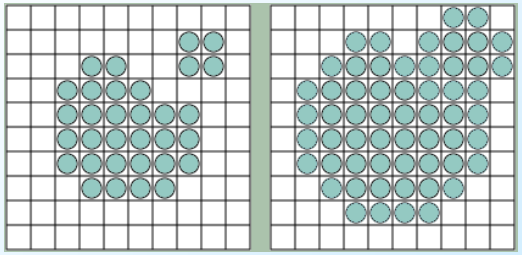
- Example of subtraction: cerebral volume changes in dementia





## *Mathematical operations*

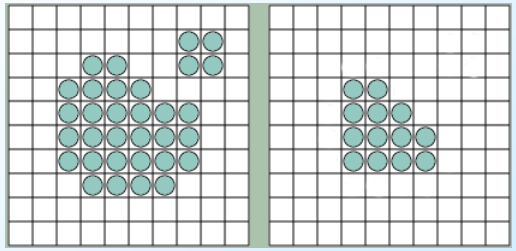
- Dilation is used to connect features in an image



Structural element: 

## *Mathematical operations*

- Erosion is used to disconnect features in an image and remove small ones



Structural element: 



## *Mathematical operations*

- It is possible to change the structural element to adjust the operators:
  - Different shapes.
  - Different sizes.
- It is possible to combine dilation and erosion to combine their effects:
  - Dilation followed by erosion = Closing.
  - Erosion followed by dilation = Opening.
  - Both tend to smooth the image's features.

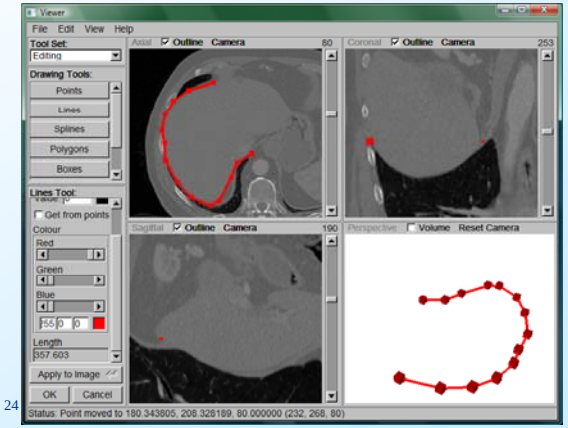
## *Manual correction*

- Goal: fine tune an image by editing it.
- Editing can be done:
  - Pixel by pixel.
  - Using lines or splines.
  - Using predefined 2D or 3D shapes (rectangle, brick, sphere…).



## *Manual correction*

- Example of line editing: separating the liver from the ribs using a 3D spline



## *Contents*

- Pre-processing
- Segmentation
- Applications
- Summary and Conclusion



## *Segmentation*

- Needed for:
  - Improving the analysis of an image when there is no direct correspondence between the image pixel properties and the type of tissue.
  - Separating (labelling) the pixels of an image according to semantic content (studied structure).
  - Facilitating the manipulation and visualization of the data with a computer.

## *Segmentation*

- Involves the partitioning of an image or volume into distinct (usually) non-overlapping regions in a meaningful way.
- Can also be thought of as a *labelling* operation: a label corresponding to tissue type/anatomical structure is assigned to each pixel or voxel in the image.

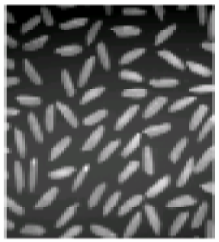


## *Segmentation*

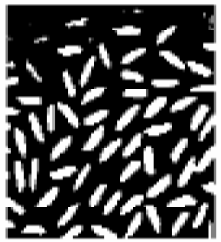
- Identifies separate objects within an image.
- Finds regions of connected pixels with similar properties.
- Finds boundaries between regions.
- Removes unwanted regions.

## *Segmentation*

- Simple example: segmentation of rice grains



Original image



Segmented (binary) image

Each pixel is assigned a label:

- 0 = not rice grain pixel
- 1 = rice grain pixel



## *Segmentation*

- Types of image segmentation
  - Image domain:
    - Manual.
    - Thresholding.
    - Region growing.
    - Hierarchical.
  - Feature domain:
    - Supervised segmentation.
    - Unsupervised segmentation.

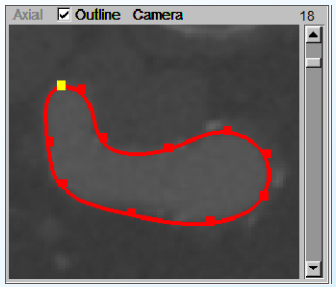
## *Segmentation*

- Manual segmentation
  - Outlines the studied structure in each slice.
  - Only on the contour or on the whole object.
  - Lines or splines can be used.
  - Usually time consuming.



## *Segmentation*

- Manual segmentation
  - Example of aorta segmentation with a spline:




The spline delineates the contour


Once applied, the contour pixels are highlighted

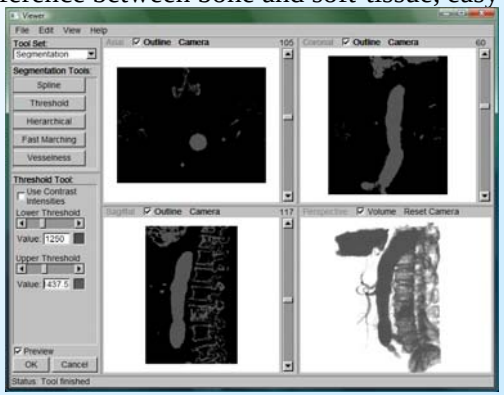
## *Segmentation*

- Thresholding
  - Relies on intensity differences between structures in an image.
  - Can be extended to multiple threshold levels.
  - Advantage: simple to implement
  - Disadvantages:
    - Low tolerance to intensity rescaling,
    - Difficult to set threshold,
    - Little use of spatial information.



## *Segmentation*

- Thresholding
  - Example of aorta segmentation in CTA.
  - Big intensity difference between bone and soft-tissue, easy to partition into:
    - Bones,
    - Vessels,
    - Other soft tissues.



## *Segmentation*

- Region growing
  - Relies on intensity differences, but includes the notion of spatial proximity of pixels, and a *seed point* for the region.
  - Advantages:
    - Simple to implement,
    - Human interaction is easy to provide (via seed point).
  - Disadvantages:
    - Low tolerance to intensity rescaling,
    - Difficult to set growing criteria and stopping criteria,
    - Needs human intervention for defining seed point.



## *Segmentation*

- Region growing
  - Example of aorta segmentation in CTA:
    - First, a probability map is built to separate roughly the structures.
    - Then seeds are placed in the studied structure.
    - Finally, the region is growing to fit the structure.

## *Segmentation*

- Hierarchical segmentation
  - Clusters image pixels into regions of similar intensity to create an intensity hierarchy.
  - Marking seeds inside and outside the desired structure starts the merging of the hierarchy.
  - Iteratively separates the inside and outside of the structure.

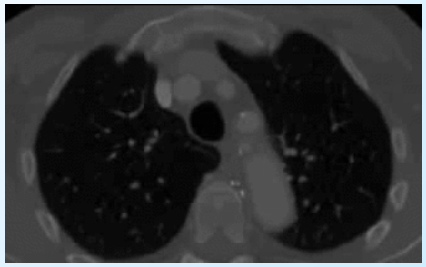


## *Segmentation*

- Hierarchical segmentation
  - Advantages:
    - Fast,
    - Reasonably easy to implement.
  - Disadvantages:
    - Medium tolerance to intensity rescaling,
    - Needs human intervention for defining seed points.

## *Segmentation*

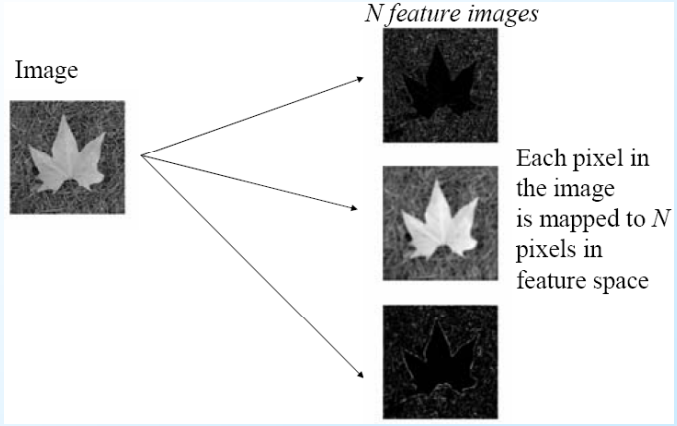
- Hierarchical segmentation
  - Example of aorta segmentation in CTA:
    - First, the intensity hierarchy is built to pre-separate the structures.
    - Then seeds are placed in and out the studied structure.





## *Segmentation*

- Feature domain segmentation






*Courtesy of Dr. F. Bello, Dept. of Biosurgery*

## *Segmentation*

- Two types of feature domain segmentation:
  - Supervised: a set of training data is given, a learning algorithm uses this to determine a classification rule for new data.
  - Unsupervised: algorithms attempt to discover clusters (or groups of data points) in feature space.





## *Segmentation*

- Feature domain segmentation:
  - Advantages:
    . Very powerful,
    . Tremendously flexible.
  - Disadvantages:
    . Generates increased computation (because each pixel is mapped to *N* pixels),
    . Not obvious what features should be used,
    . Large feature spaces require lots of data (for automated learning) or training examples (for supervised learning).

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## *Applications*

- Quantitative, or semi-quantitative diagnostic image analysis.
- Surgical planning.
- Computer assisted surgery.

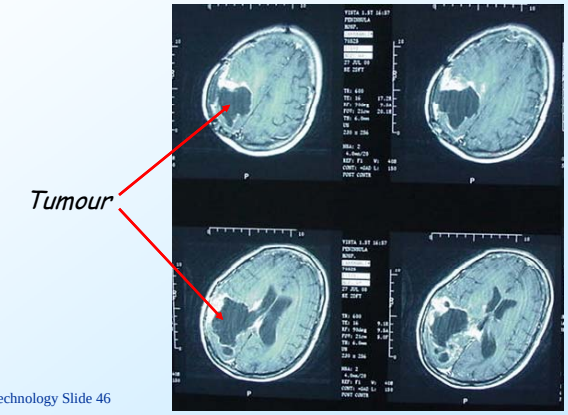
## *Applications*

- Diagnostic analysis
  - Patient come with headache, visual troubles, and speech difficulties.
  - Diagnosis?



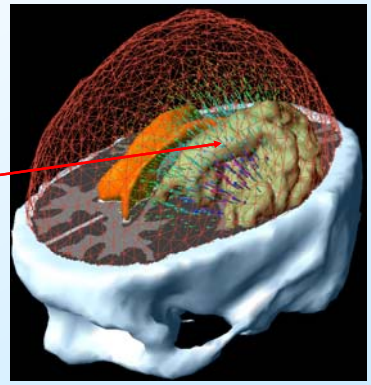
## *Applications*

- Diagnostic analysis
  - CT scan of the brain shows a tumour:



## *Applications*

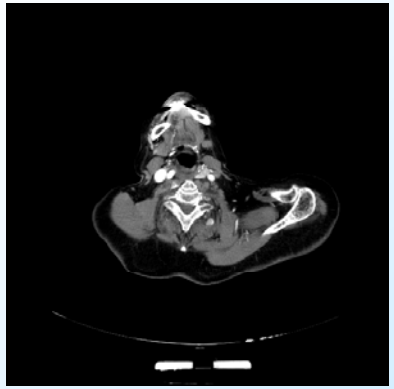
- Diagnostic analysis
  - Segmentation and 3D rendering reveals the tumour size and influence:

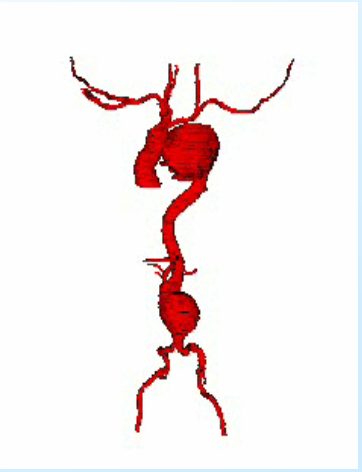





## *Applications*

- Surgical planning
  - Diagnosis: aortic aneurisms





## *Applications*

- Surgical planning
  - Diagnosis: aortic aneurisms
  - How to treat the patient?



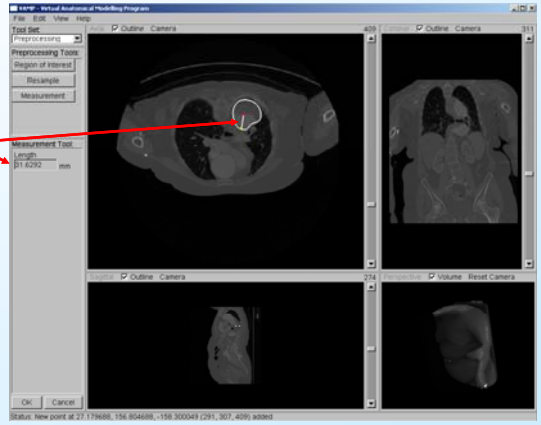
## *Applications*

- Surgical planning
  - Interventional Radiology to deploy stents to stabilise the aneurysms.
  - First, need to know the exact size of the aneurysms and choose the right instruments.

## *Applications*

- Surgical planning

*Inner diameter: 31mm*



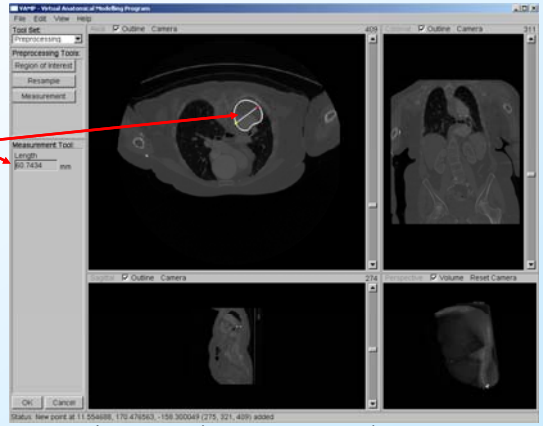
*Original CTA with superimposed segmentation*



## *Applications*

- Surgical planning

*Outer diameter: 60mm*



*Original CTA with superimposed segmentation*

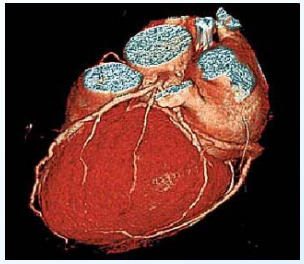
## *Applications*

- Computer assisted surgery
  - Da Vinci robot heart surgery



## *Applications*

- Computer assisted surgery
  - Da vinci robot heart surgery



*Organ segmentation*


*Augmented surgery (real surgery with an overlay of the virtual organs)*

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## *Summary*

- We have seen:
  - Key points of digital image processing.
  - Definition of image enhancement and some medical/surgical applications.
  - Overview of image segmentation.
  - Introduction to the most common image segmentation techniques.
  - Three possible applications in surgery.

## *Conclusion*

- Medical imaging is very powerful on its own, but not always intuitive.
- Pre-processing and segmentation are key techniques:
  - To improve the various imaging modalities.
  - To allow interpretation for better diagnosis.
  - To integrate in planning and training software.
- Segmentation is a fast evolving field but there is still a lot to do:
  - Completely automatic.
  - Motion compensation.
  - …



# *Image Segmentation and Pre-processing*

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