Image Segmentation and Pre-processing

Vincent Luboz
Department of Surgery and Cancer
Imperial College London

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.

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**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 $n \times n$ sub-region of the image.
- $n$ is usually 3 or 5.
- Example on a 4x4 sub-image:

<table>
<thead>
<tr>
<th>121</th>
<th>118</th>
<th>124</th>
<th>127</th>
</tr>
</thead>
<tbody>
<tr>
<td>81</td>
<td>113</td>
<td>109</td>
<td>126</td>
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<td>90</td>
<td>88</td>
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<tr>
<td>83</td>
<td>80</td>
<td>81</td>
<td>79</td>
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</tbody>
</table>

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.

<table>
<thead>
<tr>
<th>121</th>
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</tr>
</tbody>
</table>

Raw sub-image

$3 \times 3$ 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.

<table>
<thead>
<tr>
<th>Raw sub-image</th>
<th>3x3 average value</th>
</tr>
</thead>
<tbody>
<tr>
<td>121 118 124 127</td>
<td>124 118 113 109 126</td>
</tr>
<tr>
<td>81 113 109 126</td>
<td>90 87 84</td>
</tr>
<tr>
<td>93 80 61 79</td>
<td>83 80 81 79</td>
</tr>
</tbody>
</table>

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: 

![Image of structural element](image.png)
**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...).

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

- Example of aorta segmentation with a spline:

  ![Image 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.

- 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.

- 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.

Advantages:
- Fast,
- Reasonably easy to implement.

Disadvantages:
- Medium tolerance to intensity rescaling,
- Needs human intervention for defining seed points.
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.

Feature domain segmentation

Each pixel in the image is mapped to $N$ pixels in feature space.
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.

- 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?

• 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?

• 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

Outer diameter: 60mm

Original CTA with superimposed segmentation
Applications

- Computer assisted surgery
  - Da Vinci robot heart surgery

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

Organ segmentation
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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.
  - ...