Medical Image Segmentation: Radiomics

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SEGMENTATION: DEFINITION

• Process of **partitioning** a digital image into **groups of pixels** (segments)

• Goal:
  – Produce a more **meaningful representation** for easier analysis
MEDICAL IMAGE ANALYSIS: APPLICATION FOR SEGMENTATION

- Radiomics
  - Image features derived from segmented tumors are correlated with outcomes
- Improving diagnostic accuracy
  - Image-guided targeted biopsy
- Treatment planning
  - Improving accuracy and efficiency of radiation treatment planning
- Monitoring efficacy of (new) Treatments
  - Continuous monitoring of tumor volume changes during the course of therapy

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HOW SEGMENTATION WORKS

- Group pixels in the image based on their similarity to one another
  - Similarities are computed using
    - Image intensities, features (edges, gradients), textures
SEGMENTATION METHODS

• **THRESHOLDING**
  – Image into target (structure of interest) and background using specific thresholds

• **CLUSTERING**
  – Pixels are grouped based on their similarity to derive distinct groups of pixels (clusters)

• **REGION GROWING**
  – Pixels are grouped starting from **seed points** that identify the target

• **VARIATIONAL METHODS**
  – Partial differential equations drive the segmentation using constraints derived from edge gradients (Fast marching)
SEGMENTATION METHODS

• SEMI-AUTOMATIC & INTERACTIVE
  – User identifies target (& background) to constrain and drive the segmentation
    • Graph cuts, random walker, grow-cut, …

• MACHINE LEARNING
  – Learning of target and background statistics can be used for detection and segmentation
    • Random forests, SVM, deep learning,…

• ATLAS-BASED SEGMENTATION METHODS
  – Segmentation is primarily driven by registration

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INTENSITY THRESHOLDING

• Very easy to implement
  \[
  I(x) < \tau, \quad \text{tumor} \\
  \text{else} \quad \text{background}
  \]

• Choice of threshold \( \tau \) determines accuracy

• Threshold selection
  – Prior knowledge (PET SUV uptake values for tumors)
  – Detecting inflection points on image histogram
    • Otsu thresholding
INTENSITY CLUSTERING

• Commonly used techniques:
  – Fuzzy c-means clustering
  – K-means clustering

• More advanced techniques
  – Spectral clustering
  – Hierarchical agglomerative clustering
  – Kernel K-means
  – Deep clustering

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CLUSTERING

• Idea: Split the data into **distinct number of groups** where the data points **within** each group is **more similar** to one another than to **data points in other clusters**

• Can use just intensity, multiple image features, multiple sequences (MRI), etc.
CLUSTERING

• **Pros:**
  – No supervised training is necessary

• **Cons:**
  – Accuracy depends on the distribution of data and method
REGION GROWING

• Produces a segmentation of a region based on the statistical similarity of pixels to user selected seed points

• Statistical properties can be computed based on pixel intensities, image features

• Pros:
  – Easy to implement, very few tunable parameters

• Cons:
  – Accuracy is highly dependent on seed placement
  – Works best only when target is surrounded by very high contrast background

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VARIATIONAL METHODS

• Images are modeled as smooth surfaces where segmentation is derived by evolution of contours
  – Examples: active contour, level-set, fast marching

• Contour evolution is initialized by user-placed seed points

• Pros:
  – More robust than region growing methods as these explicitly leverage edge information in the image

• Cons:
  – Relies on presence of strong edges
  – Absence or blurring of edges (tumor-tissue boundary) can lead to leakage
INTERACTIVE SEGMENTATION

• **User-driven** segmentation where user imposes **hard constraints** on segmentation by placing **markers (on pixels)** to identify target (tumor) and background

• **Pros:**
  – Highly accurate segmentations can be produced regardless of target-background contrast

• **Cons:**
  – Segmentation varies with user input
MACHINE LEARNING-BASED METHODS

• Extracts model of target from several training images to detect and segment on novel images
  – Random Forest-based organ segmentation (Zisserman, Criminisi, ...)
  – many others

• Pros:
  – Once trained, detection can be computationally fast
  – Many structures can be detected simultaneously

• Cons:
  – Large hand-labeled training set is necessary
ATLAS -BASED SEGMENTATION

- Segmentation relies on achieving reasonably accurate registration to prior atlases
  - Pohl et.al, Rueckert et.al, ...

- Pros:
  - Can be used to generate segmentation of several structures (EMSegmenter in 3DSlicer)

- Cons:
  - Relies on achieving accurate image registration
  - Registration itself is computationally intensive and as number of atlases increases, computation goes up
  - Implementation is non-trivial
COMPARISON OF METHODS

PROS

• Thresholding
  – Simple to implement

• Clustering
  – Unsupervised method

• Region growing
  – Simple to implement

• Variational methods
  – Leverage edge information and can be robust

CONS

Selecting appropriate threshold for large variety of images is not trivial

Assumes target has good contrast with background

Highly influenced by target/background similarity

Absence of strong edges can cause segmentation leakage
COMPARISON OF METHODS

**PROS**

- **Interactive methods**
  - Can achieve robust segmentation

- **Atlas-based**
  - Can simultaneously segment multiple structures

- **Machine learning**
  - Reasonably accurate and fast segmentation

**CONS**

- Segmentation varies based on user input
- Requires accurate registration
- Computationally intensive
- Requires reasonably large training data
ACHIEVING GOOD SEGMENTATION IS ALL ABOUT IMAGE REPRESENTATION
IMAGE FEATURES FOR SEGMENTATION
TEXTURES

• Is a property of areas
  – Texture is a contextual property that is defined using gray values (pixel intensities) on a spatial neighborhood
  – Involves spatial distribution of the gray levels
  – Can be perceived at different levels; coarse, medium, fine, ...
GRAY LEVEL CO-OCCURRENCE MATRIX

- Captures the frequency of occurrence of a co-occurring pair of pixels at specific angle offsets using specific quantization of pixel intensities

There are 3 levels (0, 1, 2) Co-occurrence matrix shows the relation of pixels pairs at offset (1,1)
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USING HARALICK TEXTURES FOR SEGMENTATION

• When the target has a distinct texture from its background

• Textures should not be used when the target and background have similar texture
PATCH-BASED FEATURES

- Computed from a sliding window \((NxNxM)\) moved across the image
- Statistics are computed inside the window
- Simple features include moments of histogram:
  - Mean, standard deviation, kurtosis, skewness
- More advanced include Histogram of oriented Gradients (HoG), Haar wavelets, etc
EDGE-BASED FEATURES

• Edges can provide additional constraints and force segmentation to stay within target

• Edge detection methods
  – Sobel edges
  – Laplacian of Gaussian
  – Gabor filters
  – Wavelets
  – ...

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ADVANCED FEATURES

• Multi-spectral images
  – FLAIR, T2w, T1 pre and T1 post contrast MRI, ADC, etc

• Temporal component of DCE MRI

• Lower dimensional representation of images
  – Anger et.al

• ...

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HOW DO WE KNOW WHICH FEATURES TO USE

• Depends on the problem

• Explore your data!
  – Start with a small set and increase depending on accuracy needs and computational requirements

• When using large number of features consider using feature selection
  – Remove redundant or useless features and keep only the useful features based on the data
SUMMARY

• Segmentation is all about finding a grouping of pixels into regions to produce a more meaningful representation of the image

• Several methods exist for producing segmentation
  – Easy to non-trivial implementation
  – Fast to long computation times

• Image representation affects segmentation accuracy