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

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

INTENSITY THRESHOLDING

- Very easy to implement $\begin{cases} I(x) < \tau, & tumor \\ else & background \end{cases}$
- Choice of threshold τ 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

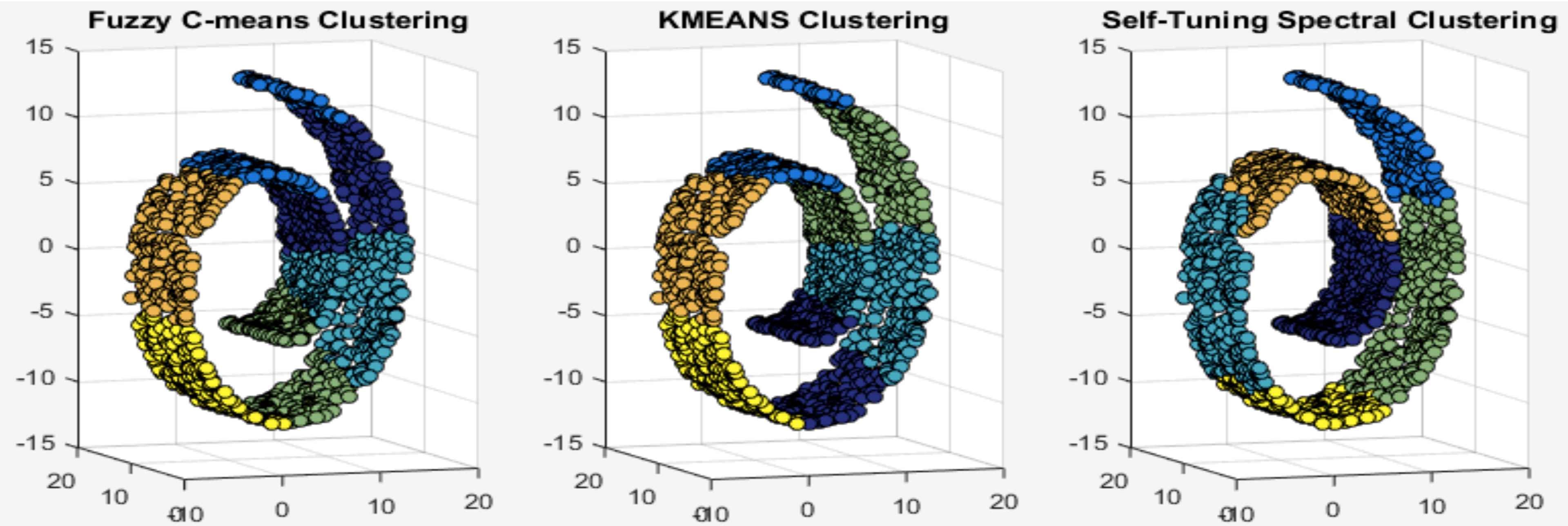
CLUSTERING

- 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

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

INTERATIVE 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	CONS
• **Interactive methods** – Can achieve robust segmentation	Segmentation varies based on user input
• **Atlas-based** – Can simultaneously segment multiple structures	Requires accurate registration Computationally intensive
• **Machine learning** – Reasonably accurate and fast segmentation	Requires reasonably large training data

ACHIEVING GOOD SEGMENTATION IS ALL ABOUT IMAGE REPRESENTATION

IMAGE FEATURES FOR SEGMENTATION

TEXTURES

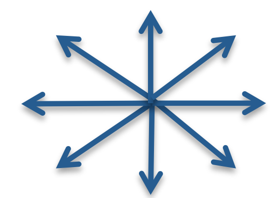
- Is a property of areas
  - Texture is a contextual property that is defined using gray values (pixel intensities) on a spatial neighborhood
  - Involves spatial distribution of the gray levels
  - Can be perceived at different levels; coarse, medium, fine, …

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

0	0	0	1	2
1	1	0	1	1
2	2	1	0	0
1	1	0	2	0
0	0	1	0	1

$$\begin{array}{c} \\ 0 \\ 1 \\ 2 \end{array} \frac{1}{16}\begin{array}{c} \begin{array}{ccc} 0 & 1 & 2 \end{array} \\ \begin{bmatrix} 4 & 2 & 1 \\ 2 & 3 & 2 \\ 0 & 2 & 0 \end{bmatrix} \end{array}$$



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

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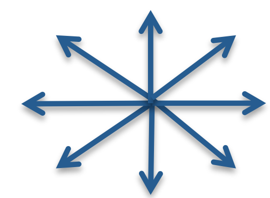

$$
\begin{matrix}
0 & 0 & 0 & 1 & 2 \\
1 & 1 & 0 & 1 & 1 \\
2 & 2 & 1 & 0 & 0 \\
1 & 1 & 0 & 2 & 0 \\
0 & 0 & 1 & 0 & 1
\end{matrix}
\quad \rightarrow \quad
\begin{matrix} & \mathbf{0} & \mathbf{1} & \mathbf{2} \\ \mathbf{0} \\ \mathbf{1} \\ \mathbf{2} \end{matrix}
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$$

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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
  - …

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
- …

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