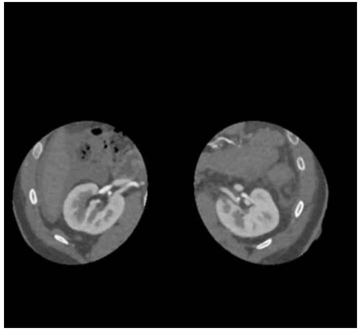
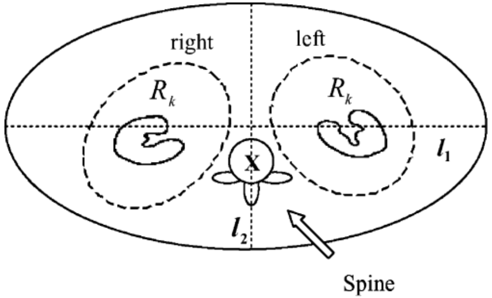
Automatic Kidney Segmentation in CT Scan Series

Main Ideas

1. Using spine as the landmark to locate the kidney, and some prior medical knowledge to extract a smaller elliptical candidate region.
2. Choosing a soft clustering algorithm instead of dynamic thresholding or region growing to better deal with the inhomogeneity inside the injured kidneys.
3. Starting from the middle slice of CT scan sets which always contains largest kidneys, and using the previous kidney mask as a reference to next one to enable automatic segmentation.

[1] Computer-Aided Kidney Segmentation on Abdominal CT Images, Daw-Tung Lin, et. al.





X: (0.5*l*1, 0.56*l*2), (x0, y0): 0.28*l*1 to the spine

Short axis: 0.4*l*1, Long axis: 0.6*l*2

Rotation angle: 60 degrees. [1]

1

Cavity Boundary Detection

1. Discard pixels outside the abdominal boundary
2. Find contours, fit ellipses for each contours, choose the ellipse which fit the cavity boundary best

2

Candidate Region Extraction

1. Allocate the spine landmarks.
2. Use heuristics about the relative location to find the elliptical candidate regions for left and right kidneys.

3

Spatial Constrained Kernelized Fuzzy C-means Clustering

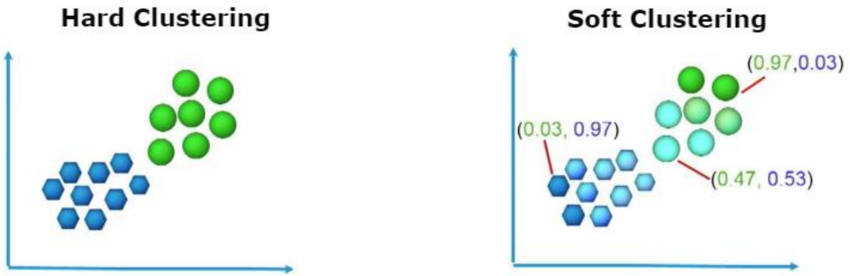
4

Automatically Go Up and Down

Reference Paper: Zhang D Q, Chen S C. A novel kernelized fuzzy c-means algorithm with application in medical image segmentation[J]. Artificial intelligence in medicine, 2004, 32(1): 37-50.

Fuzzy C-means

Clustering Method
- Hard Clustering(K-Means)
- Soft Clustering(Fuzzy C-Means)



1 **Cavity Boundary Detection**

1. Discard pixels outside the abdominal boundary
2. Find contours, fit ellipses for each contours, choose the ellipse which fit the cavity boundary best

2 **Candidate Region Extraction**

1. Allocate the spine landmarks.
2. Use heuristics about the relative location to find the elliptical candidate regions for left and right kidneys.

3 **Spatial Constrained Kernelized Fuzzy C-means Clustering**

4 **Automatically Go Up and Down**

Fuzzy C-means

Input Data:

$$X = \{x_1, x_2, \dots, x_n\}, x_k \in \Re^p$$

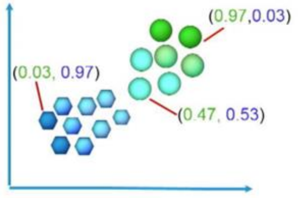
Centroids:

$$V = \{v_1, v_2, \dots, v_c\}, v_k \in \Re^p$$

Partition Matrix:

$$U = \begin{pmatrix} u_{11} & \cdots & u_{1c} \\ \vdots & \ddots & \vdots \\ u_{n1} & \cdots & u_{nc} \end{pmatrix}, U \in \mathbb{R}^{n \times c}$$

Soft Clustering



n=16, p=2, c=2

1. **Cavity Boundary Detection**
   1. Discard pixels outside the abdominal boundary
   2. Find contours, fit ellipses for each contours, choose the ellipse which fit the cavity boundary best
2. **Candidate Region Extraction**
   1. Allocate the spine landmarks.
   2. Use heuristics about the relative location to find the elliptical candidate regions for left and right kidneys.
3. **Spatial Constrained Kernelized Fuzzy C-means Clustering**
4. **Automatically Go Up and Down**

Fuzzy C-means

For CT images of size N x M, each pixel is a data point.

$$\begin{bmatrix} x_{11} & \cdots & x_{1M} \\ \vdots & \ddots & \vdots \\ x_{N1} & \cdots & x_{NM} \end{bmatrix}$$

So the size of partition matrix U should be: N x M x C

1 **Cavity Boundary Detection**

1. Discard pixels outside the abdominal boundary
2. Find contours, fit ellipses for each contours, choose the ellipse which fit the cavity boundary best

2 **Candidate Region Extraction**

1. Allocate the spine landmarks.
2. Use heuristics about the relative location to find the elliptical candidate regions for left and right kidneys.

3 **Spatial Constrained Kernelized Fuzzy C-means Clustering**

4 **Automatically Go Up and Down**

Fuzzy C-means

Objective Function:

$$J = \sum_{i=1}^{n} \sum_{j=1}^{c} u_{ij}^{m} \left\| x_i - v_j \right\|^2$$

Updating Rules:

$$v_k = \frac{\sum_{i=1}^{n} u_{ik}^{m} \cdot x_i}{\sum_{i=1}^{n} u_{ik}^{m}}$$

$$u_{ij} = \frac{1}{\sum_{k=1}^{c} \left(\frac{\left\| x_i - v_j \right\|}{\left\| x_i - v_k \right\|} \right)^{\frac{2}{m-1}}}$$

1 **Cavity Boundary Detection**

1. Discard pixels outside the abdominal boundary
2. Find contours, fit ellipses for each contours, choose the ellipse which fit the cavity boundary best

2 **Candidate Region Extraction**

1. Allocate the spine landmarks.
2. Use heuristics about the relative location to find the elliptical candidate regions for left and right kidneys.

3 **Spatial Constrained Kernelized Fuzzy C-means Clustering**

4 **Automatically Go Up and Down**

Kernelized Fuzzy C-means

Mapping data points into feature space:

$$K(x,y) = \langle \Phi(x), \Phi(y) \rangle = \exp\left(\frac{-\|x-y\|^2}{\sigma^2}\right)$$

$$J_m = \sum_{i=1}^{c}\sum_{k=1}^{N} u_{ik}^m ||\Phi(x_k) - \Phi(v_i)||^2$$

$$\begin{aligned} ||\Phi(x_k) - \Phi(v_i)||^2 &= (\Phi(x_k) - \Phi(v_i))^T(\Phi(x_k) - \Phi(v_i)) \\ &= \Phi(x_k)^T\Phi(x_k) - \Phi(v_i)^T\Phi(x_k) \\ &\quad - \Phi(x_k)^T\Phi(v_i) + \Phi(v_i)^T\Phi(v_i) \\ &= K(x_k, x_k) + K(v_i, v_i) - 2K(x_k, v_i) \end{aligned}$$

$$J_m = 2\sum_{i=1}^{c}\sum_{k=1}^{N} u_{ik}^m (1 - K(x_k, v_i))$$

1 **Cavity Boundary Detection**

1. Discard pixels outside the abdominal boundary
2. Find contours, fit ellipses for each contours, choose the ellipse which fit the cavity boundary best

2 **Candidate Region Extraction**

1. Allocate the spine landmarks.
2. Use heuristics about the relative location to find the elliptical candidate regions for left and right kidneys.

3 **Spatial Constrained Kernelized Fuzzy C-means Clustering**

4 **Automatically Go Up and Down**

Kernelized Fuzzy C-means with Spatial Constraints

$$J_m = \sum_{i=1}^{c} \sum_{k=1}^{N} u_{ik}^{m} \left(1 - K\left(x_k, v_i\right)\right) + \alpha \sum_{i=1}^{c} \sum_{k=1}^{N} u_{ik}^{m} \left(1 - K\left(\bar{x}_k, v_i\right)\right)$$

Update Rules:

$$v_i = \frac{\sum_{k=1}^{n} u_{ik}^{m} \left(K\left(x_k, v_i\right) x_k + \alpha K\left(\bar{x}_k, v_i\right) \bar{x}_k\right)}{\sum_{k=1}^{n} u_{ik}^{m} \left(K\left(x_k, v_i\right) + \alpha K\left(\bar{x}_k, v_i\right)\right)}$$

$$u_{ik} = \frac{\left(\left(1 - K\left(x_k, v_i\right)\right) + \alpha \left(1 - K\left(\bar{x}_k, v_i\right)\right)\right)^{\frac{-1}{(m-1)}}}{\sum_{j=1}^{c} \left(\left(1 - K\left(x_k, v_j\right)\right) + \alpha \left(1 - K\left(\bar{x}_k, v_j\right)\right)\right)^{\frac{-1}{(m-1)}}}$$

1 **Cavity Boundary Detection**

1. Discard pixels outside the abdominal boundary
2. Find contours, fit ellipses for each contours, choose the ellipse which fit the cavity boundary best

2 **Candidate Region Extraction**

1. Allocate the spine landmarks.
2. Use heuristics about the relative location to find the elliptical candidate regions for left and right kidneys.

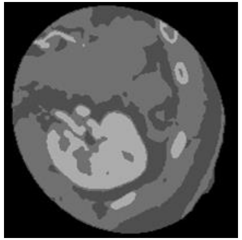
3 **Spatial Constrained Kernelized Fuzzy C-means Clustering**

4 **Automatically Go Up and Down**

Kernelized Fuzzy C-means with Spatial Constraints

Steps:

- Initiate the partition matrix U.
- Update the centroid V.
- Update the partition matrix U.
- Terminate when max(|U_old - U|) <= 10^-7.



- Open then Choose the connected component which is large enough and closest to the spine and value larger than the 2nd cluster.
- Close then dilate to contain the surroundings.
- Get the rectangular boundary of the kidney mask.

1 **Cavity Boundary Detection**

1. Discard pixels outside the abdominal boundary
2. Find contours, fit ellipses for each contours, choose the ellipse which fit the cavity boundary best

2 **Candidate Region Extraction**

1. Allocate the spine landmarks.
2. Use heuristics about the relative location to find the elliptical candidate regions for left and right kidneys.

3 **Spatial Constrained Kernelized Fuzzy C-means Clustering**

4 **Automatically Go Up and Down**

1. Perform SKFCM in the small rectangular region we get from the previous kidney.

2. Do the same operation as the first slice. (*Note: if there's no eligible connected region, use the previous kidney as the mask*).

3. Get the bounding rectangle of this kidney, check if its location & shape similar to the previous rect. If not, shrink the previous one by 10 pixels and use it.

4. For the last few slices, use the previous kidney as the mask and erode with a 3x3 kernel every slice.

1 **Cavity Boundary Detection**

1. Discard pixels outside the abdominal boundary
2. Find contours, fit ellipses for each contours, choose the ellipse which fit the cavity boundary best

2 **Candidate Region Extraction**

1. Allocate the spine landmarks.
2. Use heuristics about the relative location to find the elliptical candidate regions for left and right kidneys.

3 **Spatial Constrained Kernelized Fuzzy C-means Clustering**

4 **Automatically Go Up and Down**