Registration of 2D Deformable Model to 2D CT Image

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Part I

Problem Formulation
Let $M$ denote the 2D model image.

Let $C = \{ C_i \}$ denote the contours of anatomies in the model image.

Let $S$ denote a function related to shape information. $S(p_t)$ is the curvature of $C_i$ at point $p_t$. 
Example: Input Model
Let $T$ denote the target 2D CT image to be registered to.
Let $E_T$ denote the set of edge points of $T$
Example: Target & Edge
The output is:
- the contours of corresponding anatomies in the target image.
Define the following:

- Let $D = \{D_i\}$ denote a set of deformation functions, i.e. $D_i$ moves a point $p_t \in C_i$ to a new location $D_i(p_t)$.
- Let $f$ be a correspondence function from $C$ (contour model) to $E_t$ (target edge points), that is, $f(p_t) \in E_t$.
- Let $T$ denote a 2D affine transformation of $C$. 
The problem can be defined as:

- find the affine transformation $T$, correspondence $f$, and for each $C_i \in C$, find the deformation $D_i$ that minimize the edge point error $E_p$:

$$E_p = \sum_i \sum_{p_t \in C_i} \| D(T(p_t)) - f(p_t) \|$$

and the shape difference $E_S$:

$$E_B = \sum_i \sum_{p_t \in C_i} \| S(D(T(p_t))) - S(p_t) \|$$
Let $A = \{A_i\}$ denote the actual contours, $C' = \{C'_i\}$ denote the extracted contours. The performance measure can be defined as:

$$E_p = \sum_i \sum_{q_t \in A_i} || q_t - f'(p_t) ||$$

where $f'(q_t)$ is the closest point in $C'_i$ to $q_t$. 
Part II

Algorithm
Outline of Algorithm

1. Global Transformation
2. Nearest Connected Components
3. Dual-GVFSnake
Firstly, find the global transformation:

- Get the boundary of the target image.
- Using the boundary of the model, and boundary of the target as parameters, run ICP.
- Get the global affine transformation $T$. 
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Nearest Connected Components

Note that:

- Most of the edges in the target image are distinct.
- For each anatomy, intensities of pixels on it do not differ too much.

Therefore, we can:

- Compute all connected components in the edge image.
Nearest Connected Components (Cont.)

For each contour $C_i$,

- 1. Compute the intensity information inside/outside that contour. If the intensity distribution of one side of the contour is uniform, then keep this information as a feature.

- 2. Compute the Nearest Components from $T(C_i)$, i.e. for each component $Comp_j$

\[
d_j = \sum_{p_t \in Comp_j} \| p_t - g(p_t) \|
\]

where $g(p_t)$ is the closest point in $T(C_i)$ to $q_t$. If $d_j$ is less than a threshold $d_T$, keep $Comp_j$ as one of the nearest component.

- 3. Delete the points in $Comp_j$ that do not have the feature of $C_i$. 
For each contour $T(C_i)$,

1. Run $GVFSnake$ on the image created by filtered nearest connected components. Get $G_i$.

2. Using $G_i$ as the initialization, run $GVFSnake$ on the target image. (Refinement)

Step 2 generate the final result $C'_i$. 
Part III

Tests & Discussion
Test 1, Input Model

Registration of 2D Deformable Model to 2D CT Image
Test 1: Target & Edge
Test 1: Global & Comp

Registration of 2D Deformable Model to 2D CT Image
Test 1

Note that the nearest component of the spine is not well found, because of the significant deformation. If we use this intermediate result, the final result would not get correct.
The solution is: run snake before computing nearest components!
Test 1: Dual-GVFSnake

Registration of 2D Deformable Model to 2D CT Image
Test 1: Model & Result

\[ E_p \rightarrow 0 \]
Test 2: Target & Edge
Test 2: Global & Nearest Components

Registration of 2D Deformable Model to 2D CT Image
Test 2: Model & Result

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Registration of 2D Deformable Model to 2D CT Image
Test 3, Input Model

Registration of 2D Deformable Model to 2D CT Image
Test 3: Target & Edge
Test 3: Global & Nearest Components
Test 3: Model & Result
Reference
