Particle Growing Method in Medical Image Segmentation

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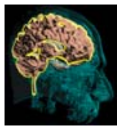
Medical Image Processing

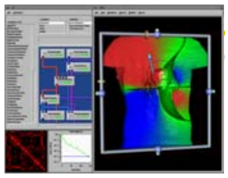
- Data
  - Sampled representation (Image)
  - Acquired from medical instrumentation as CT or MRI scanners
- Registration
  - Aligns or develops correspondences between data
  - CT scan may be aligned with MRI scan to combine
- Segmentation
  - Identifies and classifies the sampled data




Segmentation Issue

- Several Free Parameters
  - Control the quality of the results
- Needs for the tools that
  - Evaluates the algorithm very fast
  - Visualizes the results very fast when we change the parameters

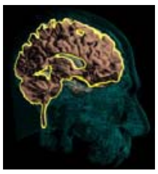
Previous Works



- ITK(Insight Toolkit)
  - NLM, NIH open source project
  - Leading-edge segmentation and registration algorithm
- GLUI
  - GLUT-based C++ user interface library which provides controls such as buttons, checkboxes, radio buttons, and spinners to OpenGL applications
- VTK- 3D visualization toolkit (Kitware)
- Utah
  - SCI-RUN – Problem Solving Environment for simulation, modeling, and visualization of scientific problems
  - Bio-PSE – superset of SCIRun, adding capabilities for investigating bioelectric field problems

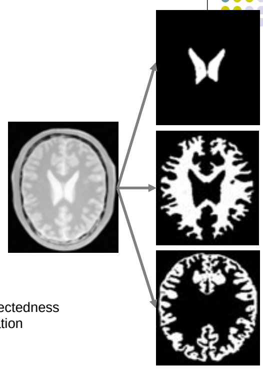
Latest Papers in Segmentation

- Siggraph papers
  - Ex:Thermo-key-Image Segmentation using Thermal Methods, 2003
- IEEE Visualization 2004
  - Medical Visualization
  - Implicit Surfaces, Level Sets
    - Ex:Interactive Deformation and Visualization of Level Set Surfaces Using Graphics Hardware



ITK Applications for Segmentation

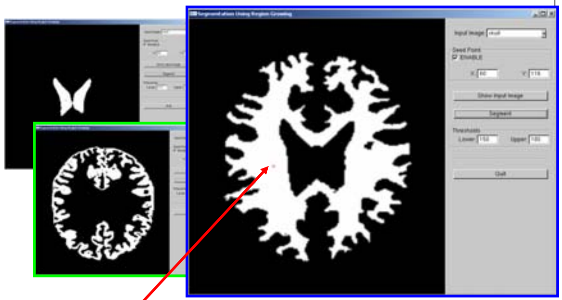
- Region Growing
  - Connected Threshold
  - Otsu Segmentation
  - Neghborhood Connected
  - Confidence Connected
  - Isolated Connected
  - Confidence Connected in Vector Images
- Level Sets
  - Fast Marching Segmentation
  - Shape Detection Segmentation
  - Geodesic Active Contours Segmentation
  - Threshold Level Set Segmentation
  - Canny-Edge Level Set Segmentation
  - Laplacian Level Set Segmentation
- Hybrid
  - Fuzzy Connectedness and Confidence Connectedness
  - Fuzzy Connectedness and Voronoi Classification



1. Region Growing

- Basic segmentation filter in ITK
- Starting from boundary preserving smoothing
  - Removes noise
- Seed Selection
- Region Growing based on two thresholds
  - Upper threshold
  - Lower threshold
- Fast, but we should provide two thresholds

Result of Region Growing



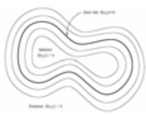
Seed

Structure	Seed Index	Lower	Upper
White matter	(60,116)	150	180
Ventricle	(81,112)	210	250
Gray matter	(107,69)	180	210

0.064 Sec

0.058 Sec

2. Level Set Methods



- Level Set Function: $\psi(\mathbf{X},\mathbf{t})$
- Generic level-set equation

$$\frac{d}{dt}\psi = -\alpha \mathbf{A}(\mathbf{x})\cdot\nabla\psi - \beta P(\mathbf{x})\,|\nabla\psi| + \gamma Z(\mathbf{x})\kappa\,|\nabla\psi|$$

Advection Propagation Spatial modifier for curvature *K*

- Track the evolution of contours and surfaces
  - By Computing the update to the solution ψ of the PDE
- Can omit one or more terms depending on the algorithm
- Typical Way in Practice
  - Contour is initialized by a user
  - Evolve until it fits the form of the segment in the image

2-(1) Fast Marching Method

- The simplest level set approach
- Usually used as the initial step for other level set methods
- Propagates a contour from a set of user-selected seed
- Maintains the internal pixel(or voxel) lists
- Contour advances with a speed image
  - Computed from the intensity of input image gradient magnitude
- Very fast in all the level methods, but sometimes it cannot detect the complete segmentation

2-(1) Fast Marching *Preprocess*

- Noise Minimization
  - itk::CurvatureAnisotropicDiffusionImageFilter
- Gradient of the Image
  - itk::GradientMagnitudeRecursiveGaussianImageFilter

-1	0	1

-1
0
1

Fig1 : Calculate Gradient Magnitude

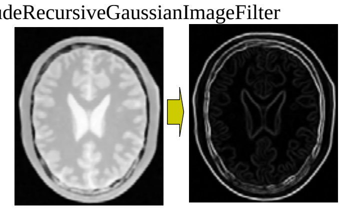


Fig2 : Original to gradient magnitude image

2-(1) Fast Marching *Preprocess*

- Speed Image
  - itk::SigmoidImageFilter

$$I = (Max - Min)\frac{1}{\left(1+e^{-\left(\frac{I-\beta}{\alpha}\right)}\right)} + Min$$

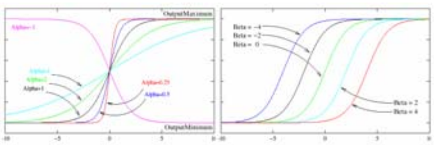
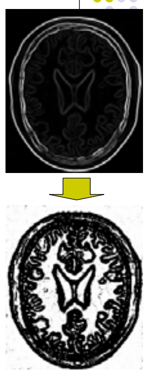
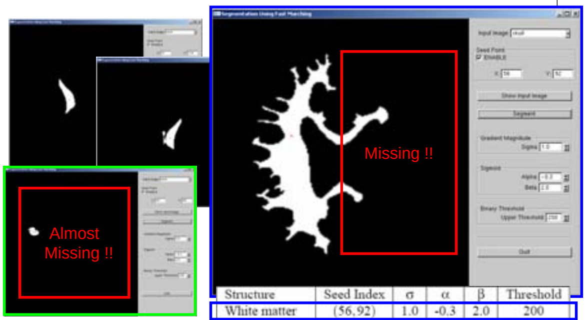


Fig: Effects of various parameters:alpha (width) beta (center)



Result of Fast Marching



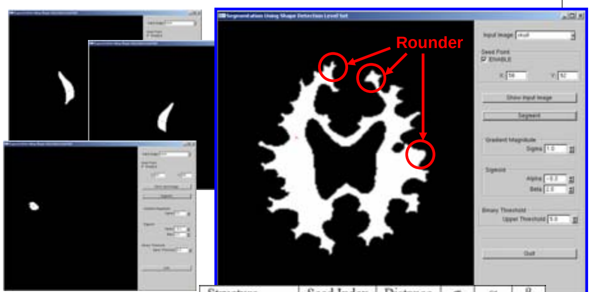
Structure	Seed Index	σ	α	β	Threshold
White matter	(56,92)	1.0	-0.3	2.0	200
Left Ventricle	(81,114)	1.0	-0.5	3.0	100
Right Ventricle	(99,114)	1.0	-0.5	3.0	100
Gray matter	(40,90)	0.5	-0.3	2.0	200

0.021 Sec

2-(2) Shape Detection Level Set Method

- Consider curvature term in general level-set PDE
- Use "Fast Marching Method" as a helper in the determination of an initial level set
- Propagates a contour with a speed
- Segmented shapes are rounder than FastMarching due to the curvature term
- Segment better, but much more slower (about 500~600 times slower) than the fast marching method

Result of Shape Detection Level Set



Structure	Seed Index	Distance	σ	α	β
Left Ventricle	(81,114)	5.0	1.0	-0.5	3.0
Right Ventricle	(99,114)	5.0	1.0	-0.5	3.0
White matter	(56,92)	5.0	1.0	-0.3	2.0
Gray matter	(40,90)	5.0	0.5	-0.3	2.0

13.54 Sec

3. Hybrid Methods

- Integrates boundary-based and region-based segmentation
  - For example:
    - Fuzzy connectedness: region-based
    - Voronoi diagram classification: boundary-based
- ITK provides two methods
  - **(1)** Fuzzy Connectedness and Confidence Connectedness
  - **(2)** Fuzzy Connectedness and Voronoi Classification
- Usually needs two steps
  - Use the first segmentation method as a prior to roughly segment or to estimate
    - Confidence Connectedness **in (1)**
    - Fuzzy connectedness **in (2)**
  - Then, use the second segmentation methods
    - Fuzzy Connectedness **in (1)**
    - Voronoi Diagram **in (2)**

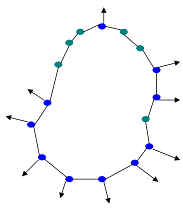
Problems in previous methods

- Region Growing
  - Needs user intervention to select thresholds
- Level Set
  - Usually slow for correct segmentation
- Hybrid
  - Needs preprocessor that produces a rough segmentation
  - Therefore, slow
- Visualization in all three methods
  - How we can extract polygons from each method for visualization is another matter

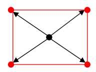
4. Particle Growing - Algorithm

Input Speed Image

- Initialization
  - Speed Image from ITK filters
  - `Generate 4 control points from seed point`
- Progress
  - `Pick a control pt from TrialQueue`
  - ```
    If(speedVal > minSpeedValue)
            march toward the average normal
    direction
            ProgressAmt*ProgressVector
            add into TrialQueue
    else
            add into BoundaryNodeQueue
    ```
- Control Point Insertion
  - ```
    If(Distance btw control pts > DistanceThr )
            add one control pts in the middle
    ```

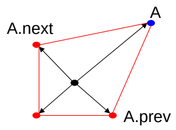


Segmented Region



Init

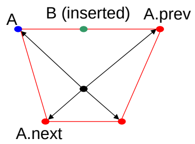
Expand the seed to 4 ctrl pts



Progress

A (98.24, 123.12)
Speed value = 0.9834 > minSpeedValue

Normal = (0.76, - 0.64)
Progress = 0.9834*(0.76, - 0.64)*ProgressAmt



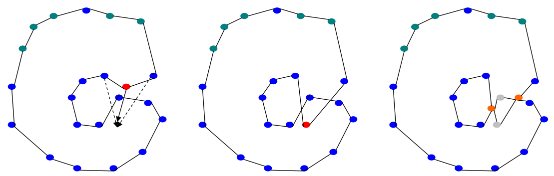
Control Point Insertion

Dist(A,A.prev) > DistanceThr
B = (A+A.prev)/2

4. Particle Growing - Problem

- Intersection
  - Cross Intersection

Green: Boundary Node
Blue: Trial Node
Red: Update Node
Orange: Intersection Node
Gray: Deletion Node

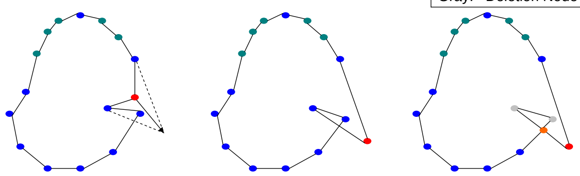


Before Intersection | *After Intersection* | *Resolve Intersection*

4. Particle Growing - Problem

- Intersection
  - Self Intersection

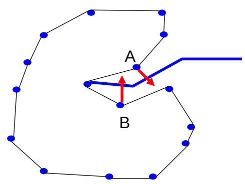
Green: Boundary Node
Blue: Trial Node
Red: Update Node
Orange: Intersection Node
Gray: Deletion Node



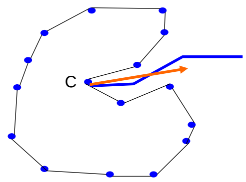
Before Intersection | *After Intersection* | *Resolve Intersection*

Resolve Intersection

- Distance Field to Prevent intersection – trial
  - Sample distance value along normal direction of progress
  - If distance value doesn't increase or decrease monotonously then intersection possibility after the progress

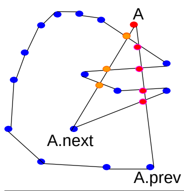


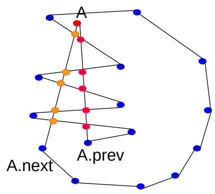
Good! Prevents A and B from potential intersection



Bad! Prevents C from marching toward although intersection doesn't occur along the path

- Heuristics to detect and remove intersection
  - If (A progress to inside of segmented area)
    first intersection nodes to second intersection nodes;
    delete A;
  - If (Intersection Nodes are Odd or Even) arrange links accordingly
  - Delete dangling nodes, Insert intersection nodes





A : Outside the segmented area A-A.next intersection node # ODD A-A.prev intersection node # EVEN	A : Inside the segmented area A-A.next intersection node # ODD A-A.prev intersection node # ODD

Performance

- Originally O(N^2) complexity for segmentation
  - Iterate the entire loop to detect intersection (per progress)
- QuadTree
  - Simple spatial partitioning
  - Intersection detected locally
  - O(N log$N$) complexity when there is no intersection
  - 3~5 times faster than original version
- Dealing with intersection
  - It takes O(N) time to deal with intersection in the current implementation
  - It makes the entire complexity O(N^2)
  - We have found a way to process it O(1), but it needs some more data structure (**Future Work**)

Result Comparisons

Execution Time	Left Ventricle	Right Ventricle	White Matter	Gray Matter	Quality Description
Region Growing	0.031	0.031	0.064	0.058	-
Fast Marching	0.024	0.023	0.021 for half	-	White matter Malfunction
Shape Detection	1.611	1.574	13.541	-	-
Particle Growing	0.005	0.004	0.088	-	-

System: Intel Pentium 4 CPU 1.5 GHz, 2GB RAM

Evaluation of Particle Growing

- Quality of Segmentation
  - Hard to evaluate the quality
  - Dependent on Speed Input Image
  - Dependent on the other parameters
    - Min-Speed, Distance Threshold, Progress Amount
- Computation Time
  - Very fast in segmenting convex region
  - Slow in very complex region
    - Currently, 2 times slower than Fast Marching
    - Self-intersections happen a lot
    - Not inherent in the algorithm, but due to the implementation

Conclusion

- Present a new segmentation method using particle growing
- Use speed input image for propagating particles
- Very fast for segmenting convex regions
- Very easy to visualize the segmented parts
  - Draw the lines in 2D
  - *Draw triangles in 3D (Future work)*

Future Works

- Fix some bugs in processing intersections
  - The program breaks sometimes
- Apply efficient data structure to help process self-intersection
  - Makes the entire algorithm work in O($N\log N$) time
- 2D to 3D extension
- Parameter adjustment and test variety of 2D and 3D images