Hybrid geodesic region-based curve evolutions for image segmentation

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Motivation

Challenges of medical images:
- Heterogeneous intensity profiles
- Poor edge information
- Proximity to other structures

Existing Approaches:
- Edge-based: "There will be strong gradients on the borders of objects"
- Region-based: "The object and background can be modeled easily"

Our contribution:

Development of a new class of algorithms and supporting mathematics capable of hybridizing these two existing approaches

Inspiration

Edge-based Geodesic Active Contours
- Find a local minimum "length" curve on an imposed Metric
- Can get trapped in insignificant local minima
- Only examines data on the contour
- Uses gradients of image (very noisy), smoothes image to compensate
- Classically presented by Caselles et. al.

$$E = \oint_{C(s)} \frac{1}{1 + \|\nabla \hat{I}\|^2} ds$$

Region-based Geometric Active Contours
- Minimizes an energy related to global image data and position of curve
- Very robust to noise and curve placement
- Makes global assumptions about image makeup
- Popular Chan-Vese and Mumford-Shaw flows are examples

$$E = \int_{x \in \Omega} (I - u)^2 dA + \int_{x \in \overline{\Omega}} (I - v)^2 dA$$

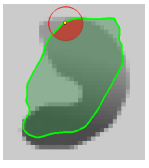
Hybrid Solution

$$E = \oint_{C(s)} \underbrace{\int_{x \in \Omega} (I\chi(x,s) - u_\ell(s))^2 + \int_{x \in \overline{\Omega}} I\chi(x,s) - v_\ell(s))^2 ds}_{\text{Region-based component over local regions}}$$

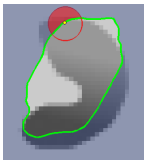
Edge-based component over every point on the curve

Concept
- Edge-based energy where each point's cost is based on a local region.
- Each point on the contour moves such that regions of nearby pixels just inside and just outside the contour are modeled optimally by their mean intensities.

Interior local region



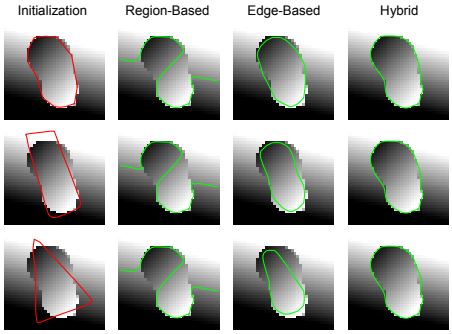
Exterior local region



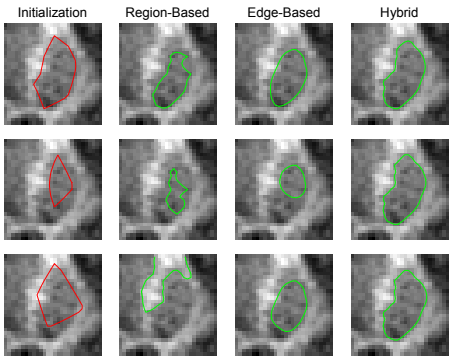
Implementation
- Gradient descent to find local minimum
- Level sets used to embed evolving contour
- Pre-computation of statistics to speed algorithm

Experiments

Synthetic Images



Medical MRI Images



Results
- **Region-based** finds an incorrect way to model regions by mean intensities
- **Edge-based** finds some strong edges, but usually finds a (wrong) local minima
- **Hybrid methods** find the correct outline of the object

Discussion

Benefits:
- Weak assumptions about image makeup
- Robust to noise and initial curve placement
- Extensible mathematical framework, proposed algorithm is a simple example

Limitations:
- Subject to initial curve placement, as with all geometric active contours
- The radius of the χ function is a free parameter

Future work:
- Automatic or adaptive setting of the radius of χ
- Incorporation of higher order statistical moments
- Extension to vector-valued images and 3D images

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