Fuzzy-Cuts: A Knowledge-Driven Graph-Based Method for Medical Image Segmentation

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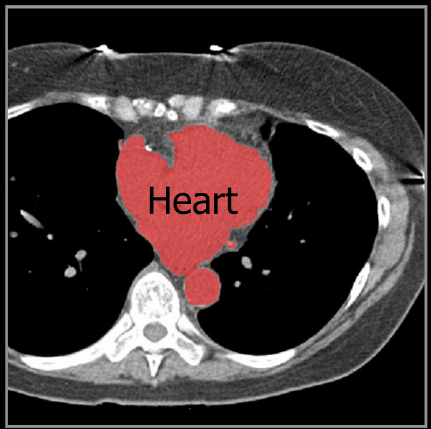
Motivation

- Image segmentation is an ill-posed problem
- Additional constraints need to be imposed to achieve the desired results
- Fortunately, in the field of medical image segmentation a significant amount of prior knowledge is available



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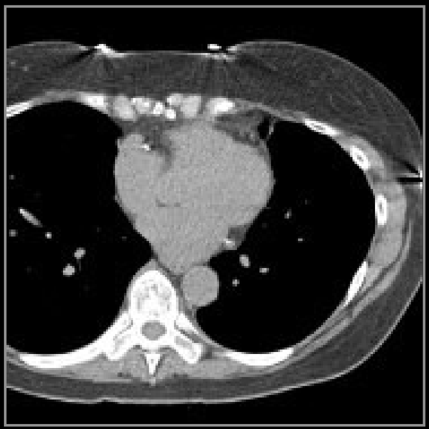
Non-contrast CT scan



Prior Knowledge

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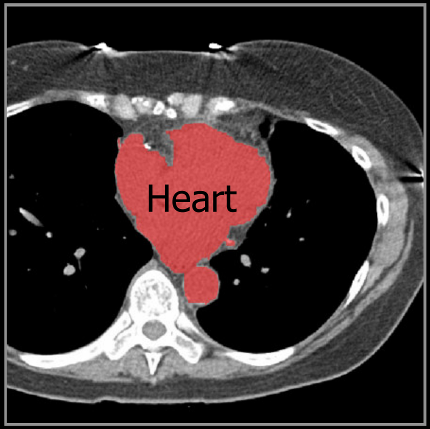
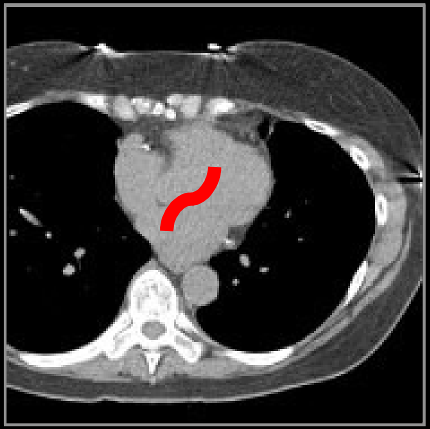
Prior Knowledge





Appearance
and
Spatial Connectivity Prior

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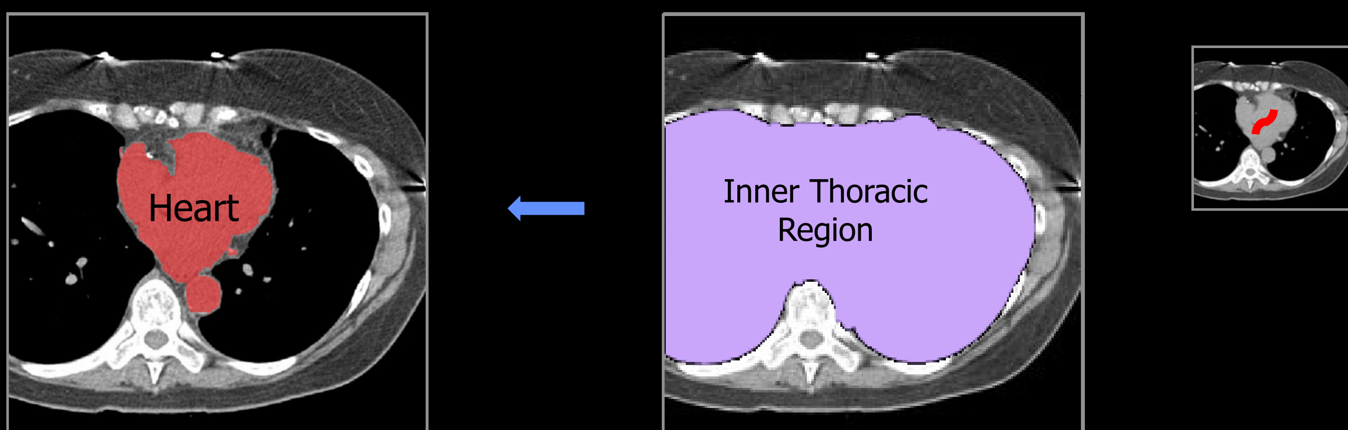
Non-contrast CT scan **Prior Knowledge**



Location Prior

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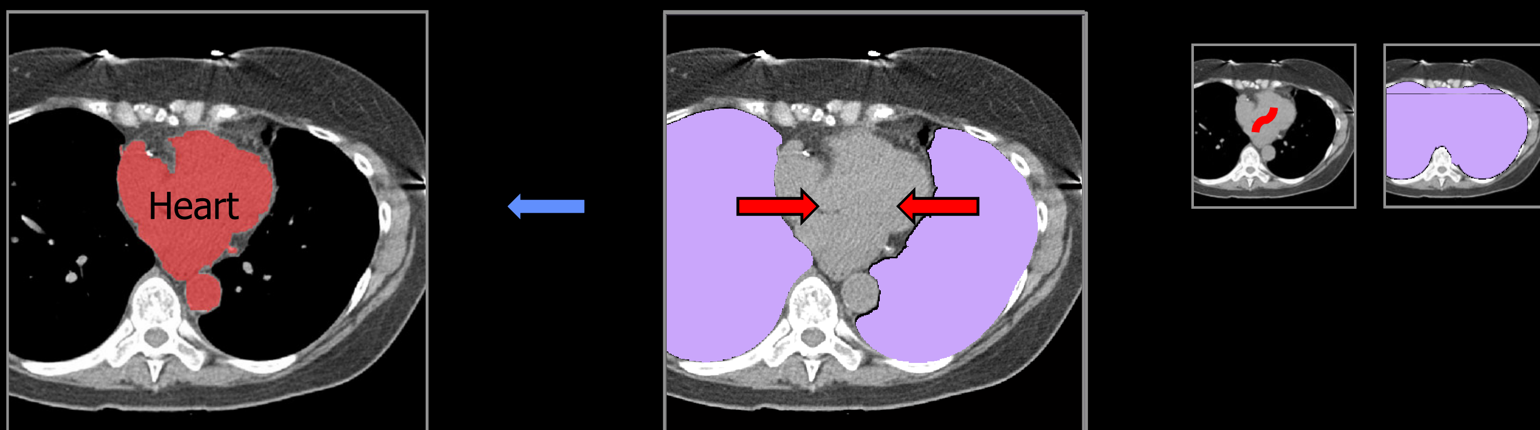

Location Prior

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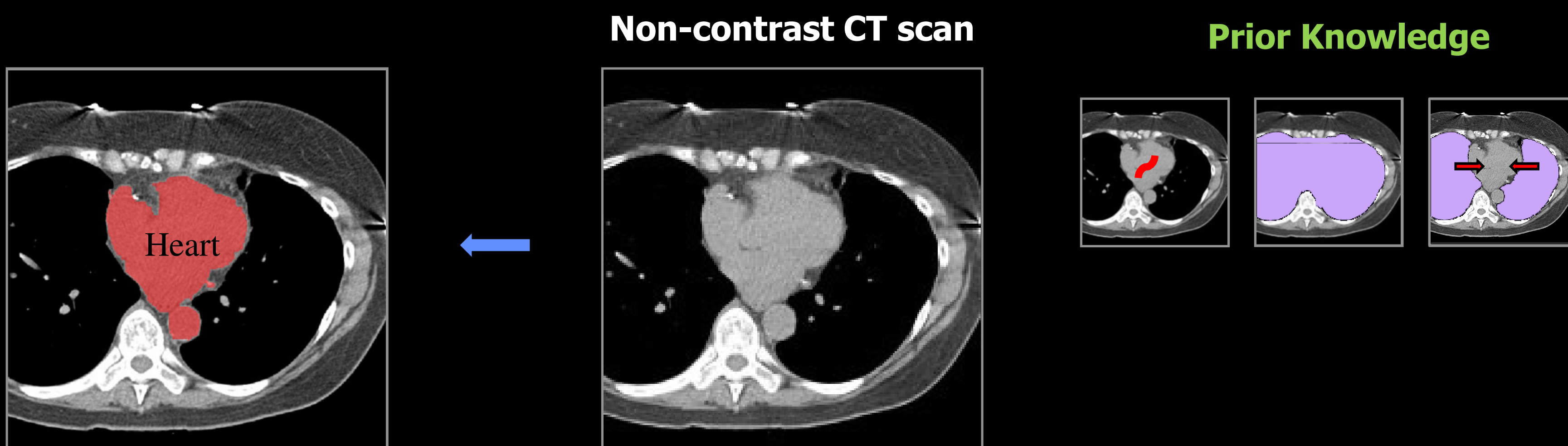


- However, it is difficult to unify various types of prior information available such as appearance, location and shape into a single framework

Objective

- Using prior knowledge to constrain the solution space of the Image Segmentation problem
- Here, we focus on three types of prior knowledge:
  - Location
  - Appearance
  - Spatial connectivity to a known seed region

Our Approach

- We propose a fuzzy theoretic model to incorporate knowledge-driven constrains into the MAP-MRF formulation of the segmentation problem

Image Segmentation

"find a mapping $f : P \rightarrow L$ *that minimizes an energy functional* $E(f \mid D)$ *conditioned over the observed image data D, where P is the set of pixels and L is the set of labels."*

- We cast the segmentation problem as a MAP-MRF problem
- The MAP-MRF solution can be computed by minimizing the following Gibbs energy function:

$$E(f \mid D) = \sum_{i \in P} V_i(f_i \mid D) + \sum_{i \in P} \sum_{j \in N_i} V_{ij}(f_i, f_j \mid D)$$

First-order Clique Potential

Second-order Clique Potential

Definition of First-order Clique Potential - $V_i(f_i \mid D)$

$V_i(f_i \mid D)$ measures the cost of assigning label f_i to pixel i given prior knowledge about the data D

We define $V_i(f_i \mid D)$ as a spatial fuzzy set defined on the image space S as shown below:

$$V_i(f_i \mid D) = \hat{c}\left(t\left(\mu_\chi^{O_{f_i}}(i), \mu_\lambda^{O_{f_i}}(i)\right)\right)$$

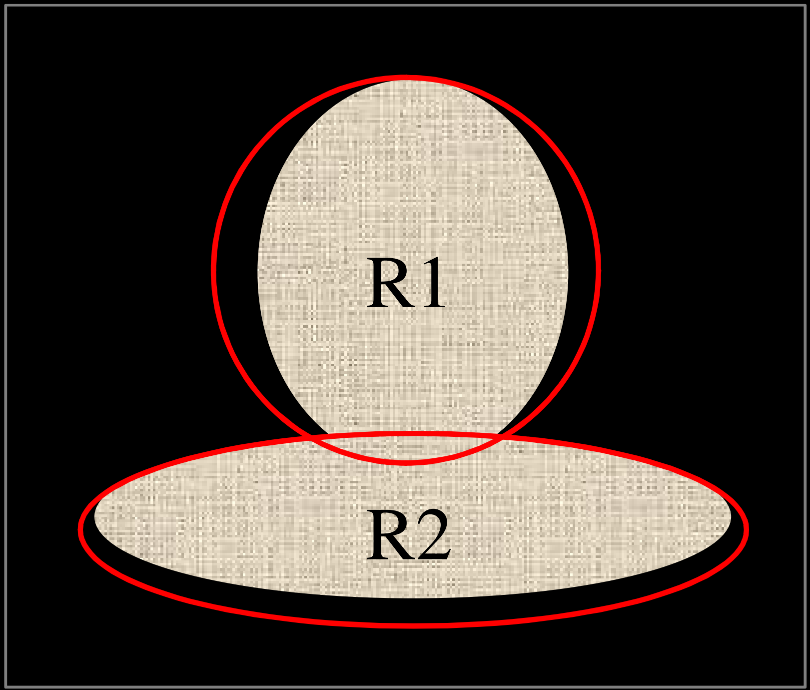
Fuzzy Connectivity Prior

Fuzzy Location Prior

Fuzzy Connectivity Prior - $\mu_{\chi}^{O_{f_i}}(i): S \rightarrow [0,1]$

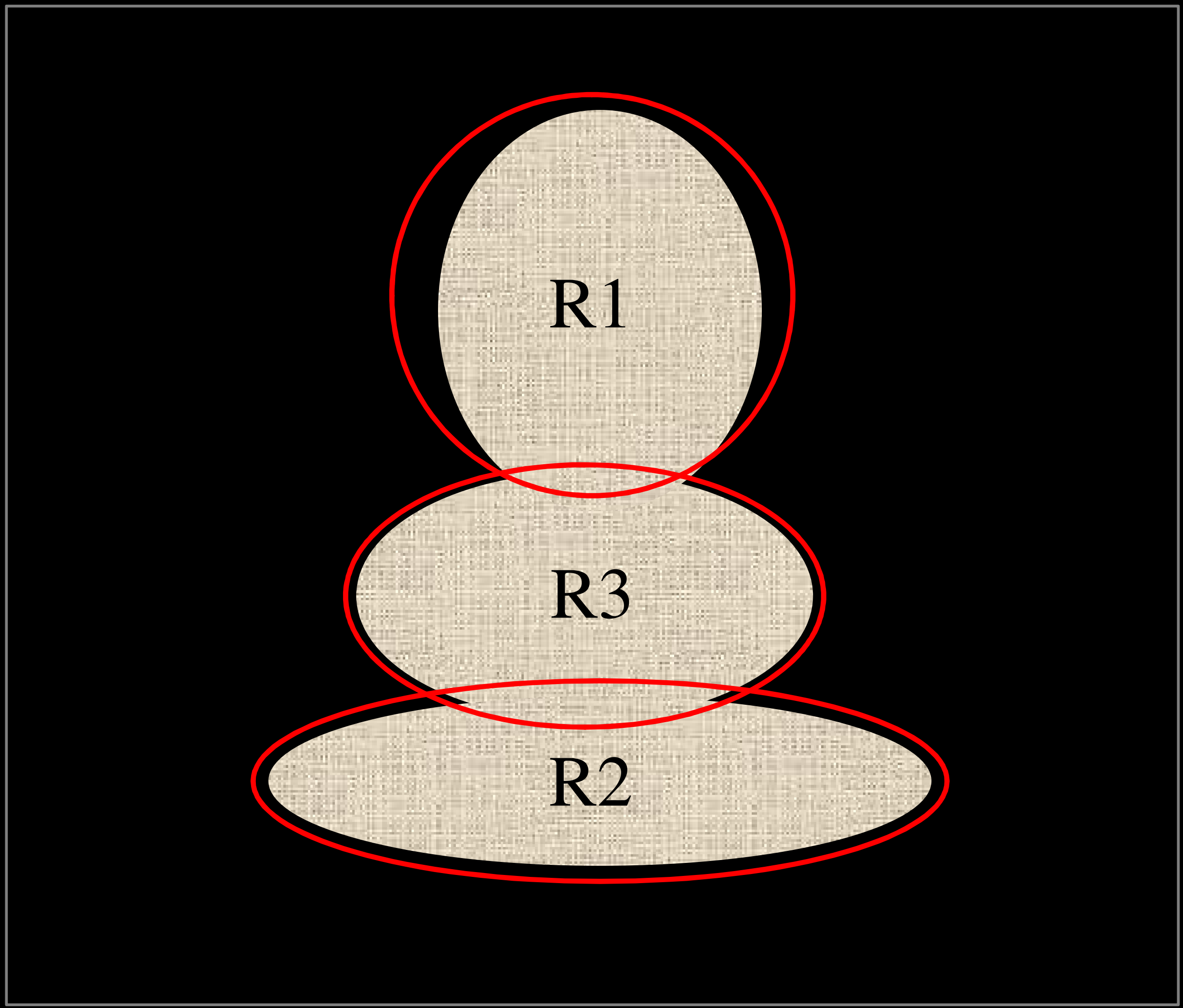
- We use fuzzy connectedness proposed by Udupa *et. al.* to model $\mu_{\chi}^{O_{f_i}}(i)$
- Fuzzy connectedness models the following notion:

> *"if two regions have about the same appearance and if they are spatially connected to each other in the image space then they most likely belong to the same object"*

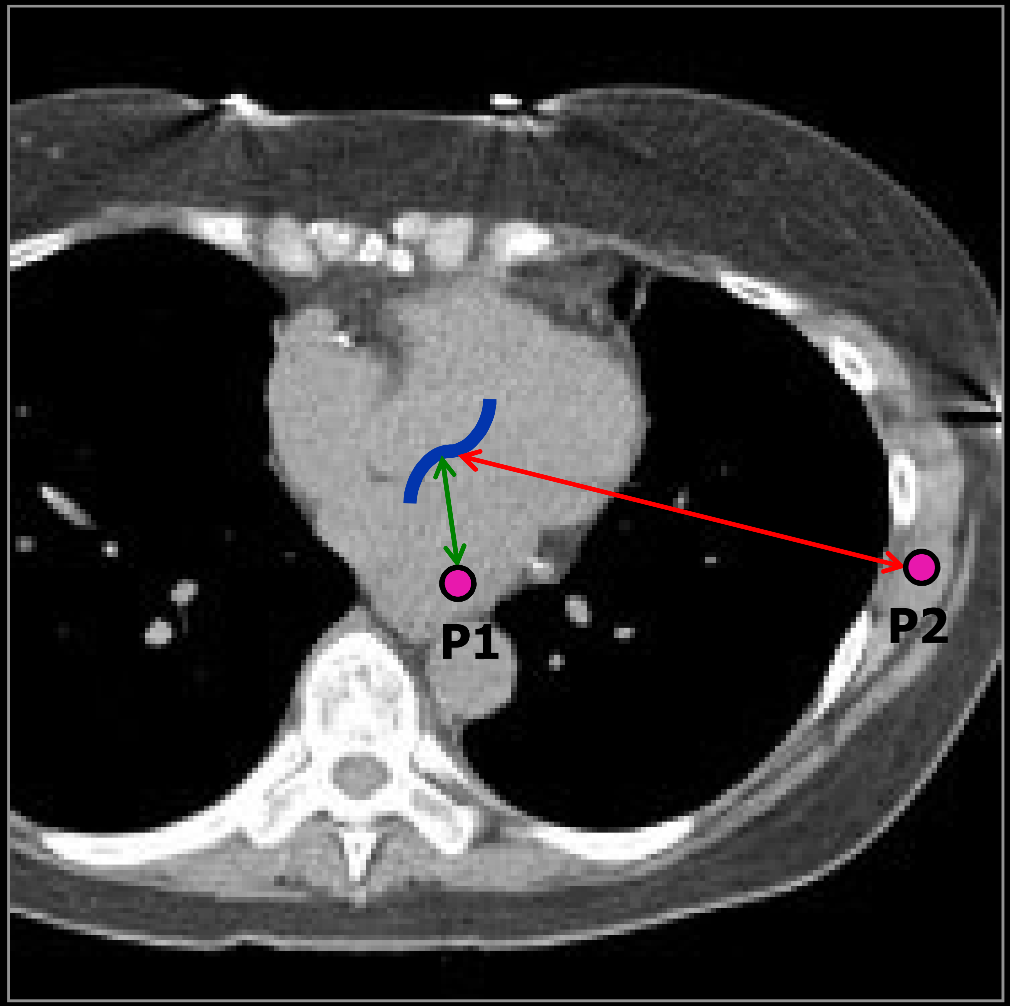


J. K. Udupa and S. Samarasekera. Fuzzy connectedness and object definition: Theory, algorithms, and applications in image segmentation. Graphical Models and Image Processing, 58(3):246–261, 1996.

Fuzzy Connectivity Prior - $\mu_{\chi}^{O_{f_i}}(i): S \rightarrow [0,1]$ ...



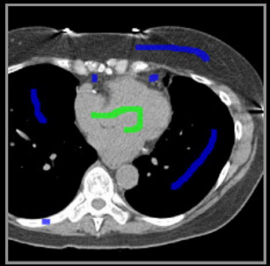
Fuzzy Connectivity Prior - $\mu_{\chi}^{O_{f_i}}(i): S \rightarrow [0,1]$ ...

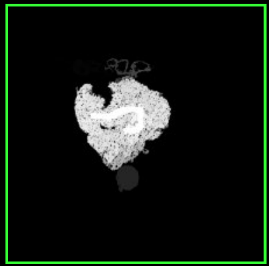


Fuzzy Connectivity Prior - $\mu_{\chi}^{O_{fi}}(i): S \rightarrow [0,1]$ ...

- We define $\mu_{\chi}^{O_{fi}}(i)$ as a spatial fuzzy set representing a fuzzy connected component of object O_{fi} given a seed region R of the object as shown below:

$$\mu_{\chi}^{O_{fi}}(i) = \max_{p_{Ri} \in P_{Ri}} \left\{ \min_{1 \le j < |p_{Ri}|} \left[\psi^{O_{fi}}(j, j+1) \right] \right\}$$





- $\psi^{O_{fi}}(p,q)$ is the fuzzy affinity function representing the affinity between two neighboring pixels p and q as shown below:

$$\psi^{O_{fi}}(p,q) = \begin{cases} \mu_{\nu}^{O_{fi}}(p,q) \cdot \mu_{\alpha}^{O_{fi}}(p,q) & if \;\; p \neq q \\ 1 & otherwise \end{cases}$$

Adjacency Test

$$\mu_{\nu}^{O_{fi}}(p,q) = \begin{cases} 1 & if \;\; q \in N_p \\ 0 & otherwise \end{cases}$$

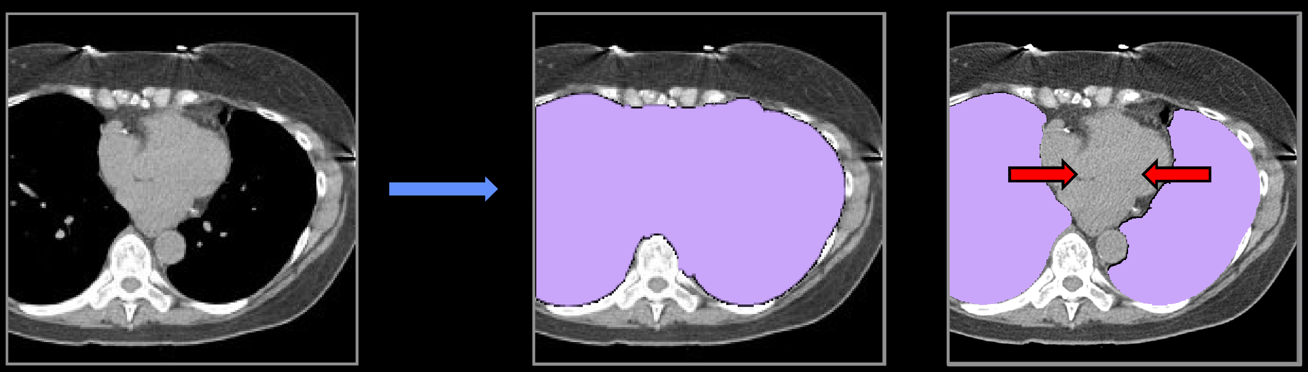
$$\mu_{\alpha}^{O_{fi}}(p,q) = w_1 \cdot \Pr\left(x = \frac{(D_p + D_q)}{2}; \theta_1^{O_{fi}} \right) + w_2 \cdot \Pr\left(x = |D_p - D_q|; \theta_2^{O_{fi}} \right)$$

Similarity in Appearance

Fuzzy Location Prior - $\mu_{\lambda}^{O_{f_i}}(i) : S \rightarrow [0,1]$

$\mu_{\lambda}^{O_{f_i}}(i)$ is a spatial fuzzy set representing the likelihood that object O_{f_i} is located at pixel i given prior knowledge about the location of the object

- An organ's location is specified in terms of its spatial relationship with neighboring organs
- For example, anatomically the heart is located:
  - "inside" the thoracic cavity
  - "between" the lungs



Fuzzy Location Prior - $\mu_{\lambda}^{O_{f_i}}(i): S \rightarrow [0,1]$ ...

- In such a scenario, we model $\mu_{\lambda}^{O_{f_i}}(i)$ as a fuzzy conjunction of its spatial relationship with each of the neighboring organs as shown below:

Spatial relationship with neighboring object K

$$\mu_{\lambda}^{O_{f_i}}(i) = t\left(\ldots, \mu_{NO_k}^{O_{f_i}}(i), \ldots\right); k = \{1, 2 \ldots, T\}$$

- A variety of ways to model fuzzy spatial relationships such as "inside", "outside", "left of", "right of" etc. are available in literature (see Bloch *et. al.*)
- If segmentation of neighboring objects is not available, we can define $\mu_{\lambda}^{O_{f_i}}(i)$ using a probabilistic atlas obtained after performing atlas registration

Definition of Second-order clique potential - $V_{ij}(f_i, f_j \mid D)$

$V_{ij}(f_i, f_j \mid D)$ measures the cost of jointly assigning a label f_i to pixel i and a label f_j to its neighboring pixel $j \in N_i$ given any prior knowledge about the data D

We define $V_{ij}(f_i, f_j \mid D)$ based on a Generalized Potts Interaction model* as shown below:

$$V_{ij}(f_i, f_j \mid D) = K(i, j \mid D) \cdot \left(1 - \delta(| f_i - f_j |)\right)$$

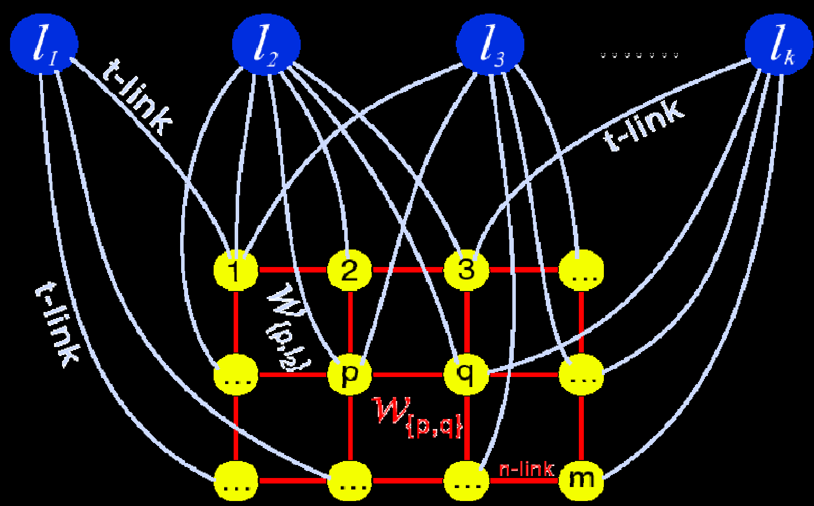
$$= \begin{cases} K(i, j \mid D) & if \;\; f_i \neq f_j \\ 0 & otherwise \end{cases}$$

$$K(i, j \mid D) = \exp\left(-(D_i - D_j)^T \Sigma_k^{-1} (D_i - D_j)\right)$$

where D_i and D_j are feature vectors of pixels i and j respectively
Σ_k is the covariance matrix

* Y. Boykov and G. Funka-Lea. Graph cuts and efficient N-D image segmentation. International Journal of Computer Vision, 70(2):109–131, 2006.

Minimizing Gibbs Energy using Graph-Cuts

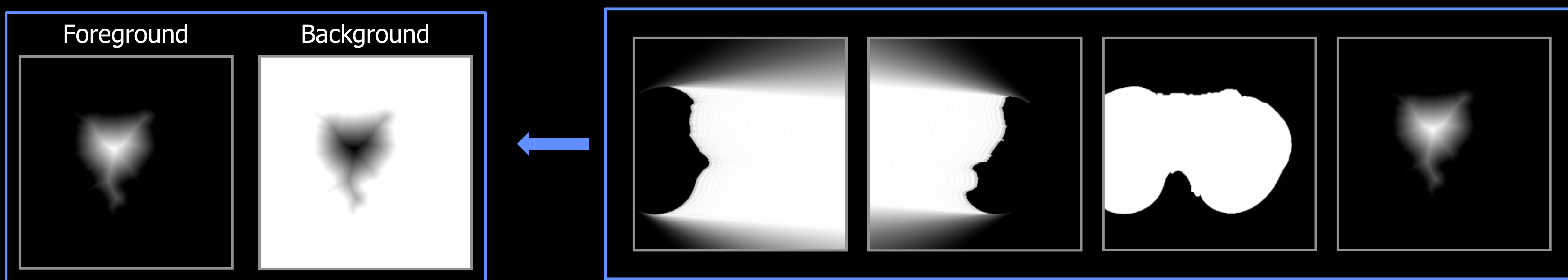


edge	weight (cost)	for
n-link - $\{i, j\}$	$K(i, j \mid D)$	$\{i, j\} \in N$
t-link - $\{i, l\}$	$W_i - V_i(l)$	$i \in P, l \in L$

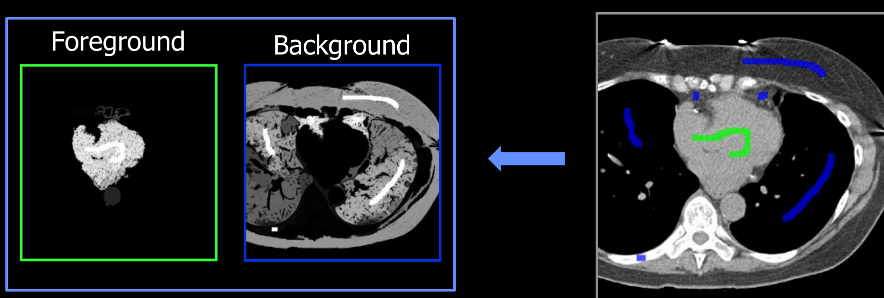
- Minimizing $E(f \mid D)$ is equivalent to find the minimum cost multi-way cut on the above graph
- For L = {0,1}, a global minimum can be obtained in polynomial time by solving the s-t minimum cut problem
- For |L| > 2, the optimal multi-way cut problem is NP-Hard

Experiments: Heart Segmentation

Fuzzy Location Priors

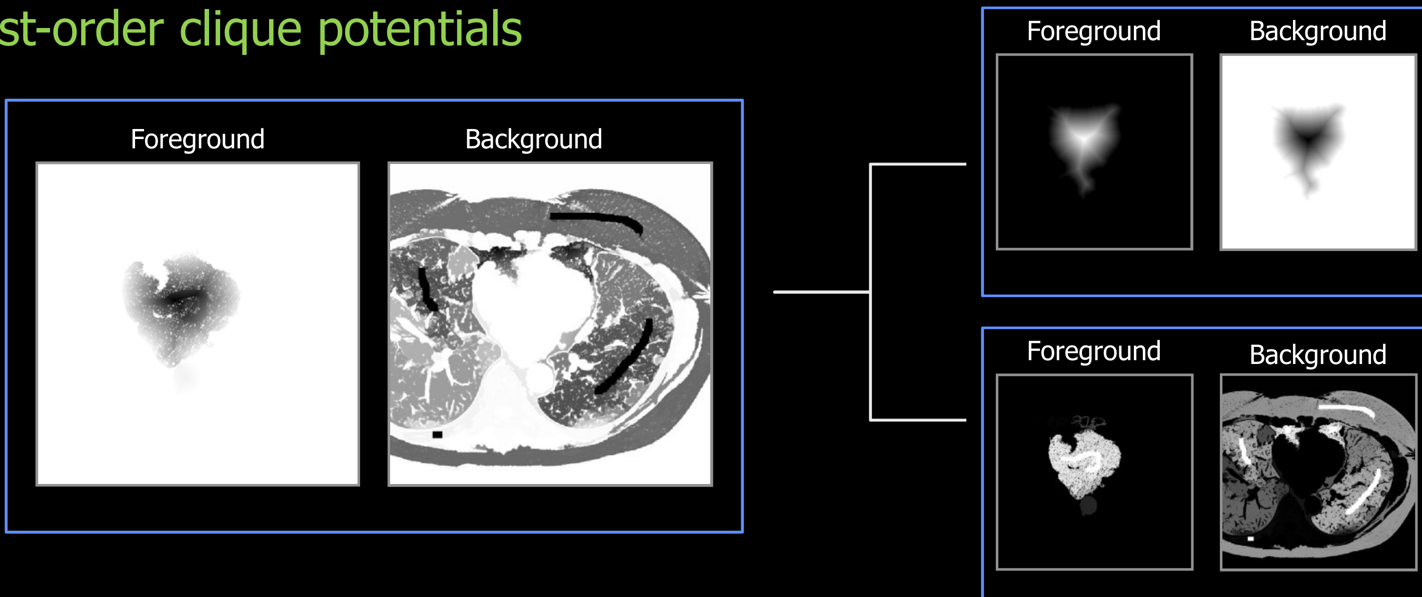


Fuzzy Connectivity Priors



Experiments: Heart Segmentation …

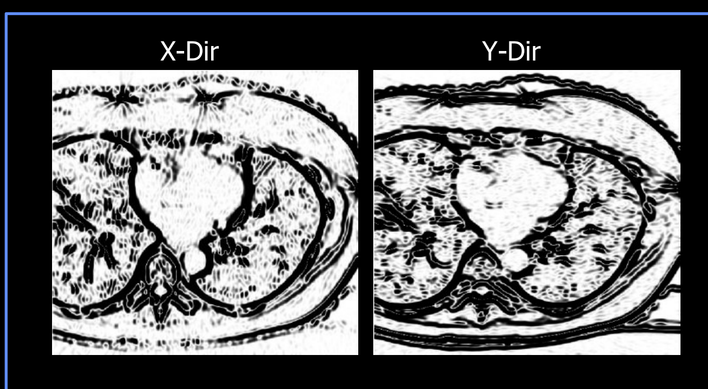
First-order clique potentials



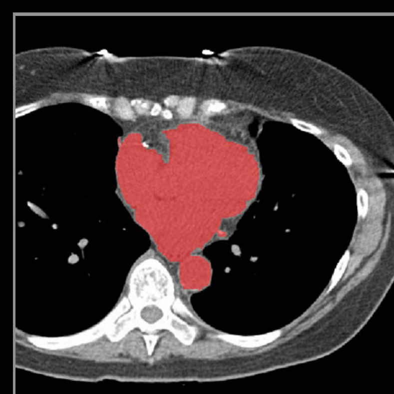
Fuzzy Location Prior

Fuzzy Connectivity Prior

Second-order clique potentials

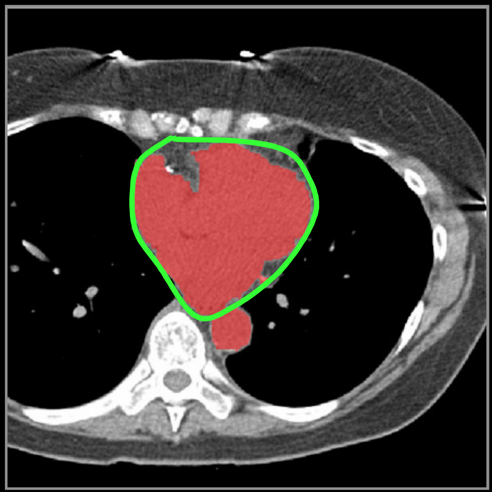


Segmentation Result



Conclusion

- Fuzzy theoretic approach to incorporate prior knowledge into the MAP-MRF formulation
- How to incorporate prior knowledge about an object's
  - "Location"
  - "Appearance and spatial connectivity to a known seed region"
- Future work will focus on the incorporation of shape priors into the proposed framework



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  - Raja Yalamanchili
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Questions

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Openings

Computational Biomedicine Lab Changing the Way People Look at Computers

Research Assistant Professor / Research Scientist position in Face Recognition

The Computational Biomedicine Lab (CBL) is growing! Applications are invited for a Research Assistant Professor / Research Scientist position at the Computational Biomedicine Lab (www.cbl.uh.edu), University of Houston in the area of Face Recognition.

CBL's Face recognition software (URxD) ranked first in the 3D-shape section of the recent Face Recognition Vendor Test (FRVT) organized by NIST (http://www.uh.edu/admin/media/nr/2007/07july/073007urxd.html). CBL provides a unique interdisciplinary research environment with internationally recognized collaborators. CBL is home to 3 tenure-track faculty, 1 adjunct faculty, 3 Research Assistant Professors, 3 Research Scientists, 8 Ph.D. students, 3 M.Sc. students and 2 interns. The position entails research in novel biometrics (www.cbl.uh.edu/URxD). The candidate will benefit from mentorship of a diverse research team and will be exposed to cutting-edge technology.

Applicants should have a doctoral degree in Computer Science, Electrical Engineering, Applied Mathematics or a related field. The successful applicant will have solid research, interpersonal, and communication skills. Prior biometrics experience is required.

The position is open immediately and the salary compensation is very competitive. For consideration, please submit your application (preferably in one single PDF-document) including a cover letter, a full CV, a statement of research interests and career goals and the names and email addresses of three references to ioannisk@uh.edu, with subject line "PDF/RAP-RS: (your name)".

For more information please email Prof. Kakadiaris (ioannisk@uh.edu).

Kiplinger has selected Houston as it's overall **#1 Best City to Live, Work, and Play** for 2008 and Forbes as **Top 5 Up & Coming Tech City**, **#1 City for Recent College Grads**, and **#3 City for Young Professionals**. Houston offers an outstanding environment for research and professional opportunities for growth and collaboration. UH is an equal employment opportunity employer and a smoke-free environment. Women and minority candidates are strongly encouraged to apply.

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CBL provides a unique interdisciplinary research environment with internationally recognized collaborators from Medicine, Biology, Mathematics, and Engineering. CBL is home to 3 tenure-track faculty, 1 adjunct faculty, 3 Research Assistant Professors, 3 Research Scientists, 8 Ph.D. students, 3 M.Sc. students and 2 interns. The position entails research in image analysis. The candidate will benefit from mentorship of a diverse research team and will be exposed to cutting-edge technology.

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