Auto-Segmentation of Spine CT for Data-Intensive Analysis of Surgical Outcome

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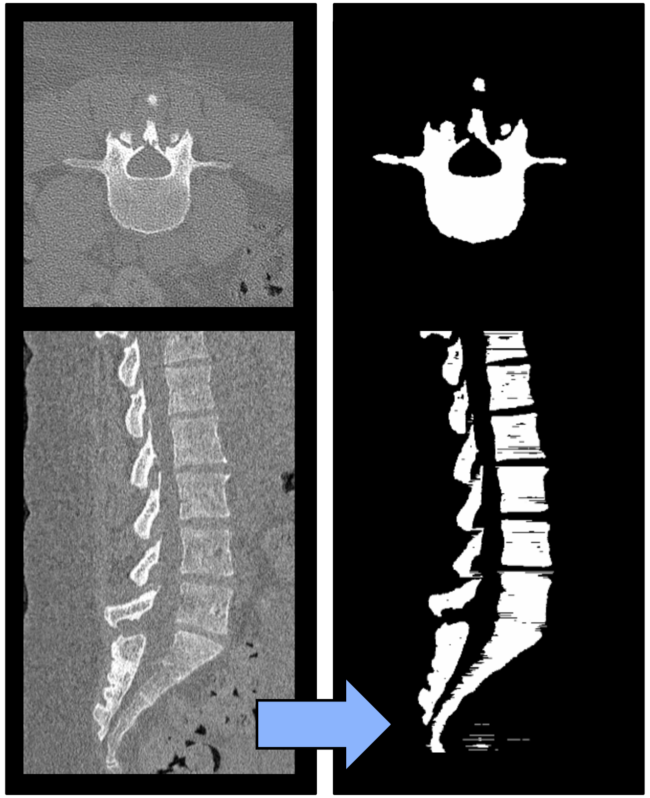
Project Goals

- Overall: To Develop and Test the "max-flow/min-cut" segmentation method for spine CT images
- **Main Deliverable 04/20:** Accurate segmentation of N=200 spine CT dataset provided by Dr. Siewerdsen



Paper Selection

Fast Approximate Energy Minimization via Graph Cuts

Yuri Boykov Olga Veksler Ramin Zabih
Computer Science Department
Cornell University
Ithaca, NY 14853

1999
Conference Paper
International Conference for Computer Vision

2001
Journal Paper IEEE Transactions on PAMI, vol. 23, no. 11, pp. 1222-123

Why Selected?

- Generalized approach on how to use graph cuts to minimize a variety of energy functions
  - One application is **segmentation** among others (i.e. stereo, image restoration, motion)
- Binary label segmentation of Spine CTs based off of implementation of theory in paper

Paper Background

Computer vision problems can be naturally formulated into energy minimization:

$$E(f) = E_{smooth}(f) + E_{data}(f).$$

For a labeling *f*

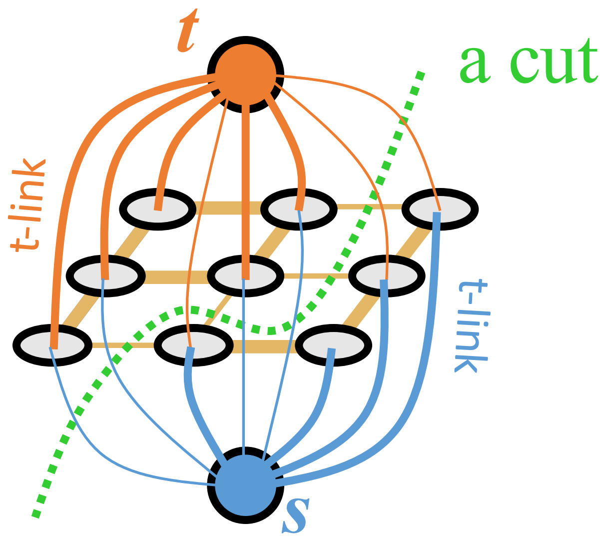
$E_{smooth}(f)$ - Quantifies the similarity of neighboring pixels based on measurables (i.e. intensity)

$E_{data}(f)$ - Quantifies how labeling compares to observed data / priors

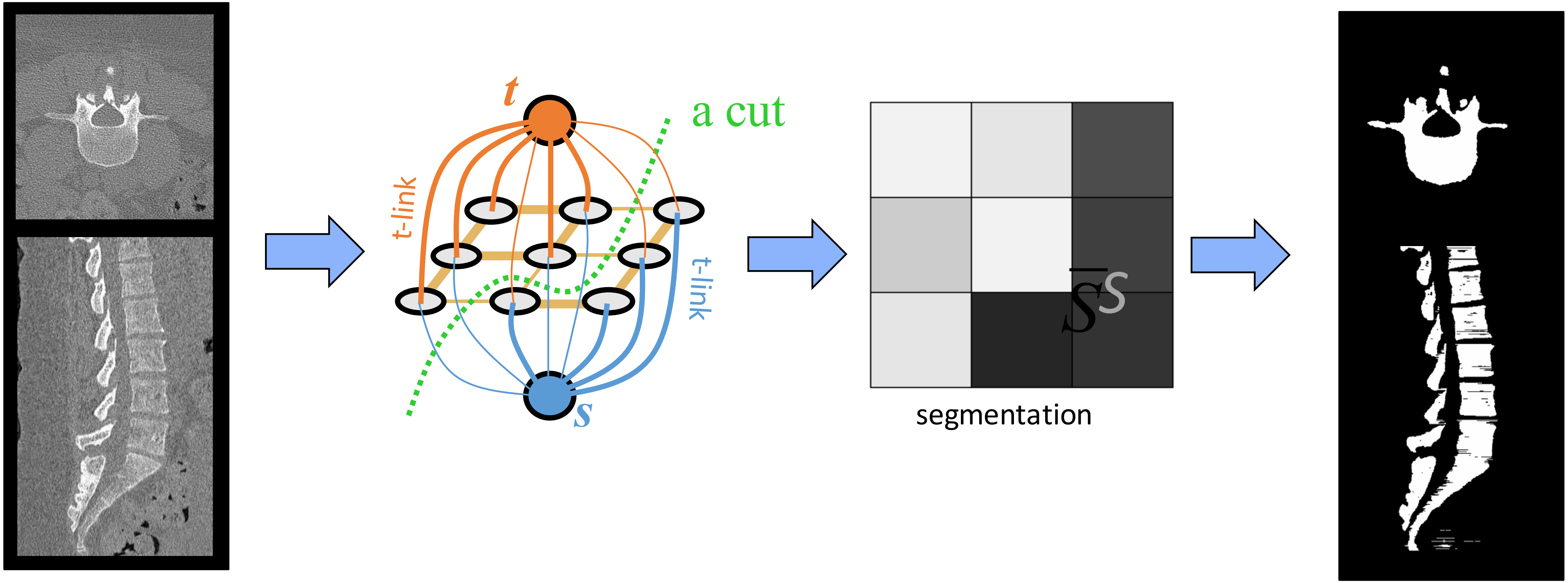
Determining the global minima is often difficult due to computational costs, many local minima, and large possible label space

Paper Goals

- How does one minimize an energy function in a quick and computationally efficient manner?
- Previous Method: Simulated annealing
  - Can approach the global minimum of arbitrary energy function
  - **Standard Moves –** can only do single pixel changes at each iteration
    - Exponential in time
- Explored Methods: Graph Cuts
  - **α-β swaps**
  - **α-expansion**
  - **Large moves –** many pixels' labels can change at each iteration
  - For binary labelling **global minimum** can be reached in **polynomial time**

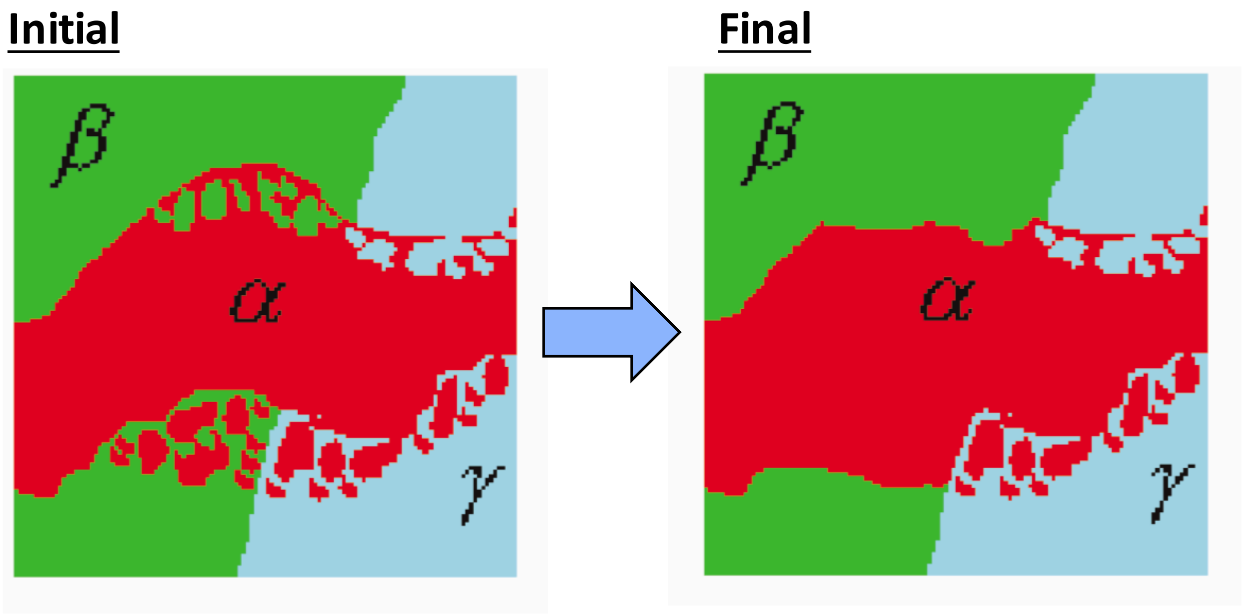


Max-Flow Min-Cut Explanation (Segmentation Example)



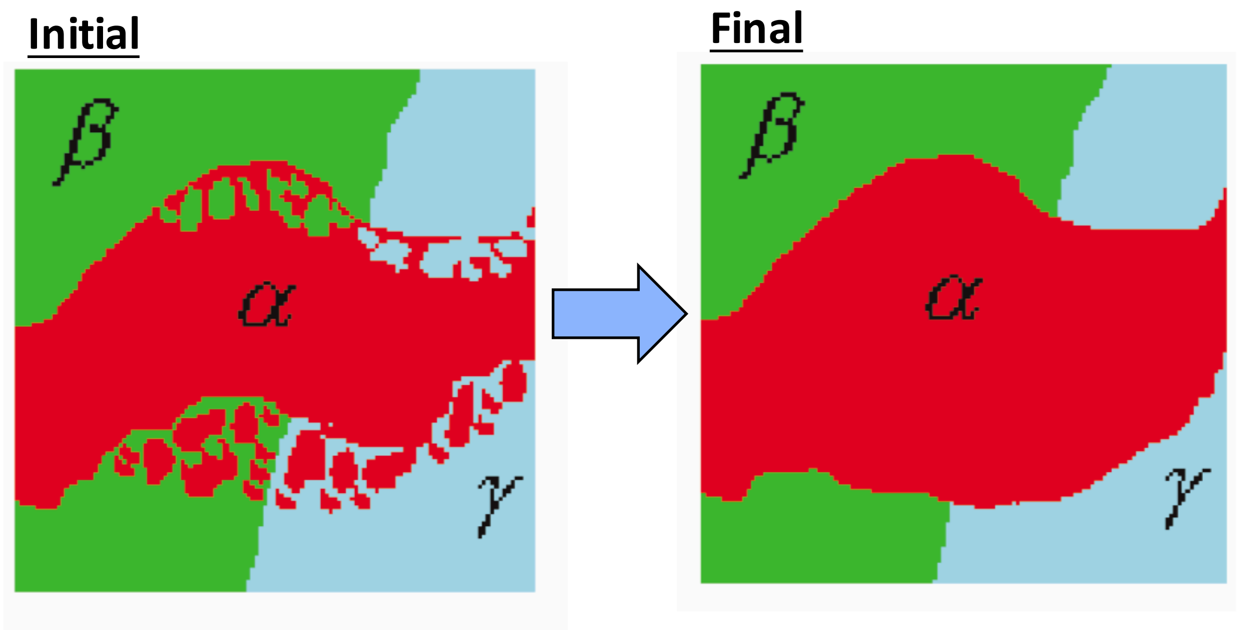
α - β swap

1. Start with an arbitrary labeling f
2. Set success := 0
3. For each pair of labels $\{\alpha, \beta\} \subset \mathcal{L}$
    - 3.1. Find $\hat{f} = \arg\min E(f')$ among f' within one α-β swap of f (Section 3)
    - 3.2. If $E(\hat{f}) < E(f)$, set f := $\hat{f}$ and success := 1
4. If success = 1 goto 2
5. Return f



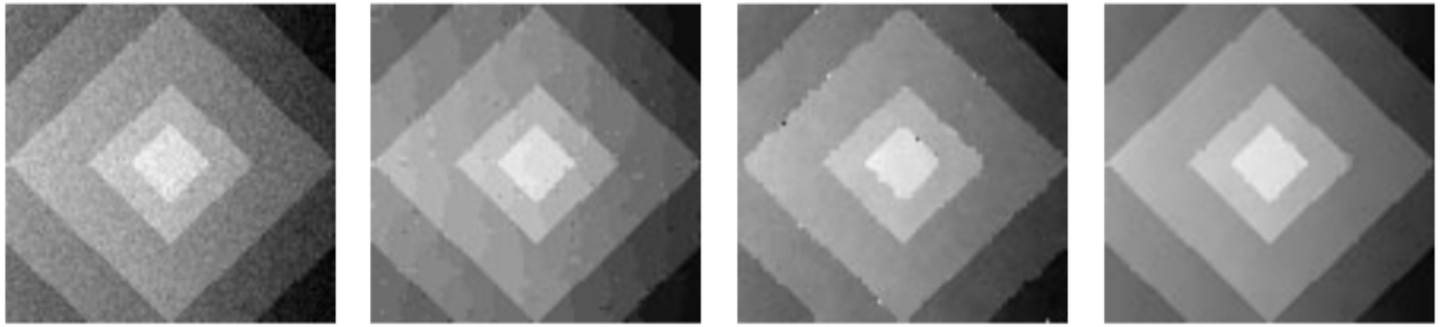
α - Expansion

1. Start with an arbitrary labeling f
2. Set success := 0
3. For each label $\alpha \in \mathcal{L}$
   3.1. Find $\hat{f} = \arg\min E(f')$ among f' within one α-expansion of f (Section 4)
   3.2. If $E(\hat{f}) < E(f)$, set f := $\hat{f}$ and success := 1
4. If success = 1 goto 2
5. Return f



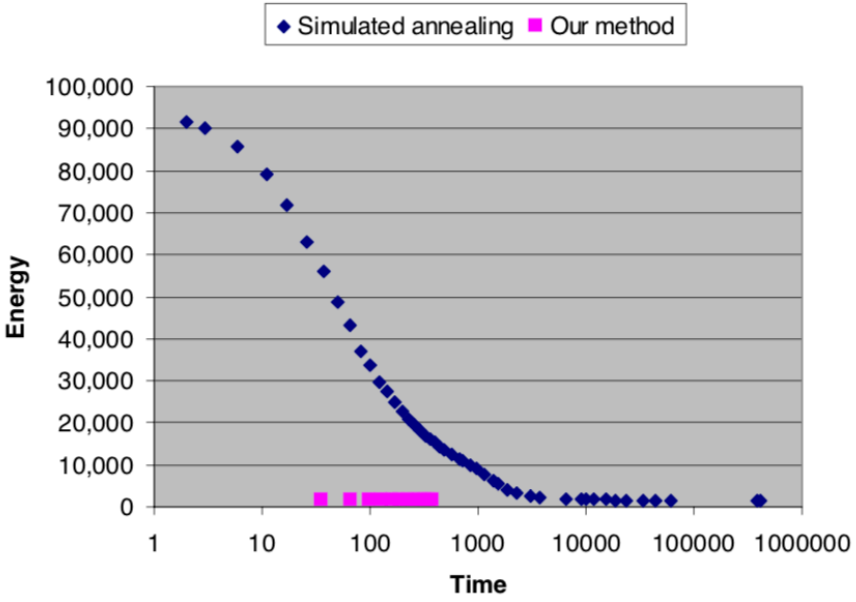
Experimental Results on Image Restoration

α – Expansion | Annealing | α - β swap



Diamond image (input) | Our method (E_2) | Annealing (E_1) | Our method (E_1)

	E			E_{smooth}		
	Our results	Annealing	Ratio	Our results	Annealing	Ratio
Diamond (image restoration, E_1)						
First cycle ($t = 36$)	1,577	55,892	**35.5**	637	9,658	**15.2**
Last cycle ($t = 389$)	1,472	15,215	**10.3**	576	8,475	**14.7**
Best annealing ($t = 417,317$)	—	1,458	—	—	571	—



Conclusion / Paper Assessment

Pros

- Generalizable to many computer vision problems (i.e. segmentation, stereo, image restoration, motion)
- Computationally efficient and speedy when compared to the then-current algorithms
- Binary labelling guarantees reaching global minimum
- For multi-labeling with α-expansion, minima has guaranteed bounds of a factor within global minimum

Cons

- The Smoothness Functions are limited to pairs of adjacent pixels
- Graph cut methods take a discrete approach

Reading List

- Boykov, Y., et al. “Fast Approximate Energy Minimization via Graph Cuts.” *Proceedings of the Seventh IEEE International Conference on Computer Vision*, 1999, doi:10.1109/iccv.1999.791245.
- Boykov, Y., et al. “Fast Approximate Energy Minimization via Graph Cuts.” *IEEE Transactions on Pattern Analysis and Machine Intelligence*, vol. 23, no. 11, 2001, pp. 1222–1239., doi:10.1109/34.969114.