Auto-Segmentation of spine CT for Data Analysis of Surgical Outcome

601.456/656 Computer Integrated Surgery II

Group 23 Project Proposal

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Summary

An automatic segmentation method for the spine is needed so spine CT may be segmented accurately and efficiently with as little human intervention. Current methods for accurate spine segmentation have included manual and semi-manual methods. While manual segmentation is highly accurate, it is extremely time consuming and although semi-manual methods are more efficient, they still require the manual placement of seed points. These methods are infeasible for a CT spine repository orders of magnitudes in size at which the need for a hands off approach to segmentation becomes imperative. The goal of this project is to use the max-flow/min-cut algorithm for segmentation of spine CT images, ultimately providing an automatic method capable of mass producing spine segmentations. This methods has been well documented[1,2,3] and provides a good method to employ for spine segmentation.

Background, Motivation, Significance

Big data approaches have become popular in many fields as computers become increasingly capable of managing larger amounts of data. At the same time, modern medicine is pushing toward a patient specific model of care that relies on big data approaches to grant more personalized care leading to better outcomes. This approach is especially useful when applied to orthopedics, where surgery has a high degree of difficulty due to limited workspace view and the need for image guided procedures. And in addition, these surgical outcomes can have a significant effect on patient's quality of life. Therefore, the use of big data in orthopedics to create customized pre-operative plan in a patient specific manner is a logical next step to achieving consistent and favorable surgical outcomes.

A place of emphasis in orthopedic surgery is the spine. Spine surgery is an enormous market with many patients suffering from chronic pain and yet spine surgeries bear a low quality of outcomes where 8-25% of patients require rehospitalization. This creates the opportunity for a high impact solution. A big data approach, targeting the spine surgery, could help to create higher quality outcomes through increased consistency and accuracy, ultimately leading to a higher quality of life for the patient. This information based approach to improving spine surgery is being created by the I-STAR lab and has been appropriately named SpineCloud. However, often the hardest part about a big data approach is obtaining the massive amount of consistent high quality data needed to produce informative decisions and in no field is this more difficult than medical imaging.

SpineCloud will focus on gathering patient specific information into a database where it may be easily compared to patient surgical outcomes. The curation of patient demographic data, image data, surgical procedures, and various pathologies will all serve as inputs to be correlated with surgical outcomes. To do this, SpineCloud takes a quantitative approach to improving patient outcomes. Thus image data used as input, requires analysis to extract relevant quantitative information. CT scans offer morphologic information about the patient, however, accurate spine segmentation in necessary to extract quantitative information from the scan. The use of various methods for segmentation are well documented but usually require a degree of manual input for the best results. The large number of scans needed for SpineCloud make any manual input for segmentation infeasible. Thus an efficient and accurate, automatic segmentation method is necessary for SpineCloud to extract useful image information for CT scans. The use of Max-Flow/Min-Cut as a solution to producing automatic segmentations of the spine from CT images will be explored. Carefully chosen, spine specific parameters, will allow for the method to produce the accurate segmentations necessary for use in SpineCloud.

Project Goal

Create an automatic segmentation method using Max-Flow/Min-Cut optimization methods, capable of providing accurate and efficient solutions.

Technical Approach

Design

Creation of an automatic spine segmentation algorithm will require a lot of parameter tuning. The Max-Flow/Min-Cut(MFMC) algorithm, upon which the automatic method will be based, is an optimization method for finding the cut through a graph that minimizes the sum of the weights cut while preventing flow between two terminal nodes[4]. This method is applied to segmentation by making a cut through a graph representative of voxels in the CT image. This results in a separation of the voxels indicating the CT segmentation. Given a graph, MFMC will always select the same optimal cut, so the nuance in tuning the segmentations come from how the graph is formed prior to the use of MFMC. Control over the final segmentation exist in pre-processing and post-processing steps as well as within various parameters specifying how the image is translated into a graph.

Production of the full 3D spine segmentation occurs through a slice by slice reconstruction. Each 2D voxel slice in the CT scan is segmented individually using MFMC optimization principles. Creation of the graph involves each voxel in the 2D slice becoming a node in the graph. Every voxel node is then connected to neighboring voxel nodes by edges. In addition to voxel nodes, two additional ‘terminal’ nodes are placed in the graph each representing one of the two labels in the segmentation, ‘spine’ or ‘background’. All voxel nodes are connected to both terminal nodes. The weights that populate the edge connections are obtained based on metrics gathered from the CT scan including Hounsfield units and gradient measures. The MFMC is applied to the graph so that weights connecting nodes are cut and voxel nodes are separated. After the cut, every voxel node is connected to a single terminal node specifying the segmentation of each 2D voxel. However there may inconsistencies in the segmentation requiring a post-processing step for refinement.

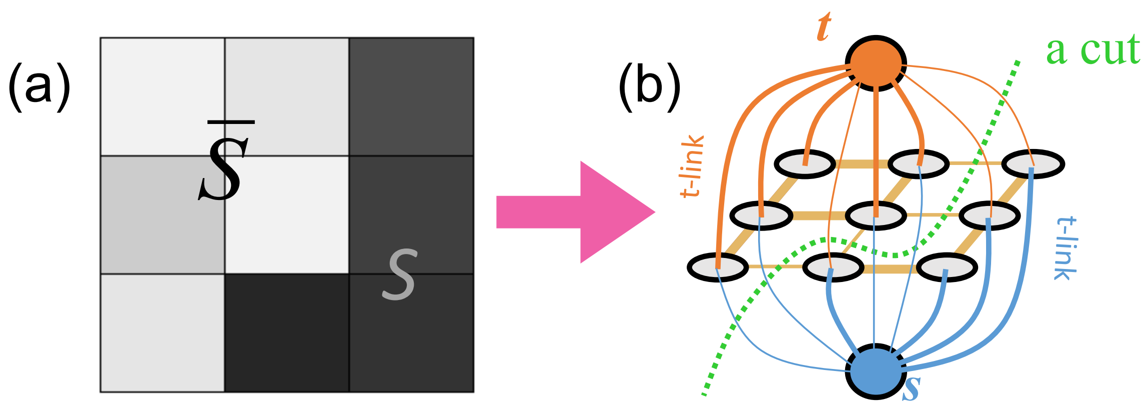


Figure 1: Generation of Graph from a 2D CT Image. (a) 2D image of CT scan with grayscale of Hounsfield units. (b) Graph representation of 2D image with a graph cut (green) preventing flow between terminal nodes(s, t).

A generalized implementation of the Max-Flow/Min-Cut segmentation algorithm was provided by the I-STAR lab. Additionally I-STAR provided a dataset of 20 manually segmented lumbar spine segments coming originally from The Cancer Imaging Archives(TCIA). This dataset will be named N20 and serve as a ground truth segmentation for validation. There is also a dataset of 200 CT spines(N200) from patients who have undergone spine surgery in the past 10 years. The N200 dataset will serve as the first members of SpineCloud so once the MFMC segmentation algorithm has been optimized for segmentation of the spine, the algorithm will be applied to the N200 dataset.

Evaluation

Evaluation is an essential aspect of optimizing the MFMC segmentation algorithm. The N20 manually segmented lumbar spine dataset will serve as the ground truth for which to compare the MFMC automatic segmentation method. The method parameters may be optimized over the parameter space to minimize the error between the output segmentation and the ground truth. Measurement of error from the ground truth segmentation will be based on RMSE point to surface distance as well as using Dice coefficient.

Deliverables

Minimum:
- Access accuracy of the N20 manually segmented validation dataset
- Implementation of the Max-Flow/Min-Cut segmentation algorithm for the spine

Expected:
- Analysis of parameter sensitivity
- Evaluation of segmentation accuracy
- Generation of a large N200 dataset for SpineCloud

Maximum:

- Method for patient-specific parameter selection
- Method to accomodate spine anomalies

Dependencies

Physical:

- Access to the I-STAR lab
  - *If unable, ability to work remotely using team-viewer*
- Workstation computer with MATLAB

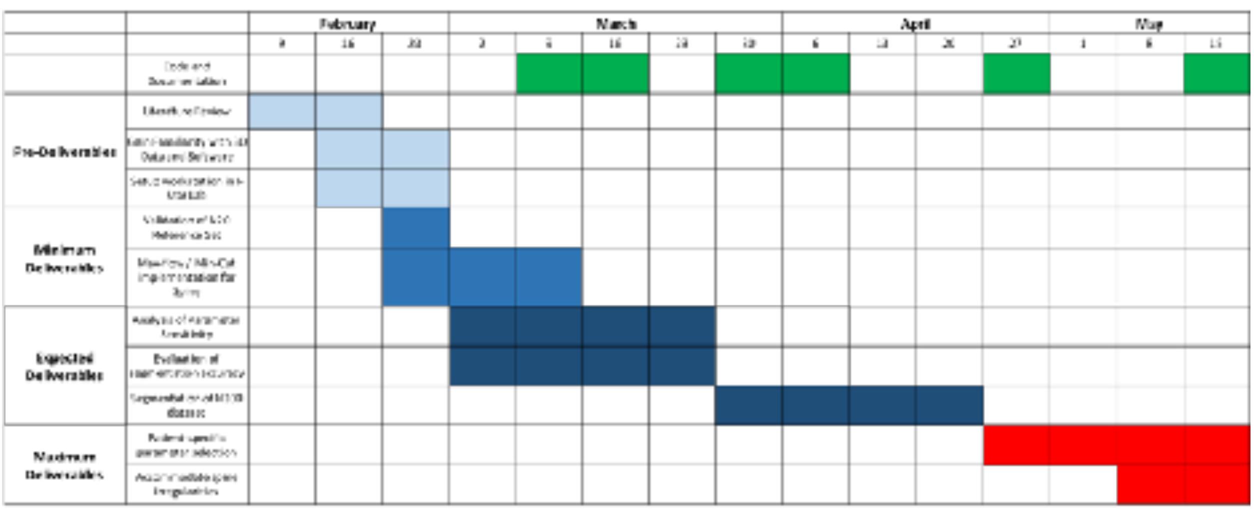
Implementation:

- The N200 and N20 CT datasets for segmentation
- Existing basic implementation of Max-Flow/Min-Cut segmentation algorithm

Scheduling:

- Weekly meeting with mentors
  - *If unable, host remote meetings using Skype*

Timeline



Acknowledgments

This project is supported by the I-STAR lab and Carnegie Center for Surgical Innovation in collaboration with mentors Dr. Jeff Siewerdsen and Dr. Tharindu De Silva. We are very appreciative of their support for this work.

References

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