Statistical Atlas of the Knee

600.446 Computer Integrated Surgery II

Project Proposal

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Summary and Goals

The main goal of this project is to improve and automate the statistical atlas building pipeline developed by Gouthami Chintalapani at the Johns Hopkins University. The current pipeline has several limitations. It requires manual segmentation to create the template mesh and the pipeline is not automated. The registration algorithm used in the pipeline, Mjolnir, is not open source, and thus offers limited opportunity for improving the registration process. Our goals are to make the segmentation semi- or fully- automated, to develop a 3D-3D model-based registration algorithm, and to automate the pipeline. Once these improvements are achieved, we will build a statistical atlas of the knee using CT images and use this statistical atlas for post-operative evaluations of anterior cruciate ligament (ACL) surgeries.

Motivation and Significance

Currently, statistical atlas building methods depend largely on manual segmentation. Manual segmentation requires a lot of time and anatomical knowledge. By minimizing the human factor through the implementation of a semi- or fully-automated segmentation algorithm, the segmentation process will be more standardized, less prone to human error and the required time will be significantly shortened. Automating the current statistical atlas building pipeline will make the atlas building process more accessible to those with little or no programming experience.

Statistical atlases have a wide range of applications, including monitoring disease progression, accounting for anatomical variation in large populations and surgical planning. Obtaining a statistical atlas of the knee will facilitate post-operative evaluations. In this project, the specific application of the knee atlas will be to estimate the bone tunnel locations after ACL surgeries.

Background

A statistical atlas is a model of an organ that captures the inherent anatomical variability in the given training population. The anatomical properties used to build these atlases include organ shape and appearance, which are extracted from scans obtained from imaging modalities such as CT or MRI. The organ shape is defined as the boundary of the organ, and the appearance is the texture or intensity values. Statistical models that only represent the shape variations are called statistical shape models (SSM) and the atlases that represent both shape and intensity are called appearance models. For this project, will focus on building a statistical shape model of the knee. [1]

There are three steps to statistical atlas construction:

1) Model Representation / Parameterization: The training images are parameterized according to a representation of anatomical properties. Landmark based and parametric models are some examples to parameterization methods.

2) Model Correspondence / Alignment: A reference image is selected from the training data set and the rest of the images are registered onto it. Different methods used for this step are iterative closest point algorithm, Procrustes algorithm, thin plate spline and mesh-based registration.

3) Statistical Analysis: This step is used to create a statistical model which represents the anatomical variability in the training population. The methods include principal component analysis (PCA), independent component analysis (ICA), kernel PCA and principal geodesic analysis (PGA).

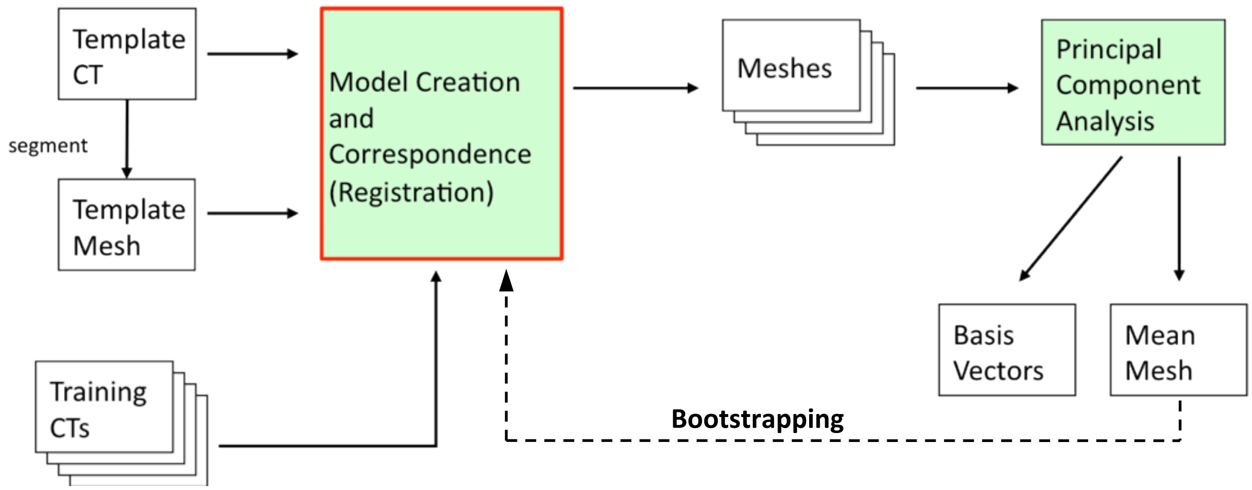

Figure. Basic atlas building process [1]

Technical Approach

Before working on automating the atlas-building pipeline and the segmentation/registration process, it is necessary to understand each component of the current implementation and how they interact with each other. The first step will be to gather all the programs and scripts required for the pipeline, and to run the whole process using sample data. Having a statistical atlas of the knee constitutes the first milestone of the project.

The second step will be to replace Analyze. ITK-SNAP, which is free software, can be substituted for Analyze to perform the preprocessing and the segmentation of the training images. Analyze is also used for other image processing tasks in the current pipeline, and MATLAB scripts can be used instead for those functions.

The third step is automating the segmentation of the knee so that it requires minimal user interaction, if not none. Obtaining a semi-automated segmentation method constitutes the second milestone of the project. We will evaluate the performance of the semi-automated segmentation method against that of the manual method by comparing the segmentation accuracies and the amount of time it takes per dataset to perform segmentation.

The fourth step is to write a shell script that will automatically guide the user through the various steps of statistical atlas building. A fully automated pipeline is the third milestone.

We will then build the atlas of the knee using the improved pipeline and use the obtained atlas to estimate the bone tunnel locations using the CT scans of patients who had ACL surgery.

An extension of the project is to develop a model-based 3D-3D registration algorithm that can be used as an alternative to Mjolnir, the registration algorithm currently used in the pipeline. Depending on the quality of the statistical atlases produced by the pipeline leading up to this step, this algorithm might be used only for the bootstrapping portion of the atlas building.

Deliverables

- Minimum
    - Replace Analyze in the pipeline (used for preprocessing of images) with ITK-SNAP
    - Replace Analyze with MATLAB to perform other image processing tasks
    - Automate the pipeline developed by Gouthami Chintalapani
    - Build a statistical atlas of the bone structures of the knee
- Expected
    - Develop a semi-automated method for segmentation of the knee
    - Prepare detailed documentation of the improved pipeline
    - Estimate bone tunnel locations using post-operative CT scans of ACL surgery patients
- Maximum
    - Develop a fully automated method for segmentation of the knee
    - Develop a 3D-3D model-based registration algorithm

Dependencies & Plan for resolving

- Knee or leg CT image datasets
    - Post-operative CT scans (Hong Kong dataset provided by Ben)
    - Whole leg CT (Hopkins dataset, pending IRB approval)
- Computer for software development
    - Lab desktop: femur.compscidhcp.jhu.edu
    - Personal computers
- Software required for the atlas building pipeline
    - MATLAB
        - Licensed software obtained from IT @ JHU
    - Analyze
    - Insight Toolkit (ITK), ITK-SNAP
    - Gouthami's scripts
- Linux account on the Stomach server

- Understanding of Gouthami's atlas building pipeline
    - Written reference documentation
    - Gouthami's PhD dissertation obtained from CS department
- Poster printing budget
    - For a 2x3 feet matte print at Digital Media Center: $32.55 (or $42.00 if paid using budget code)
- People
    - Ben and Dr. Taylor for continued help and guidance

Management Plan & Assigned responsibilities

- Regular weekly meetings with Ben
- Attend SARR meeting
- If IRB approval cannot be obtained for the Hopkins dataset, focus efforts on the Hong Kong dataset
- We will collaborate on each task and share responsibility equally.
- There are four main milestones in this project that we will use to track progress:

    1) Build a statistical atlas of the knee using the current pipeline (by end of February)
    2) Develop a semi-automated segmentation algorithm (by Spring break)
    3) Automate the pipeline
    4) Estimate the position of the ACL tunnel from post-operative CT scans

We will then assess our progress and revise our goals for the remainder of the semester depending on the limitations of the atlas obtained using the pipeline. Several possible points of focus might be addressing some of the limitations of the atlas obtained through the pipeline (ex. using another 3D-3D registration algorithm), implementing a bootstrapping mechanism in the pipeline, or further automating the segmentation.

Key dates

Task \ Week	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
Project Proposal Presentation							Spring Break							Project presentation
Background Reading														
Understand current pipeline														
Run pipeline, obtain preliminary knee atlas														
Automate segmentation														
Automate the pipeline														
Build knee atlas from CT images														
Estimate bone tunnel locations														
Documentation														
Prepare poster and submit for printing														

Reading List

[1] M.A. Baldwin, J.E. Langenderfer, P.J. Rullkoetter, and P.J. Laz. Development of subject-specific and statistical shape models of the knee using an efficient segmentation and mesh-morphing approach. Computer Methods and Programs in Biomedicine 97 (2010) 232–240.

[2] G. Chintalapani. *Statistical Atlases of Bone Anatomy and Their Applications*. Diss. Johns Hopkins University, 2010.

[3] G. Chintalapani, L.M. Ellingsen, O. Sadowsky, J.L. Prince, and R.H. Taylor. Statistical Atlases of Bone Anatomy: Construction, Iterative Improvement and Validation. MICCAI, 2007. Part I, LNCS 4791, pp. 499-506. N. Ayache, S. Ourselin, A. Maeder (editors).

[4] L.M. Ellingsen, G. Chintalapani, R.H. Taylor, and J.L. Prince. Robust deformable image registration using prior shape information for atlas to patient registration. Computerized Medical Imaging and Graphics 34 (2010) 79–90.

[5] T. Heimann, H. Meinzer. Statistical shape models for 3D medical image segmentation: A review. Medical Image Analysis 13 (2009) 543-563.

[6] H. Seim, D. Kainmueller, H. Lamecker, M. Bindernagel, J. Malinowski, and S. Zachow. Model-based Auto-Segmentation of Knee Bones and Cartilage in MRI Data. http://www.diagnijmegen.nl/~bram/grandchallenge2010/215.pdf.