Statistical Atlas of the Human Knee

Computer Integrated Surgery II
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Introduction

- A statistical atlas is a model of an organ that captures the inherent anatomical variability in a given training population. Atlases can be used to monitor disease progression and to plan for surgical operations.
- Building an atlas is a multi-step process that includes model representation, registration, and statistical analysis. The pipeline depends largely on manual work by the user to process the raw data and to execute the functions involved.
- It is important to build an automated pipeline for atlas construction in order to facilitate this procedure.
- Anterior cruciate ligament (ACL) surgery involves drilling tunnels through femur and tibia. Post-operative evaluation involves assessing the placement accuracy of these tunnels, which can be done using a statistical atlas of the knee.

Goals

- The main goal of this project is to automate the statistical atlas building pipeline developed by Dr. Gouthami Chintalapani at the Johns Hopkins University.
- This pipeline is then used to build statistical atlases of the human femur and tibia as a preliminary step for ACL surgery evaluations.

Technical Approach

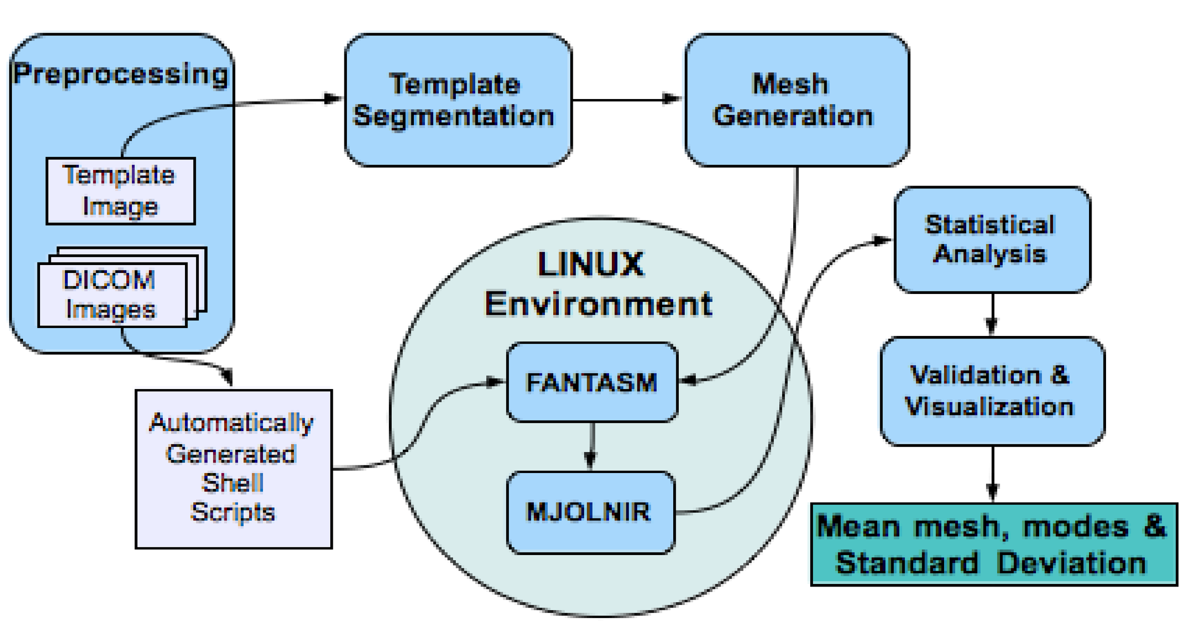

Figure 1. Automated atlas construction pipeline.

- Using this pipeline, right femur, left femur and right tibia atlases were built with 8, 8, and 5 data sets, respectively.
- For validation purposes, each subject used for building the femur and tibia atlases was estimated using

$$S^{est} = \bar{M} + \sum_{k=1}^{n} \lambda_k^{est} D_k$$

where $D = [D_1 \ \ D_2 \ \cdots \ D_N]$ contains the *N* variational modes, $\bar{M}$ is the mean image, and $\lambda^{est} = D^T(S^{true} - \bar{M})$.

- To evaluate the similarity of the left and right femur atlases, the mirror image of the right femur was obtained by flipping the mesh about a plane perpendicular to the central axis of the femur head, and the resulting mesh was rigidly registered onto the left femur mesh.
- Error between two meshes was quantified using the maximum vertex-to-vertex Euclidean distance.

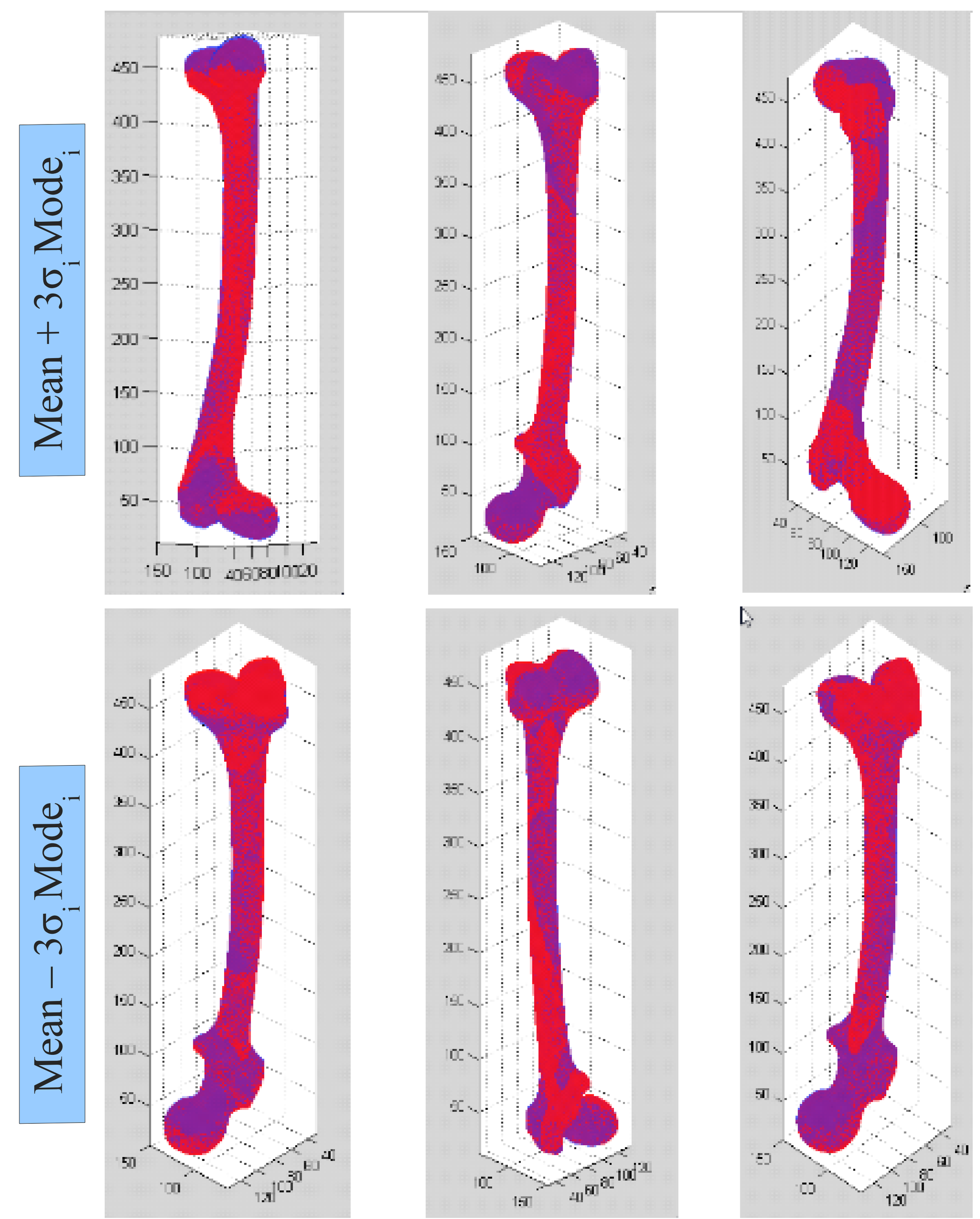

Figure 2. Superimpositions of the mean right femur mesh (blue) and its first 3 mode images (red). Each column corresponds to a different mode.

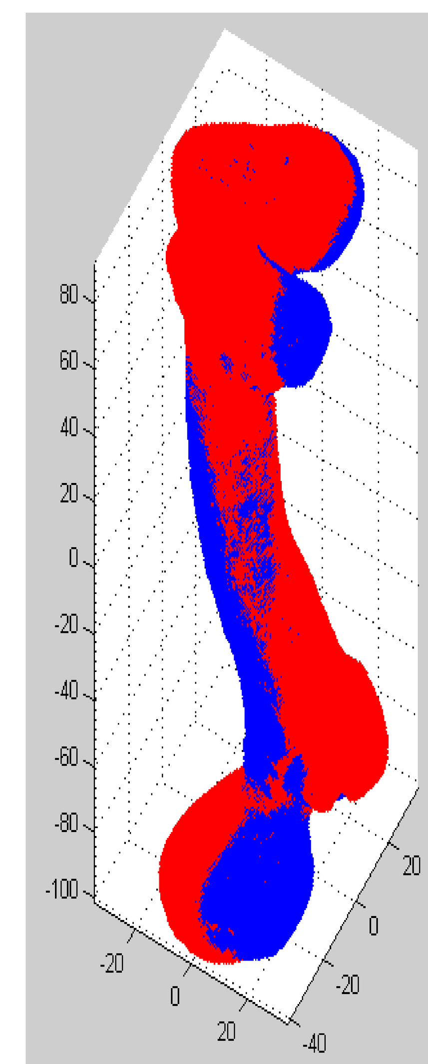

Figure 3. Superimposed meshes of the left femur (red) and the mirror image of the right femur (blue).

Results and Discussion

- The first mode captures length variations (along the z-axis) and the second mode captures girth variations.

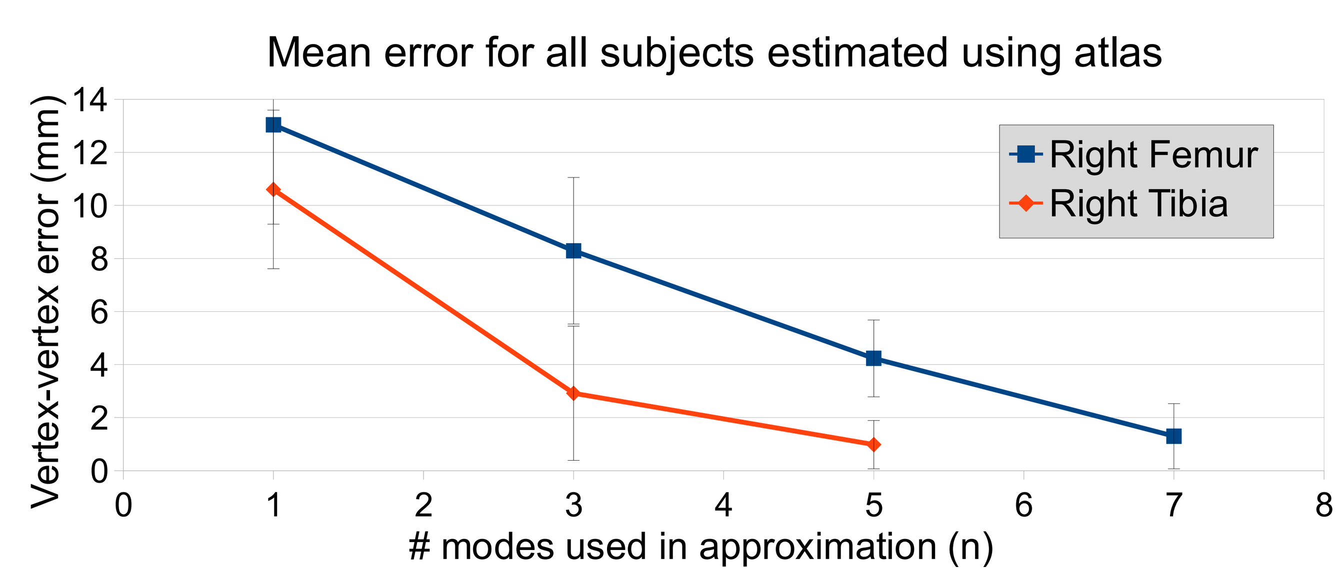

Figure 4. Mean vertex-vertex error across all subjects as a function of the number of modes used in estimating the ground truth image.

- The maximum vertex-vertex error for the left and flipped right femur meshes was 8 mm, indicating that separate atlases might not be necessary.

Future Work

- Improve the current atlas with more subject images and by using bootstrapping
- Perform further evaluation of the similarity of left and right femurs
- Estimate ACL surgery bone tunnel locations by registering post-operative X-ray scans onto the knee atlas

Lessons Learned

- Better understanding of the statistical atlas building process
- Learned about several segmentation methods during weekly paper discussion sessions with Xin Kang

Credits

- Authors have contributed equally to the implementation and execution of the project.

Acknowledgements

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