

Prior Models on Coronary Arteries to Support Coronary Artery Detection

CS 446 Computer Integrated Surgery II

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Project Summary

Detection of coronary arteries from medical image data is a difficult task due to their high anatomical variability. The goal of this project is to investigate and build coronary prior models from hand annotated coronary centerlines to support their detection as well as to allow for further statistical analysis. The technical methods will be implemented into a research prototype for deliverables and will be assessed by different applications including coronary tree matching and coronary average tree computation.

Motivation and Significance

According to American Heart Association, coronary artery disease (CAD) is a leading cause of death among cardiovascular diseases in the United States [1]. This fact puts emphasize on the necessity of its diagnosis, treatment and monitoring for which computed tomography angiography (CTA) is considered as the primary imaging modality because of its high image resolution. However, due to thin and longitudinal anatomy of coronary arteries, CTA data itself is difficult and time-consuming to be interpreted by the operators without additional post-processing. Therefore, detection of coronaries in CTA is needed for advanced visualization and quantification purposes.

Irregular topology of coronary anatomy, pathologies and imaging artifacts make the detection process challenging. A coronary prior model that is capable of capturing topological and branch variations in the population can improve this detection process by guiding commonly used local tracking methods or by supporting the prediction of global classification methods. In addition, such prior models can further provide means to perform statistical analysis on the correlation between coronary anatomy and diseases.

Background

Statistical shape models are used to represent the variations in the shape over a training set. They are built commonly by first aligning the shapes in the training set using a

parametrized or landmark based shape model and then by modeling the statistical variations in this shape model using statistical methods such as well-known principal component analysis (PCA) for euclidean manifolds, principal geodesic analysis (PGA) for non-euclidean manifolds and independent component analysis (ICA) which is a powerful latent variable model. However, these methods are well-suited for shapes sharing a common topology which is not the case for tree-like shapes.

One most important element of statistical shape analysis is the shape mean because it can best explain the entire training set and allows to compute the variability over it. However, there is not any ready definition of mean in tree-like shapes because of their topological variability. But there are techniques which make it possible to compute or approximate the mean of tree-like shapes with a well-defined unique geodesic metric.

The best known method for computing the geodesic metric between tree-like shapes is called tree edit distance (TED) [2] which defines the the geodesic distance as the minimum cost for deforming one tree to the second by simple tree operations. However, this geodesic does not satisfy the local uniqueness property which is required when computing averages.

In order to find a geodesic metric with local uniqueness for tree-like shapes, the quotient euclidean distance (QED) was proposed [3, 4] that allows local tree deformations in subspaces which are concatenated by euclidean lines. However, its expanded search space makes this method computationally expensive.

Technical Approach

In this project, hand annotated coronary centerlines in 50 CTA data will be used to build the statistical shape model. A 3D spherical model will be fitted to heart surface in order to establish a canonical coordinate system (2D manifold) with axes defined by three key anatomical landmarks at aortic valve center, mitral valve center and left ventricle endocardium apex. The correspondence between coronary trees over the training set will be obtained by projecting them onto this canonical surface.

In order to first investigate the variability of the coronary trees on the canonical surface, statistics on coronary territories will be done by computing the probabilistic distribution of coronaries over the canonical surface. This distribution will be based on vessel density maps computed using vessel distance maps [5].

Second, TED algorithm will be implemented using a dynamic programming approach with root correspondence and ordered tree assumption [6]. The geodesic metric of this algorithm will be then applied to coronary tree matching. Following the TED implementation, an algorithm for QED will be designed and implemented similar to [4]. Topological constraints such as root correspondence and ordered tree will be enforced into this design for computational efficiency. Finally, this metric will be used to compute average coronary tree via midpoint approximation [7] and to assign membership scores to unseen coronary trees.

Deliverables

Build a research prototype (Siemens proprietary) that can

Minimum

- align coronary trees in a population
- compute mean coronary density map

Expected

- compute TED-based geodesic distance between two coronary trees
- compute QED-based geodesic distance between two coronary trees

Maximum

- match two coronary trees using TED
- compute average coronary tree in a population using QED
- assign a membership score to an unseen coronary tree using QED

Milestones

1. Align coronary centerlines into the canonical coordinate system (MINIMUM)

- prototype setup: data loading/visualization/interactions
- fit spherical model to heart surface and define axes by key landmarks
- project coronary centerlines onto canonical surface for finding correspondence

Validation: overlay coronary trees on the canonical surface

2. Statistics on territories (MINIMUM)

- compute coronary vessel distance maps
- compute mean density and probabilistic distribution over the canonical surface

Validation: Overlay both coronary trees and density map on the canonical surface.

3. Geodesic distance with TED algorithm (EXPECTED)

- background reading on TED algorithm
- construct TED theoretical trees
- solve TED problem using a dynamic programming approach
- enforce topological constraints to TED

Validation: test it on example trees with ground truth distance between them.

4. Geodesic distance with QED algorithm (EXPECTED)

- reading on QED algorithm
- construct QED theoretical trees
- design and implement a QED algorithm

- enforce topological constraints to QED

Validation: test it on example trees with ground truth distance between them. Compare results to TED.

5. Applications (MAXIMUM)

- TED: coronary tree matching
- QED: compute average tree via midpoint approximation
- QED: compute distance variance of training coronary trees to average tree
- QED: compute membership score to unseen coronary trees

Validation: test on example trees with known matching. visual comparison of average tree to entire training set. Compute membership score of training examples.

Please see Figure 1 for the project timeline.

Dependencies

Data

- CTA datasets with coronary centerline annotations, heart surface model and described key anatomical landmarks → **Resolved**. Will be provided by Siemens
- Example tree pairs with ground truth matching and distance → **Resolved**. Possible to create a few examples by hand

Software

- Programming framework to build the prototype. Libraries for data loading/visualization/interactions and display of results. → **Resolved**. Will use Siemens' rapid prototyping platform.
- TED solver → **Resolved**. Dynamic programming pseudocodes and implementations available online [8].

Management Plan

- 15 hours work per week
- Weekly meetings with mentor located in Princeton, phone or in-person → **Scheduled**.

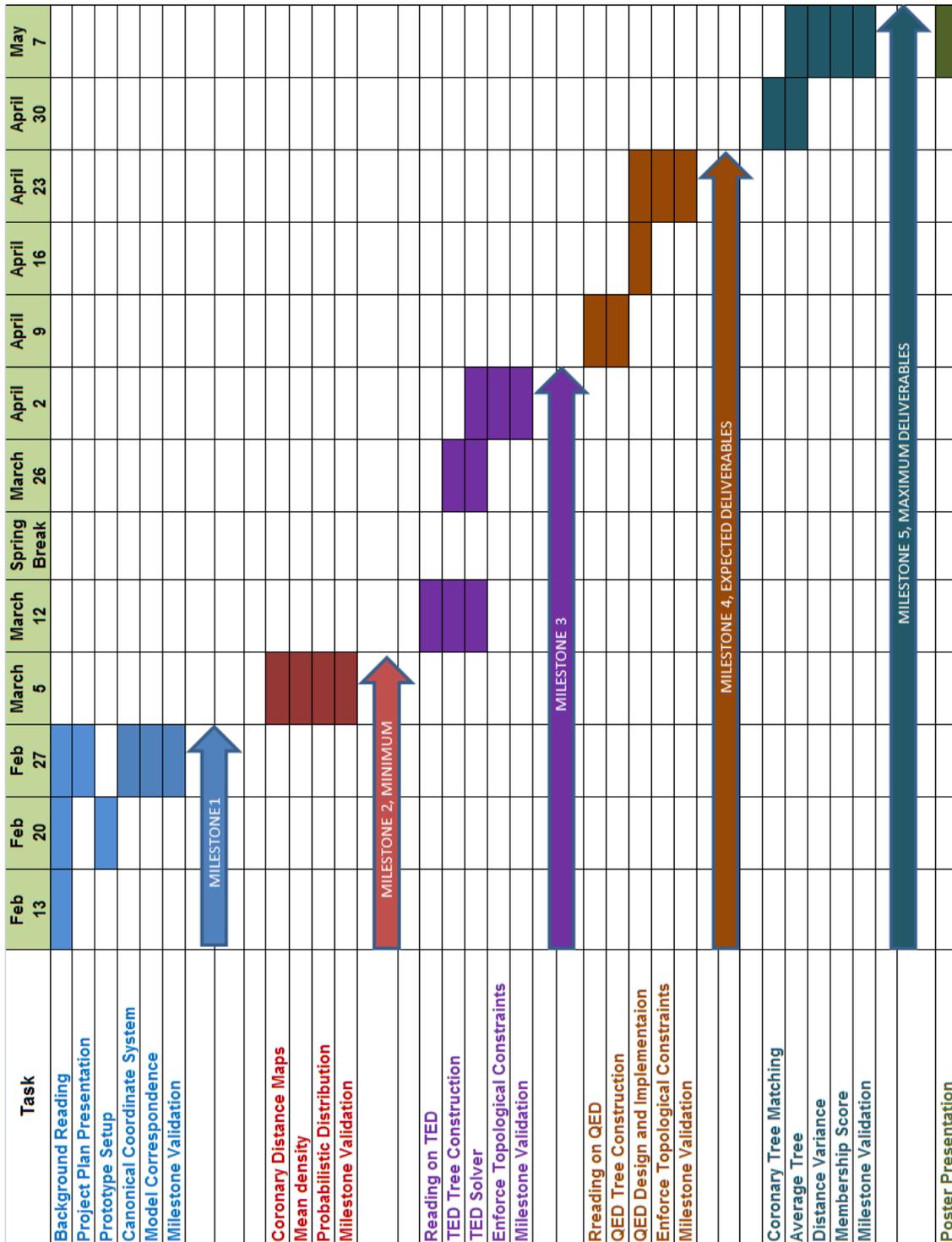


Figure 1: Project Timeline

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