JOHNS HOPKINS UNIVERSITY SIEMENS

Prior Models on Coronary Arteries to Support Coronary Artery Detection

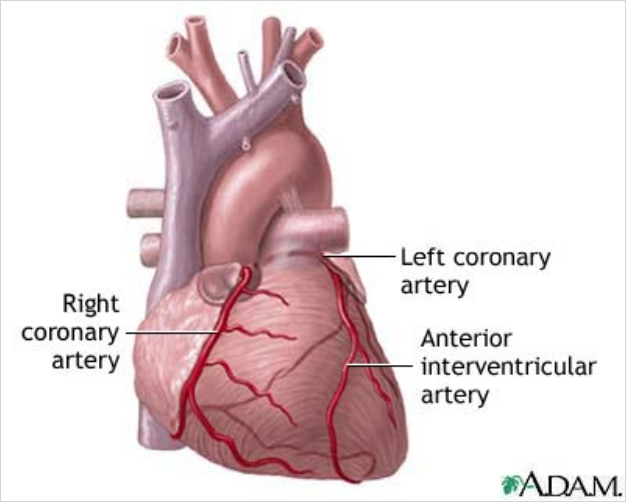
Team Members: Mehmet Akif Gulsun
Mentor: Gareth Funka-Lea, Princeton

Project Summary

Problem:

Detection of coronary arteries in CTA is a difficult task due to

- their high anatomical variability
- pathologies and imaging artifacts



nlm.nih.gov

Project Goal:

Build prior coronary models to

- improve detection
- allow for statistical analysis

Motivation: Coronary Arteries

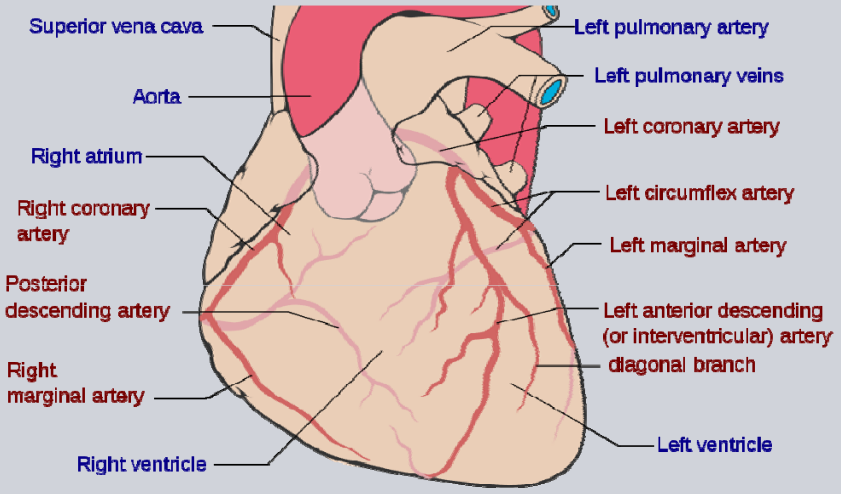
JOHNS HOPKINS UNIVERSITY SIEMENS

Function and Anatomy

- Oxygen and nutrient supply of heart

- Left and right coronary trees

- Left-(%10), Right-(70%) or Co-Dominant (%20)



wikipedia.com

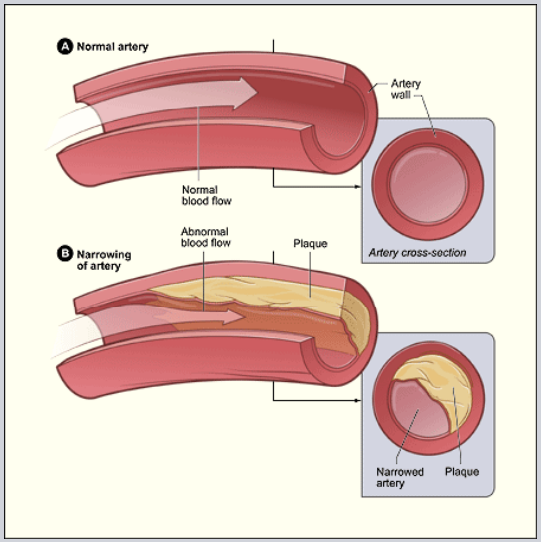
Coronary Artery Disease

- Soft and hard plaque formation (*Atherosclerosis)*

- Common Symptom: Chest pain

- Cause: Heart attack

- 53% of cardiovascular diseases. Leading cause of death in the United States!

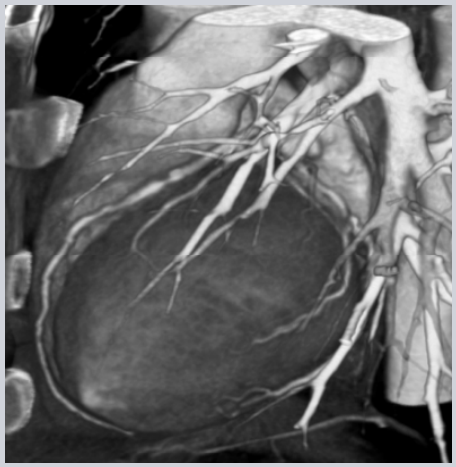


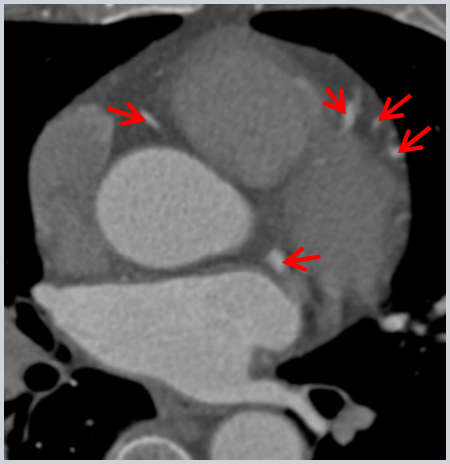
nhlbi.nih.gov

Motivation: Diagnosis, Treatment

JOHNS HOPKINS UNIVERSITY SIEMENS

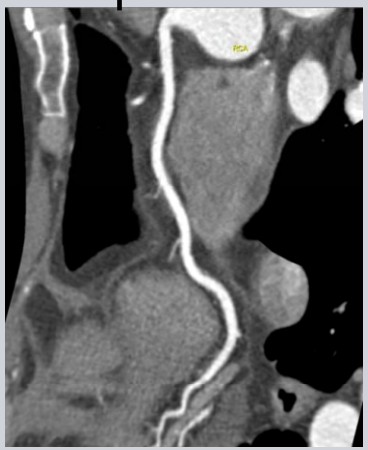
- CTA as primary imaging modality
- Difficult and time-consuming to interpret raw data



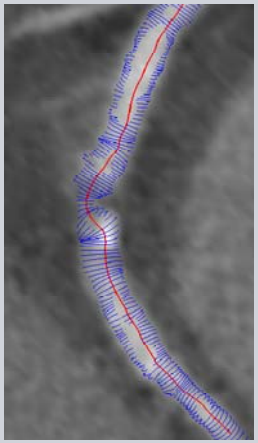


Detected Coronary Centerlines

Diagnosis and Follow-up



Treatment Planning

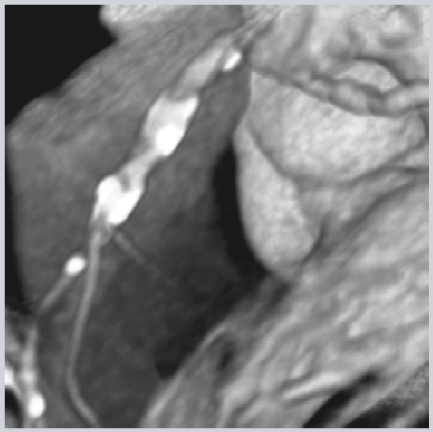


Intra-operative Guidance

Overlay on X-ray for guidance

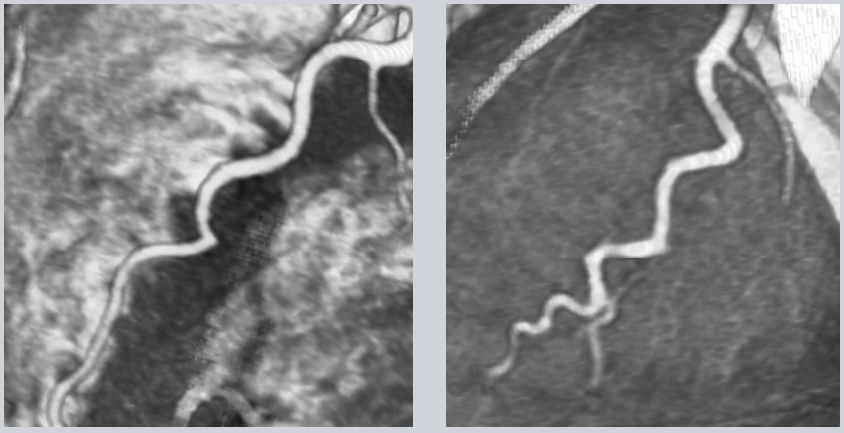
Motivation: Challenges For Detection

Irregularity of anatomy

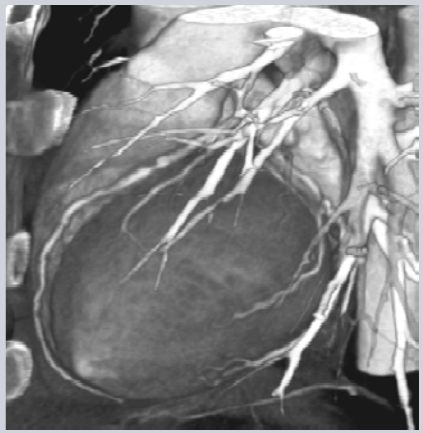


Pathologies

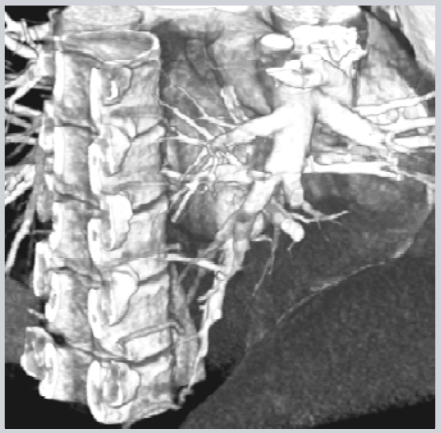
Varying Size



Curvatures



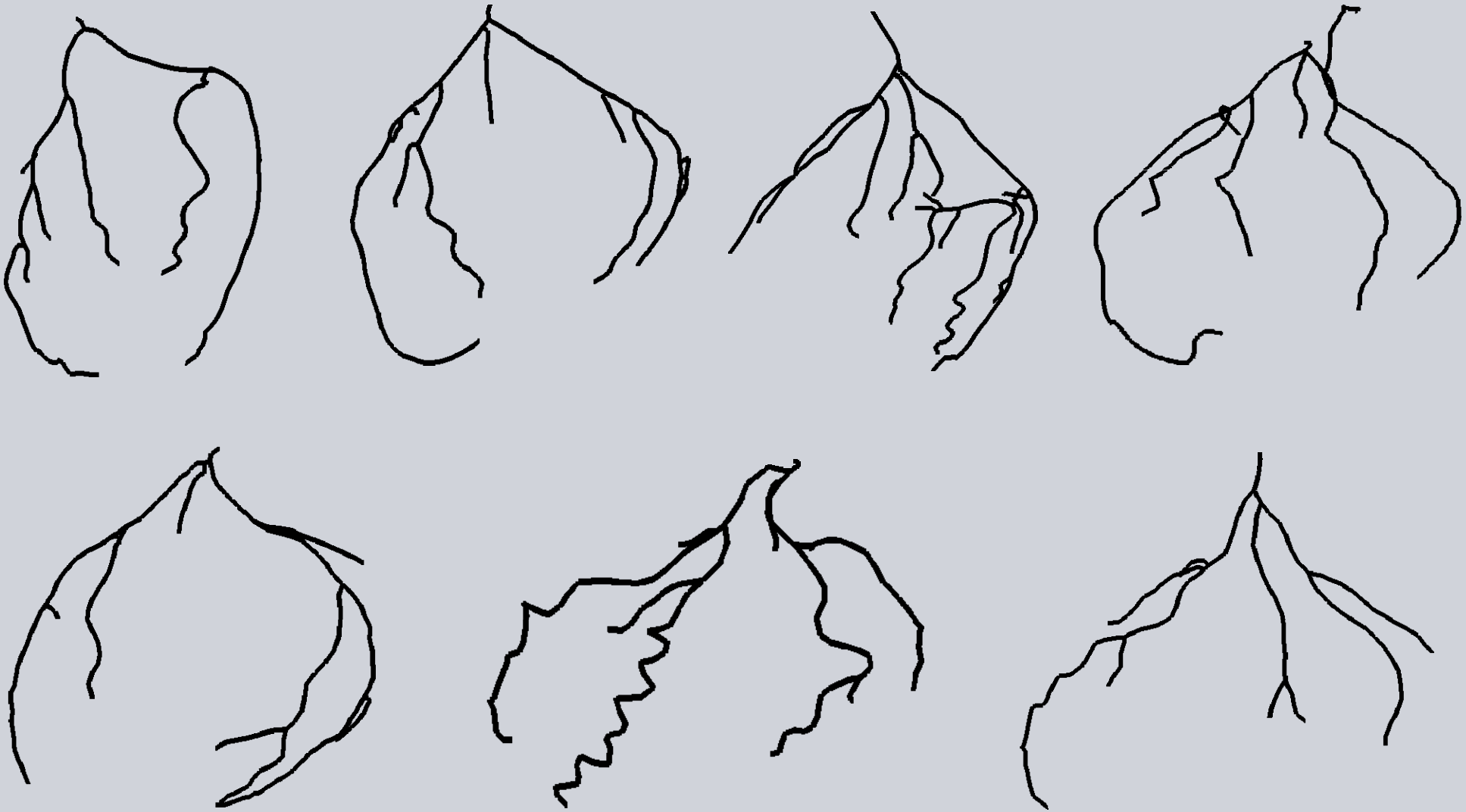
Complex Anatomy



Bones

Motivation: Coronary Samples

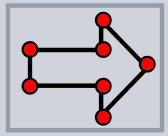
JOHNS HOPKINS UNIVERSITY SIEMENS



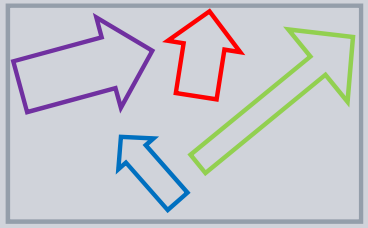
Background: Statistical Shape Models

JOHNS HOPKINS UNIVERSITY SIEMENS

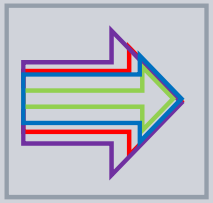
How to Build Statistical shape models?



Shape Model (Parameterized/ Landmarks)



Training Set (Represented with shape model)

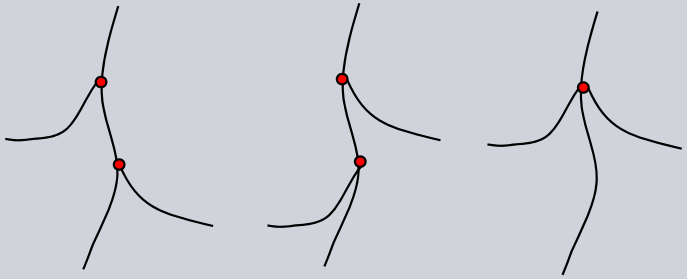


Alignment (Registration, Procrustes,…)

Shape Mean and Variability

Statistical shape analysis (PCA, PGA, ICA,…)

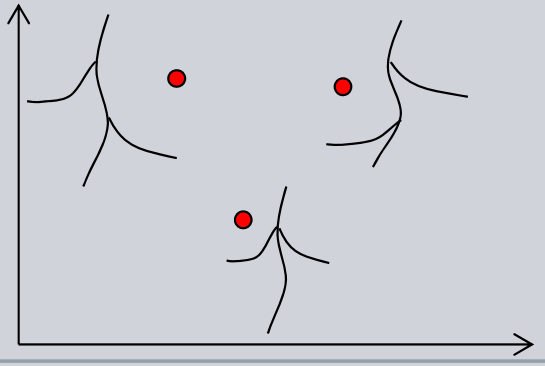
What about shape models for tree-like shapes?



varying topology

-Problem with creating a shape model

-Work in tree-like shape space



Representation:

Topology + Branch Geometry

Background: Statistical Shape Models

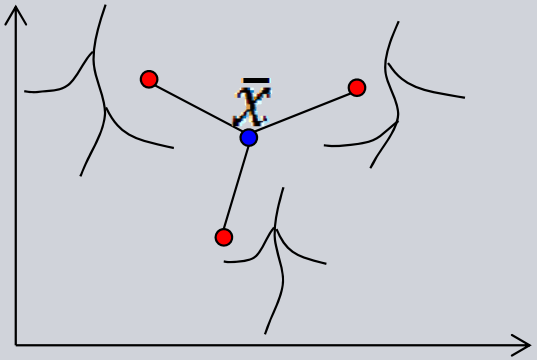
Mean lies at the heart of statistical shape analysis

- best explains the entire training set
- allows for computing variability

How to compute mean of a set of tree-like shapes?

- no mathematical definition for trees
- but there is the classical definition of mean

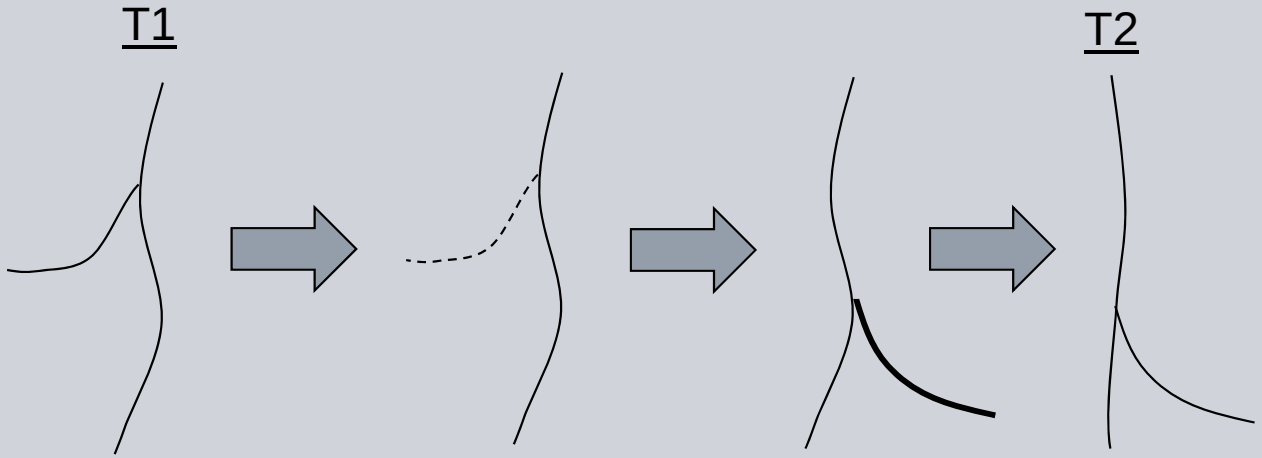
$$\bar{x} = \min_{x' \in T} \sum_{x \in T} d(x, x')^2$$



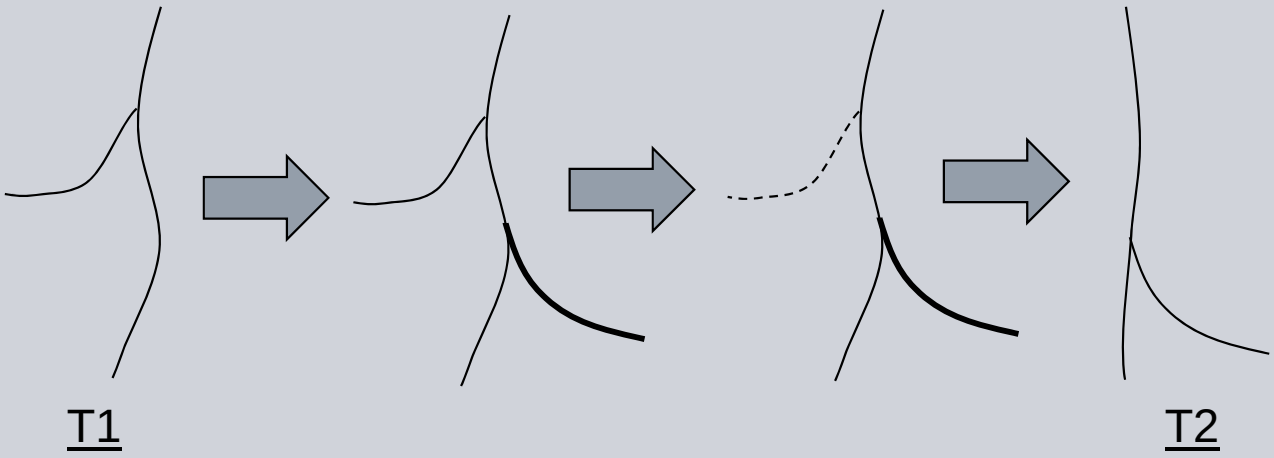
- we need unique geodesic between two trees

Background: Tree Edit Distance (TED)

- Match one tree to another by adding, removing or deforming branches with minimal cost



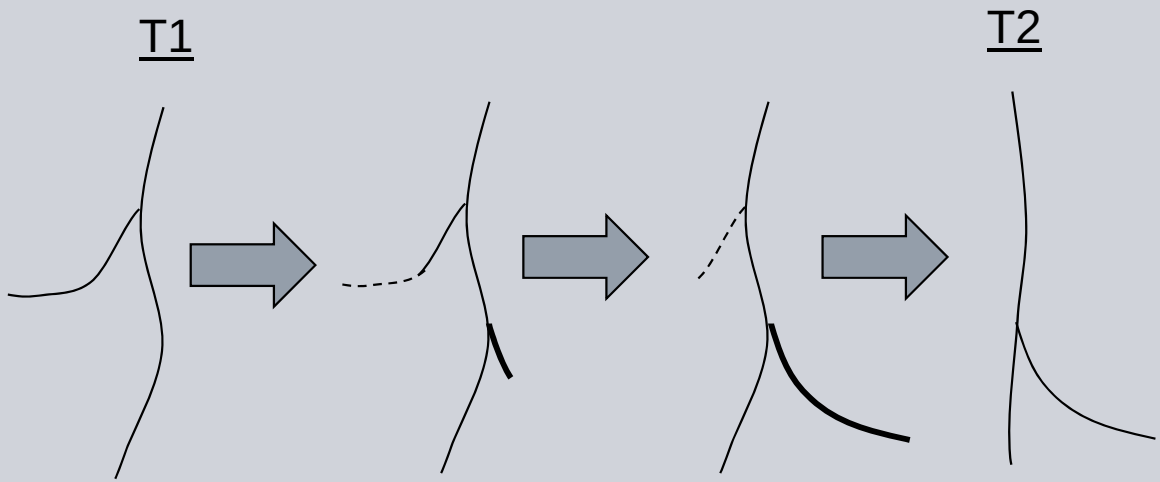
- Can be efficiently solved via dynamic programming, e.g., $O(|T|^2)$



- Geodesic path between T1 and T2 is **not** unique!

Background: Quotient Edit Distance

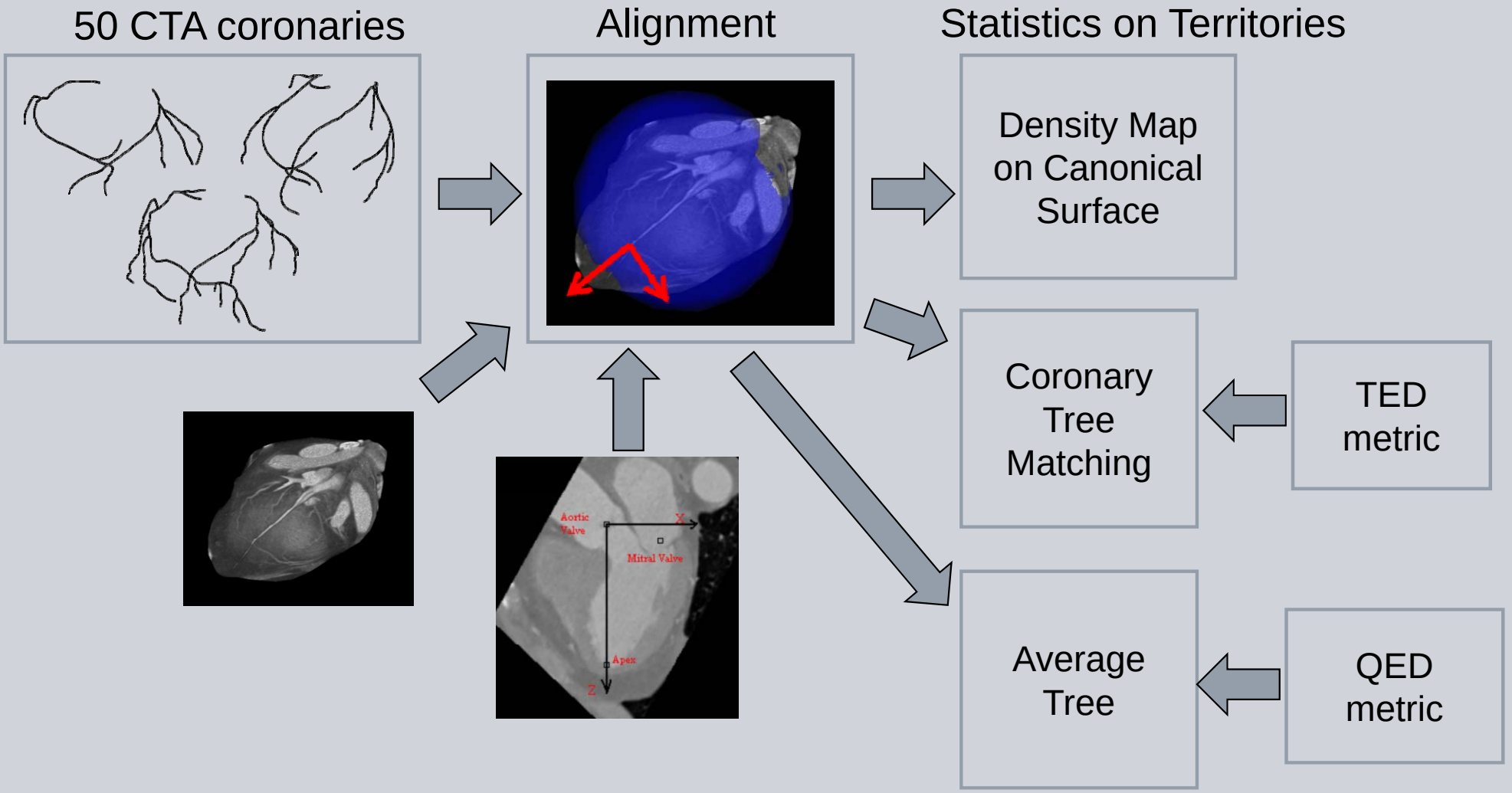
- allow for local branch deformations in addition to topology changes



- Geodesic path between T1 and T2 is unique with L_2 norm metric (Mathematically proven by Feragen, et. al.)

- Computationally expensive

Technical Approach



Technical Approach

JOHNS HOPKINS UNIVERSITY SIEMENS

TED metric

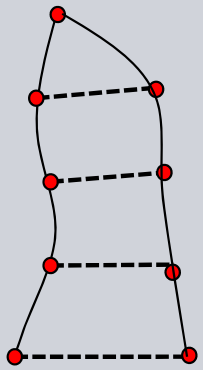
- Dynamic programming
- Rooted and ordered tree

QED metric

- An algorithm similar to Feragen's work
- Rooted and ordered tree

Branch Similarity

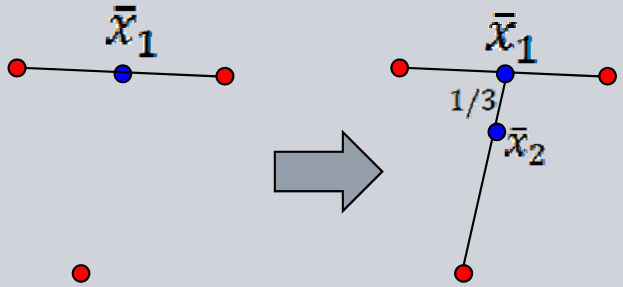
- Euclidian distance between uniformly sampled points



Average Tree Computation

- Weighted midpoint approximation

$$\bar{x} = \min_{x' \in T} \sum_{x \in T} d(x, x')^2$$



Deliverables

Build a research prototype 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

	Milestone	Planned Date
1	Alignment of coronary centerlines (MINIMUM)	March 4
2	Statistics on territories (MINIMUM)	March 11
3	Geodesic distance with TED algorithm (EXPECTED)	April 8
4	Geodesic distance with QED algorithm (EXPECTED)	April 29
5	Applications (MAXIMUM)	May 8

	Milestone Validations
1	Visualize coronary trees on the canonical surface
2	Visualize both coronary trees and density map on the canonical surface
3	Test on example trees with ground truth distance
4	Test on example trees with ground truth distance. Compare to TED.
5	Test on trees with known matching. Visually compare average tree to entire training set. Compute membership scores for training set

Dependencies

Data

- CTA datasets with coronary centerline annotations, heart pericardium models and key anatomical landmarks. *Resolved: Provided by Siemens*
- Example tree pairs with ground truth matching and distance. *Resolved: Possible to create a few examples by hand. Tools provided by Siemens*

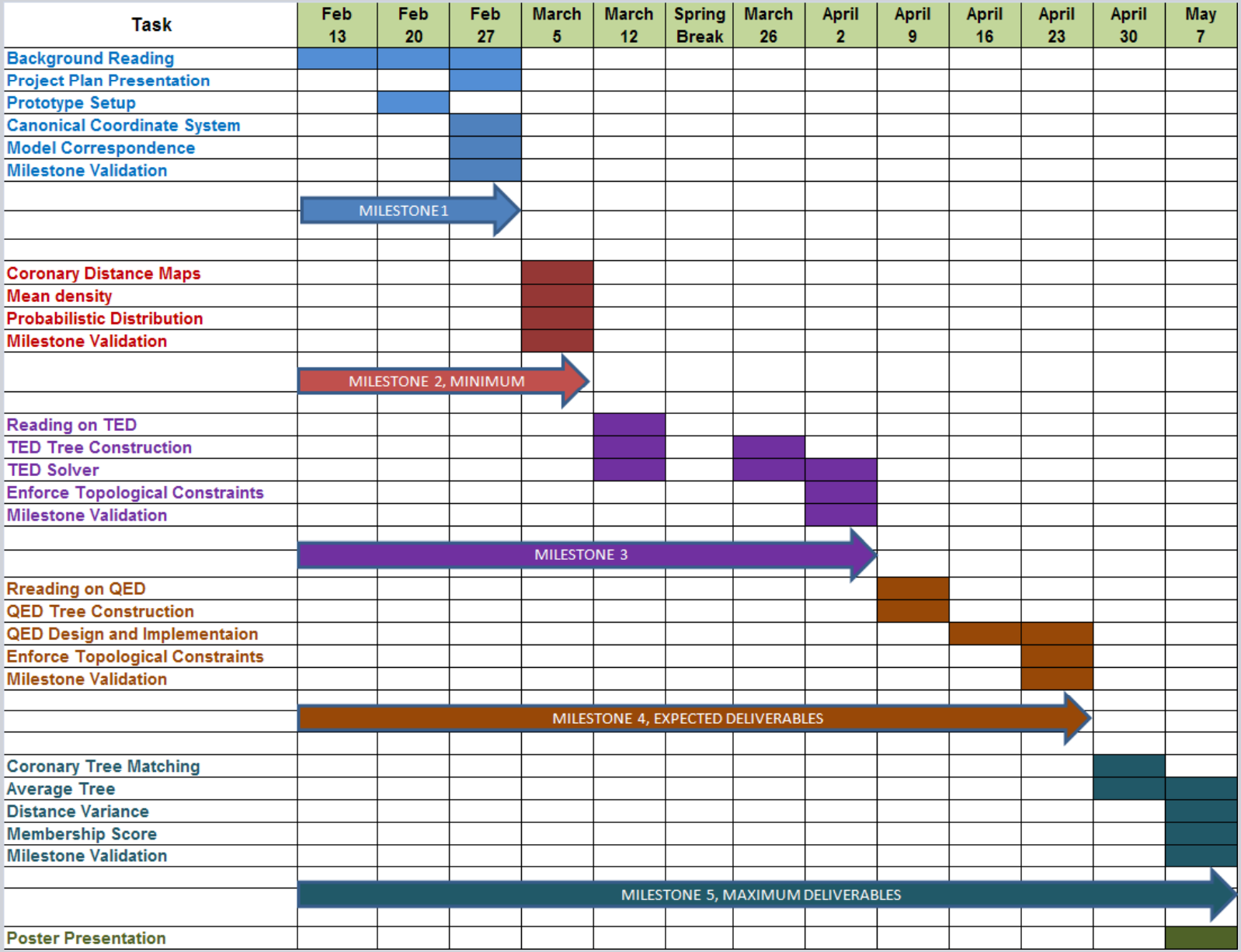
Software

- Programming framework to build the prototype. Libraries for data loading / visualization / interactions and display of results. *Resolved: Will use Siemens' rapid prototyping platform (XIP). C++ as programming language.*
- TED solver. *Resolved: Dynamic programming pseudo codes available online*

Management Plan

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

Project Timeline



Gulsun, 2012

JOHNS HOPKINS UNIVERSITY SIEMENS

References

[1] Donald Lloyd-Jones, Robert J Adams, Todd M Brown, Mercedes Carnethon, Shifan Dai, Giovanni De Simone, T Bruce Ferguson, Earl Ford, Karen Furie, Cathleen Gillespie, and et al. Executive summary: heart disease and stroke statistics–2010 update: a report from the american heart association. *Circulation*, 121(7):188–197, 2010.

[2] Philip Bille. A survey on tree edit distance and related problems. *Theor. Comput. Sci.*, 337:217–239, June 2005.

[3] A. Feragen, F. Lauze, and M. Nielsen. Fundamental geodesic deformations in spaces of treelike shapes. In *Pattern Recognition (ICPR), 2010 20th International Conference on*, pages 2089 –2093, aug. 2010.

[4] Aasa Feragen, Francois Lauze, Pechin Lo, Marleen de Bruijne, and Mads Nielsen. Geometries on spaces of treelike shapes. In *Proceedings of the 10th Asian conference on Computer vision - Volume Part II*, ACCV'10, pages 160–173, Berlin, Heidelberg, 2011. Springer-Verlag.

[5] Stephen R. Aylward, Julien Jomier, Christelle Vivert, Vincent LeDigarcher, and Elizabeth Bullitt. Spatial graphs for intra-cranial vascular network characterization, generation, and discrimination. In *MICCAI*, pages 59–66, 2005.

[6] W H Tang and Albert C S Chung. Cerebral vascular tree matching of 3d-ra data based on tree edit distance. *Medical Imaging and Augmented Reality*, page 116123, 2006.

[7] Aasa Feragen, Søren Hauberg, Mads Nielsen, and François Lauze. Means in spaces of tree-like shapes. In *ICCV*, pages 736–746, 2011.

[8] Erik D. Demaine, Shay Mozes, Benjamin Rossman, and Oren Weimann. An optimal decomposition algorithm for tree edit distance. *ACM Transactions on Algorithms*, 6(1), 2009.