Toward Reliable Multi-generational Analysis of Anatomical Trees in 3D High-resolution CT Images

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SPIE Medical Image 2003, San Diego, CA
February 18, 2003

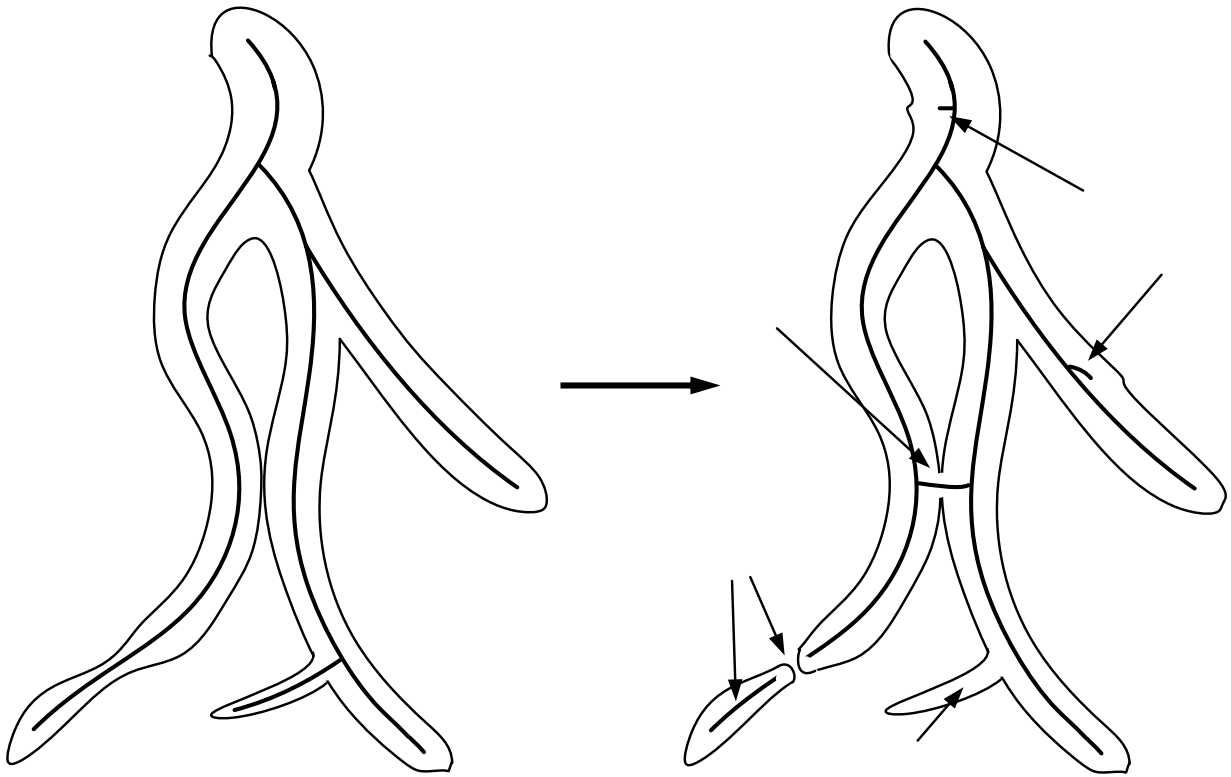
Outline

- Introduction
- Methods: 3-Stage approach
- Experimental results
- Conclusion

Introduction

- High-resolution X-ray micro-CT scanner and Multi-detector helical CT scanner
  - High-resolution 3D digital images of various anatomical tree structures
    - Coronary or hepatic vasculature
    - Airway tree
- Sheer size and complexity of these trees
  - Essentially impossible to define them interactively
- Automatic Approaches
  - image segmentation, thinning and centerline analysis (Wan et al. 2002, Quek et al. 2001, and Yim et al. 2000)
  - Principle pathway (Karau et al. 2001, Johnson et al. 2000)
  - High percentage of apparently correct branches
    - **None of them, however, guarantee geometrically accurate tree structures**

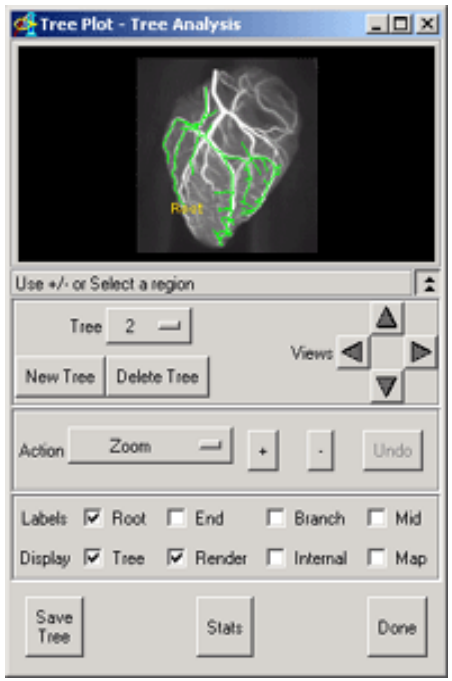
Output of Automatic Approaches: Imperfect Trees



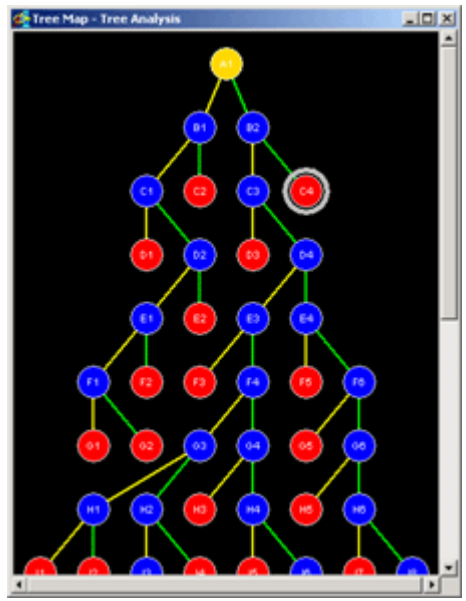
- Branches are missed
- Branches break, creating overly short branches and forming new false branches
- Extra spurious branches arise, causing false bifurcations
- Anatomically implausible loops occur

Interactive System: Tree Analysis Module for Analyze 4.0

- **Segmentation (Single Threshold)**
- **Image Projection (Rendering)**
- **Labeling**
- **Action**
  - **Group 1 (Rendering) - Rotate, Scale, Translate, Select**
  - **Group 2 (Tree Editing Tools) – Set Root, Combine Trees, Split Tree, Delete Branch, Delte Point, Add Point, Insert Point, and Move Point.**
- **Map**



Rendering and Editing



Map

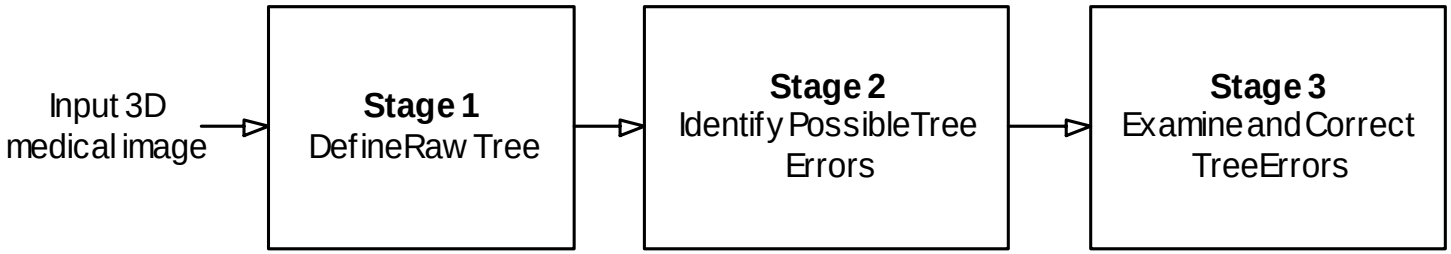
The goal of this paper

- Develop methods for defining accurate 3D tree structures and accompanied quantitative descriptions.
- Satisfy the following requirements to be useful
  - Reasonable amount of human interaction
  - Computationally efficient
  - Function effectively over a wide range of anatomical and data variations

Basic Philosophy

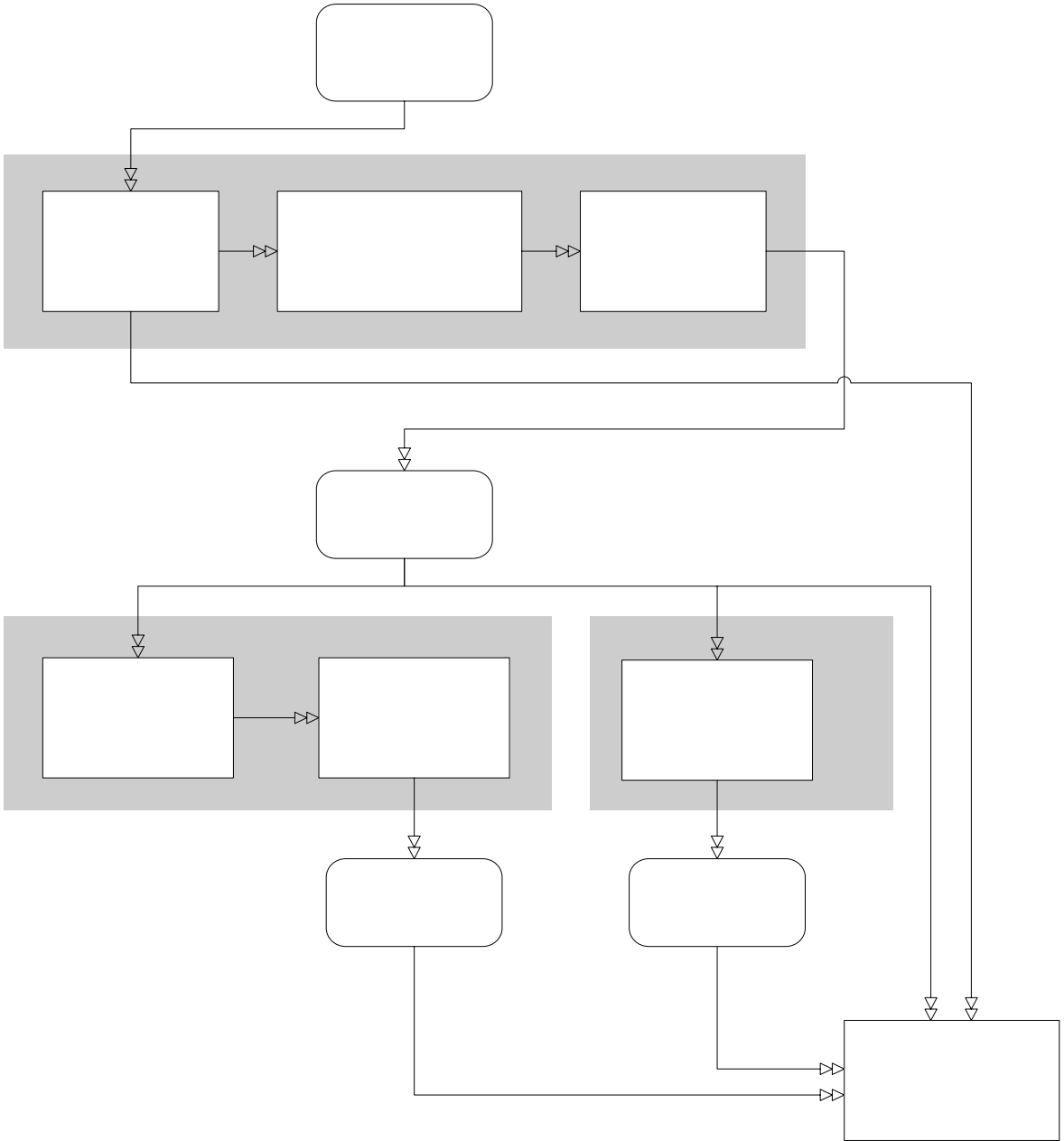
- Unrealistic to rely on improved scanning technology and automated algorithms for defining a tree
- But, automated techniques are vitally necessary
- Judicious human interaction is essential

Three-stage approach



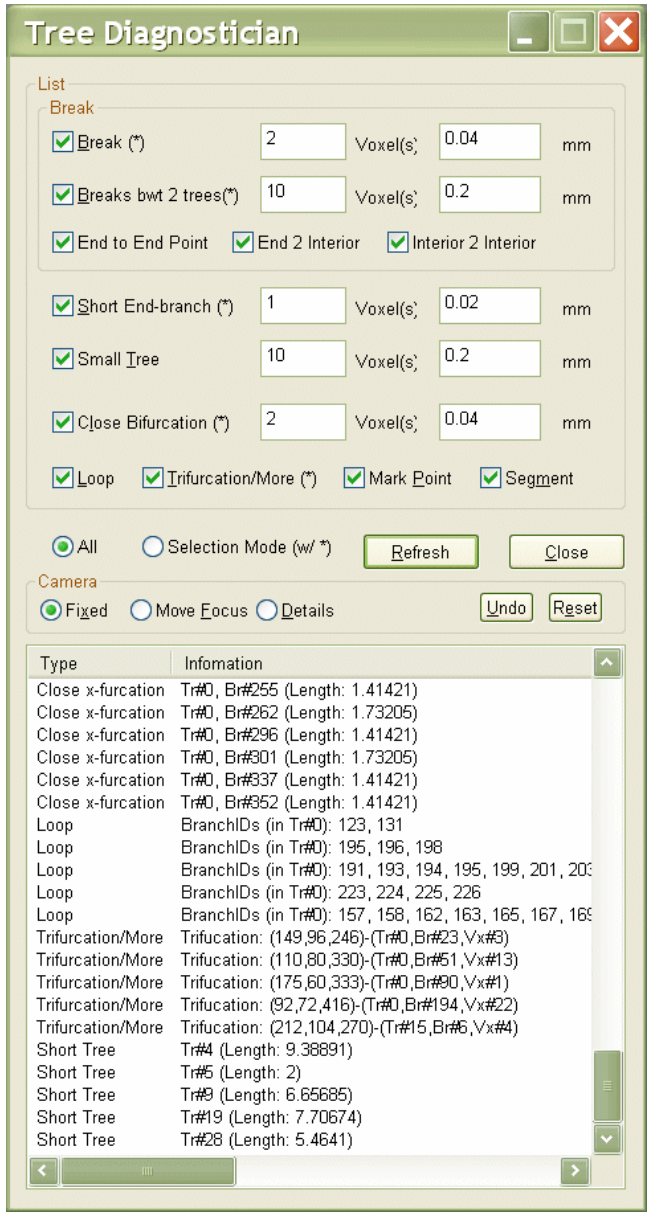
- Stage 1 – Apply an automated technique to produce a segmented tree and an associated tree description
- Stage 2 – Analyze the automatically defined tree to identify possible errors
- Stage 3 – Use a series of interactive tools to examine and correct identified errors

Stage 1: Define the Raw Tree (Wan, TMI 9/2000)



Stage 2:
Identify Possible Tree Errors using Tree Diagnostician

Branches are missed	Short end branch
Branches break	Branches break in a same tree
	Branches break between two trees
	Small Trees
	Short end branch
Spurious branches	Short end branch
Anatomically implausible loops occur	Loop
	Close bifurcation
	Trifurcation



Stage 3: Examine and Correct Tree Errors

Tools built for interrogation/correction process:

- 3D rendering system
- Locator Tools
  - Skeleton Picker
  - 3D Site Locator – Shooter
  - Intersection-Center Locator
  - 3D Cursor
- Site Bounding Box
- Editing Tools
- 2D Tree Map

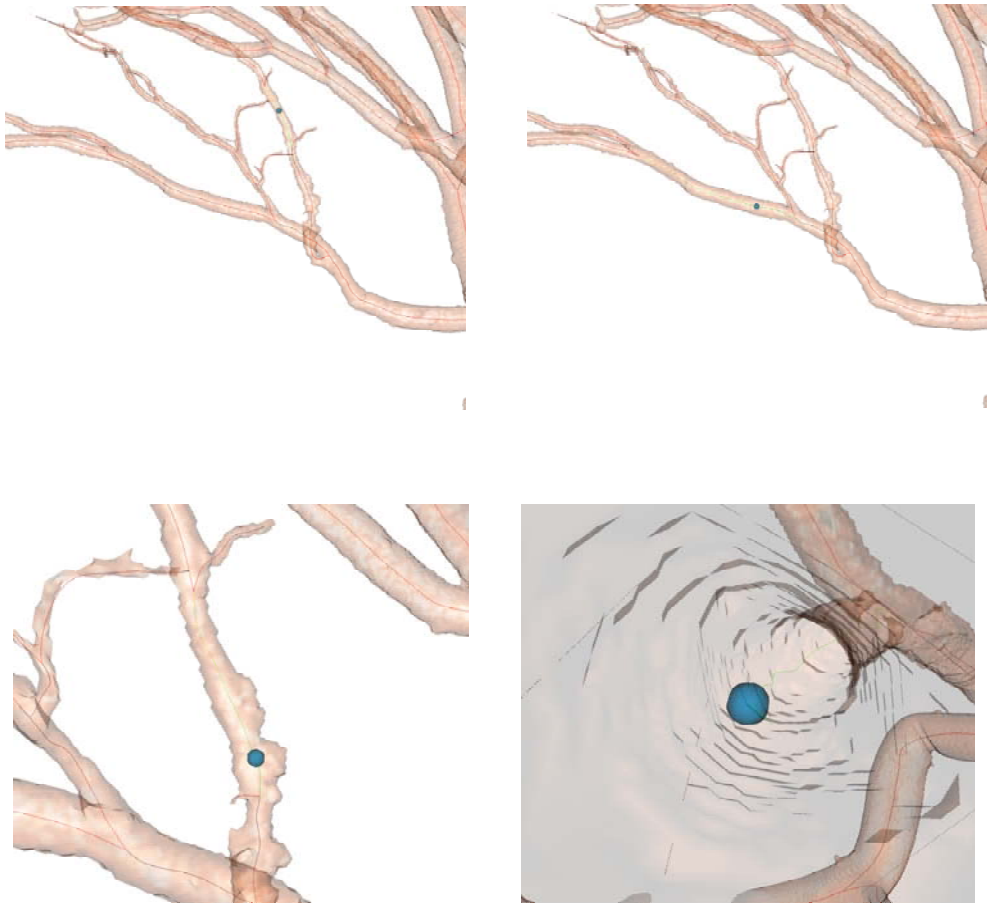
3D Rendering System

- Surface and skeleton displayed

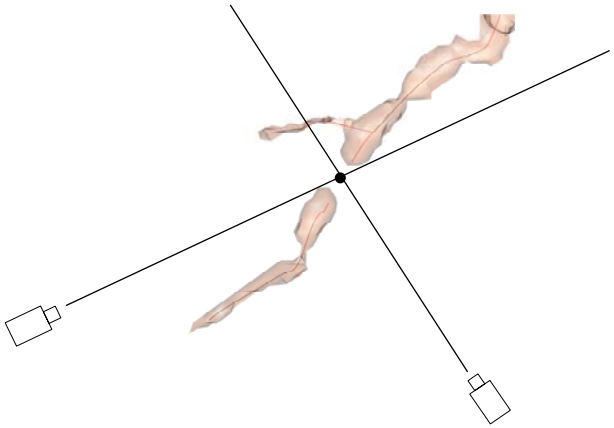
- Rotate, transpose and zoom in/out using rendering control

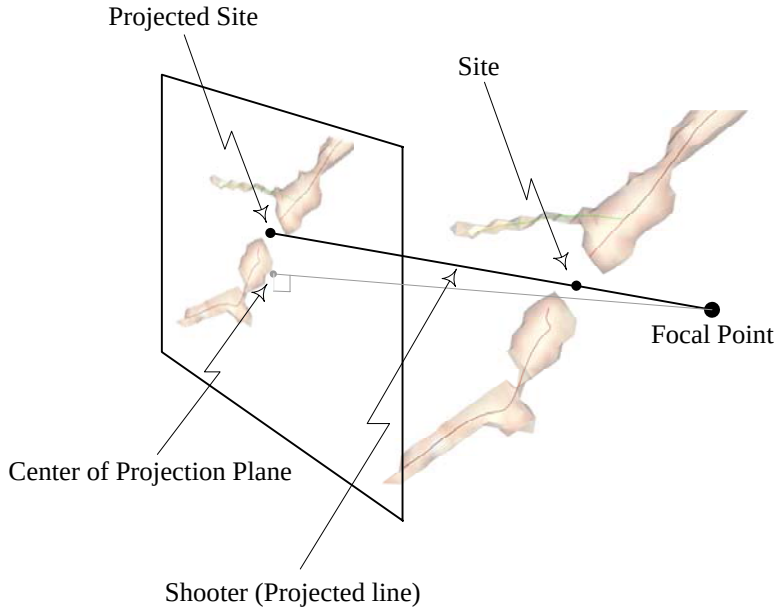
Locator Tool 1 - Skeleton Picker

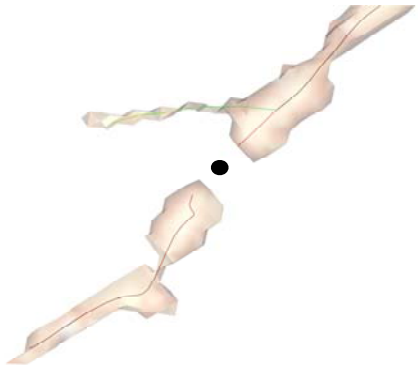
Four visualization modes for picker control



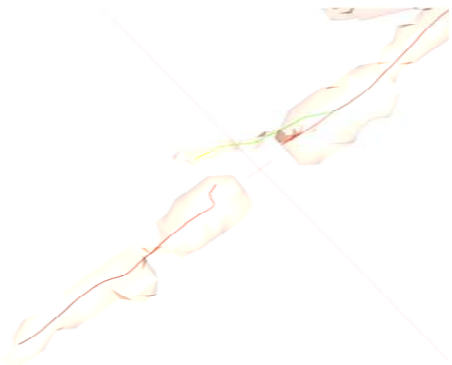
Locator Tool 2 - 3D Site Locator (Shooter)



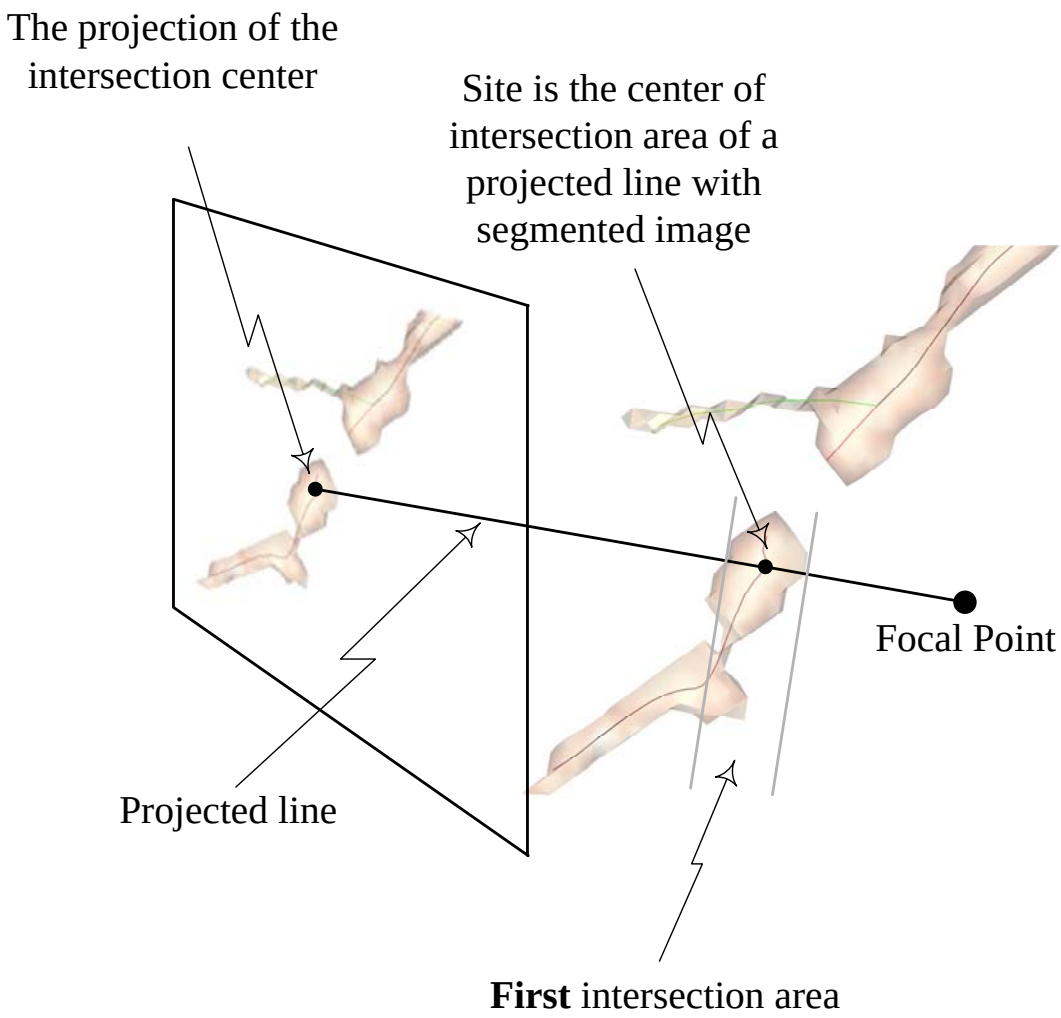




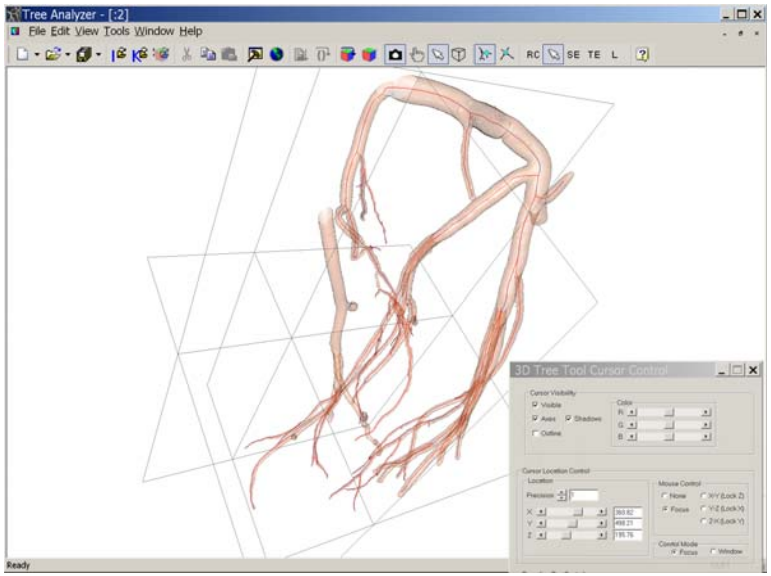
Move/Rotate
Camera

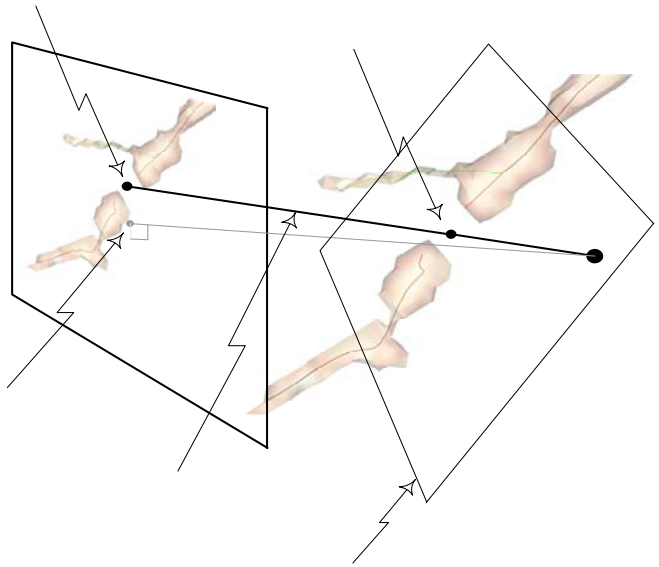


Locator Tool 3 - Intersection Center

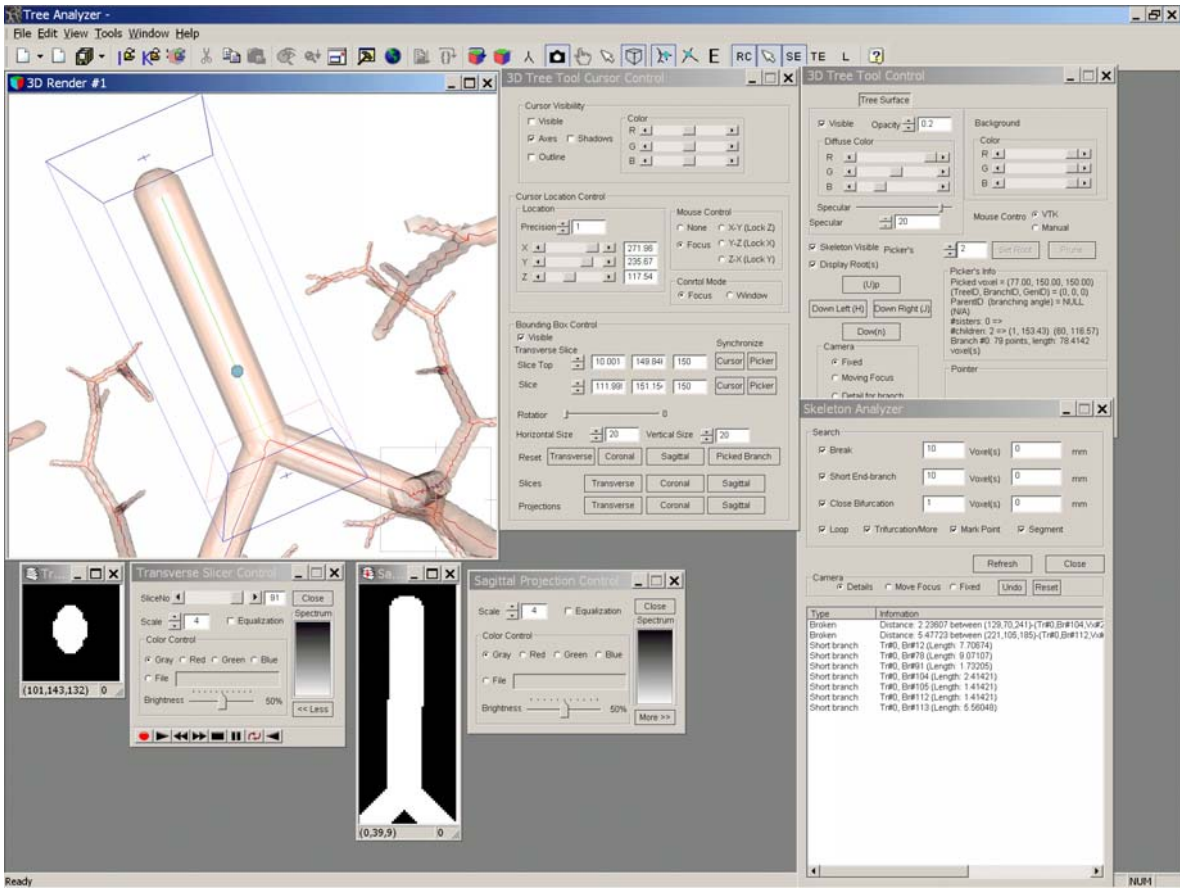


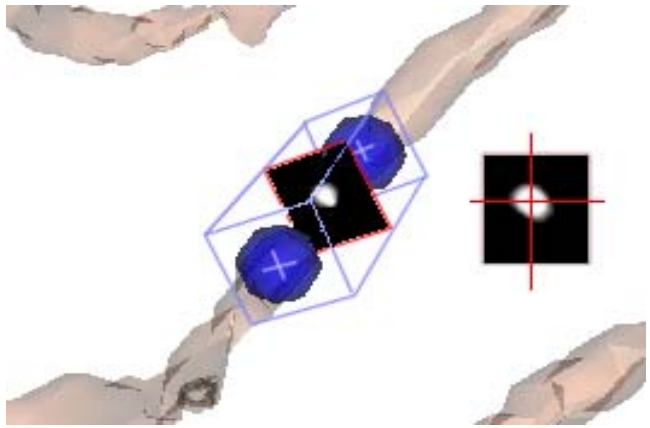
Locator Tool 4 - 3D Cursor





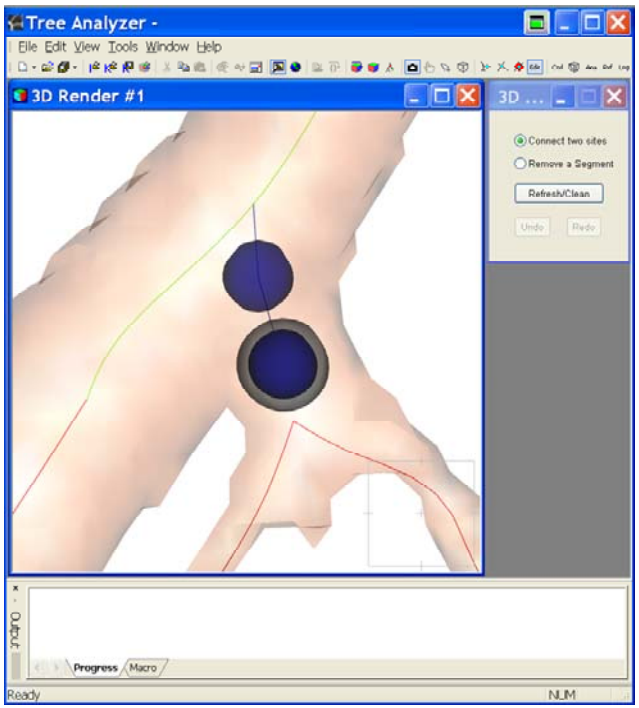
Site Bounding Box

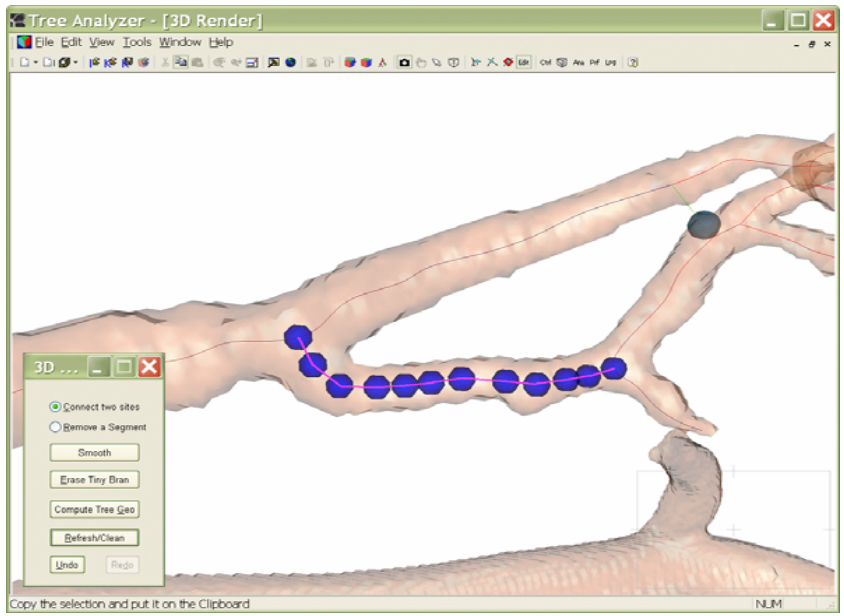




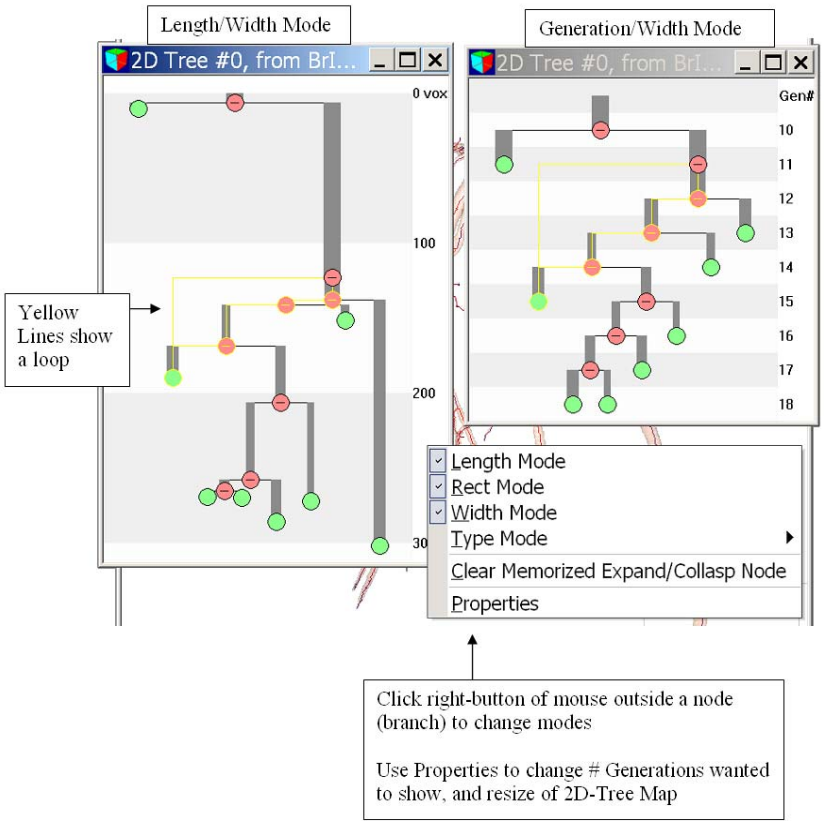
Tree Editing Tools

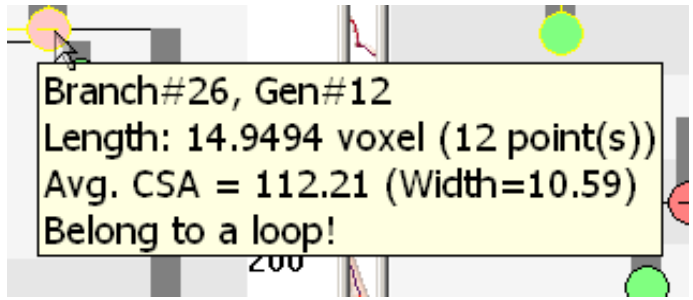
- Skeleton Editor – enables point and connection editing
- Point Editor – allows the addition or removal of specific skeletonal points
- Connection Editor – line segments can be deleted or added
- Tree root selection and tree pruning



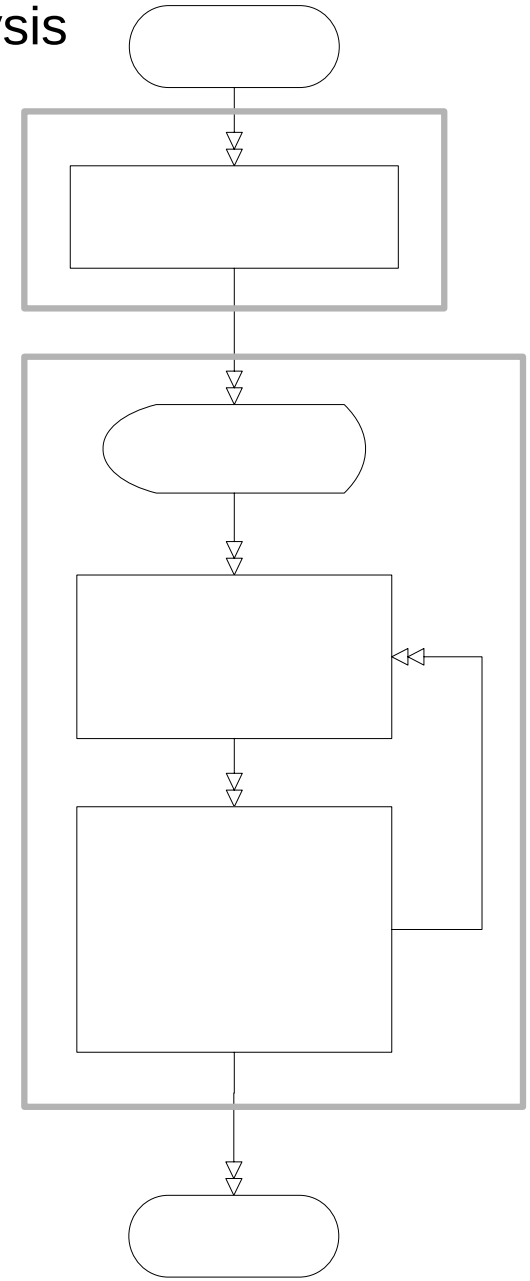


2D Tree Map
Zoom in/out and Detail-on-demand

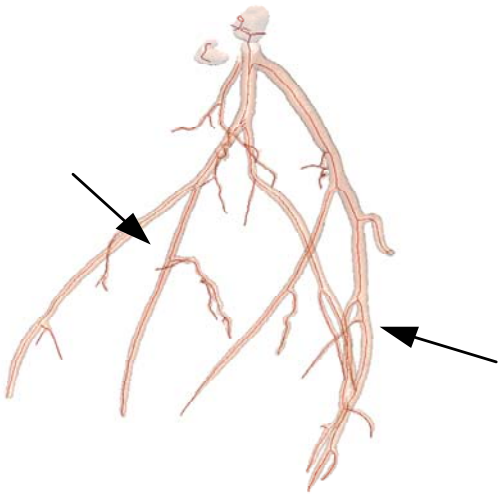


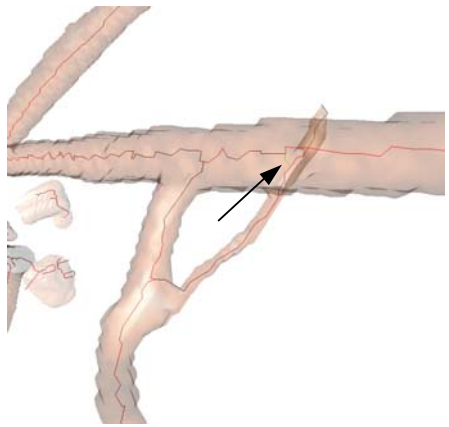


Flow Chart of Tree Analysis

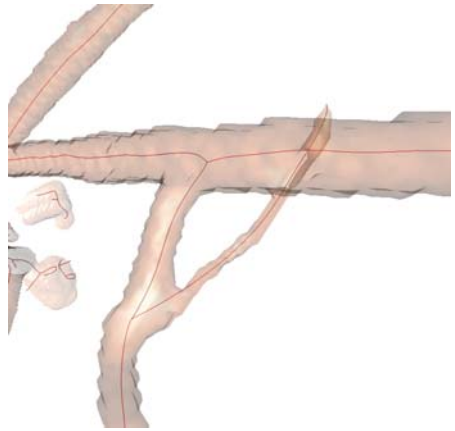


Example of loop editing

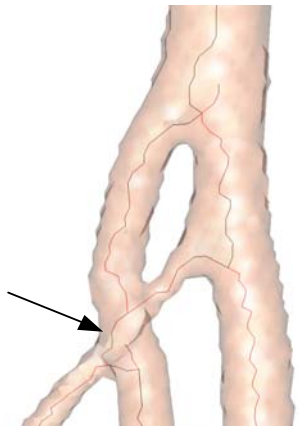




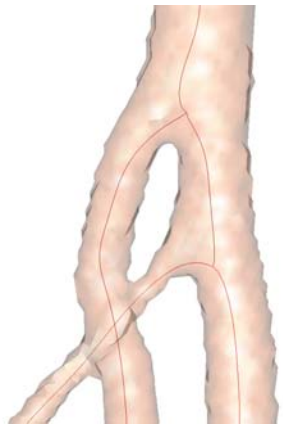
(b) connected-branch case



(c) refined skeleton

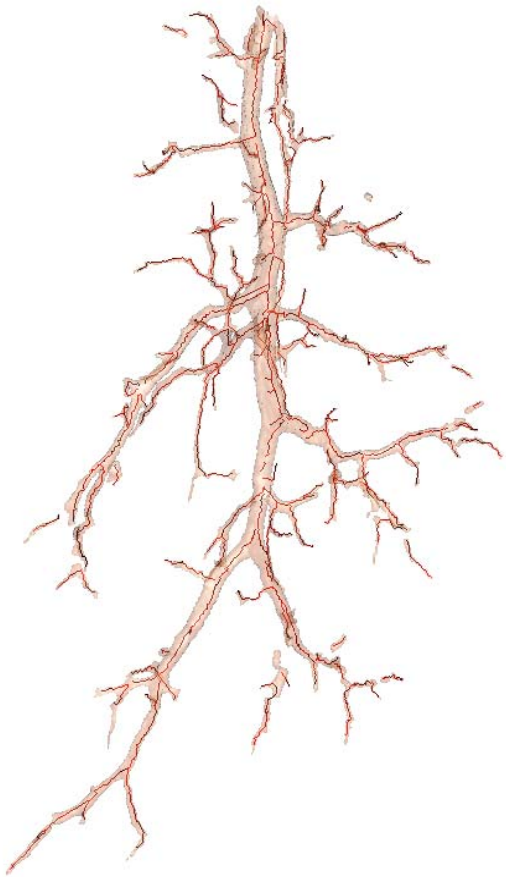


(d) shared-branch case

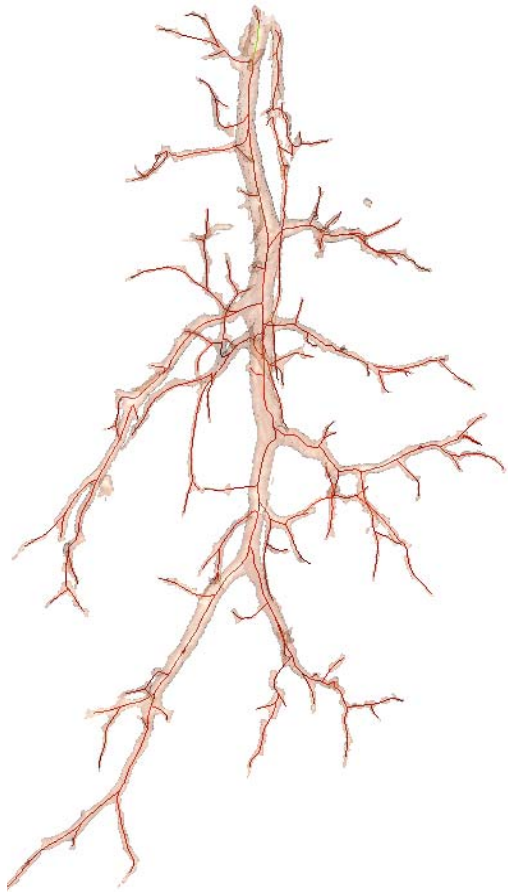


(e) refined skeleton

Experimental Results - Control2 case (Hepatic vasculature)

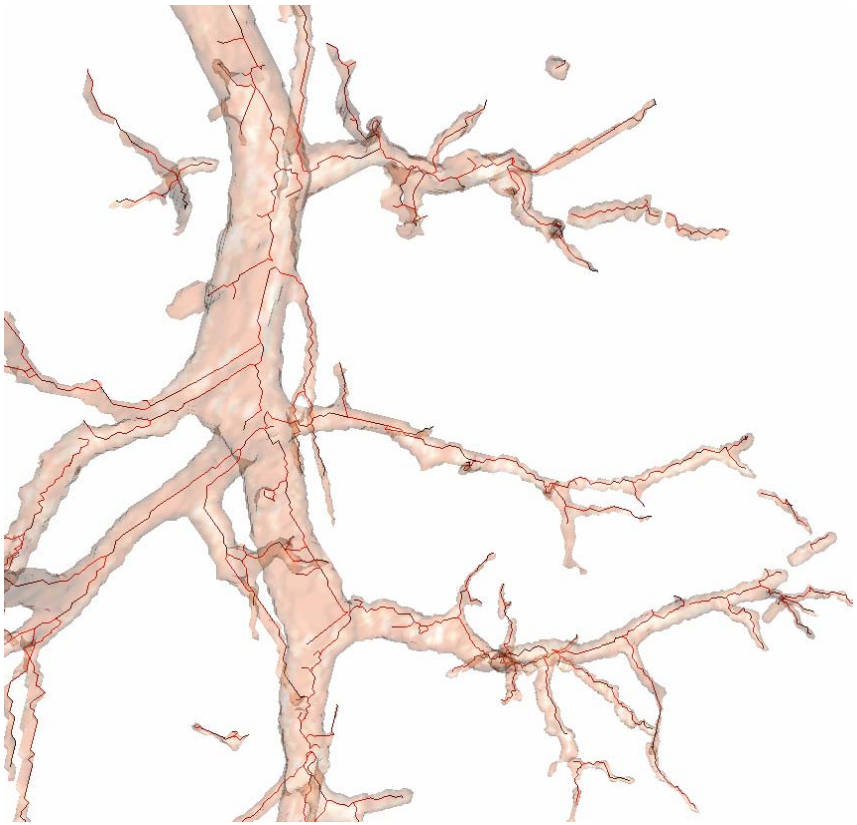


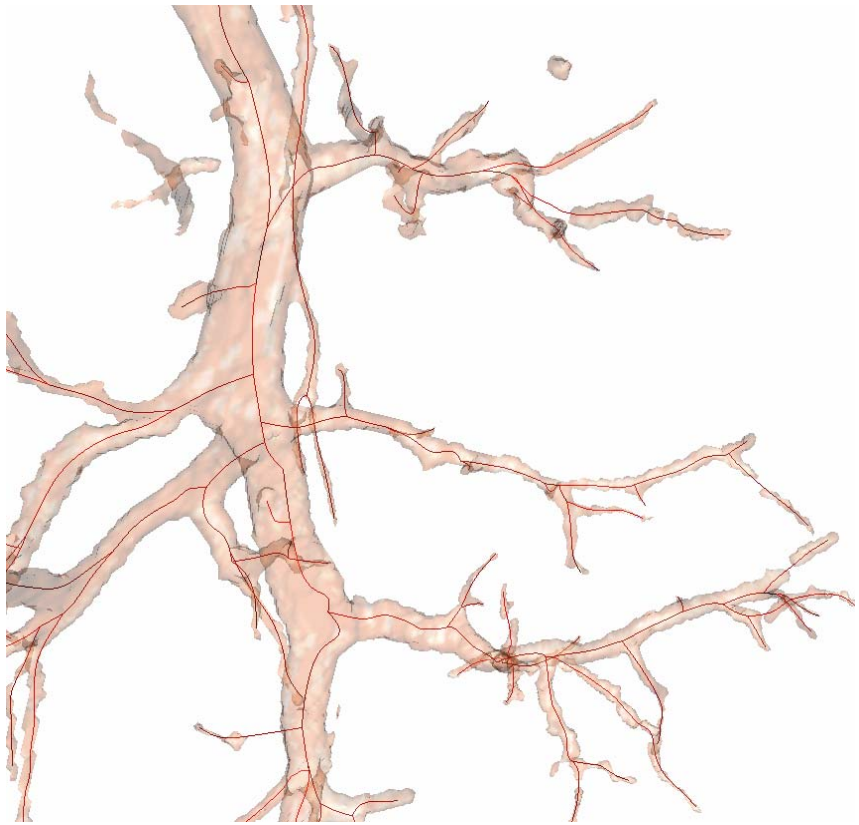
(a)



(b)

A close look at Control2 case



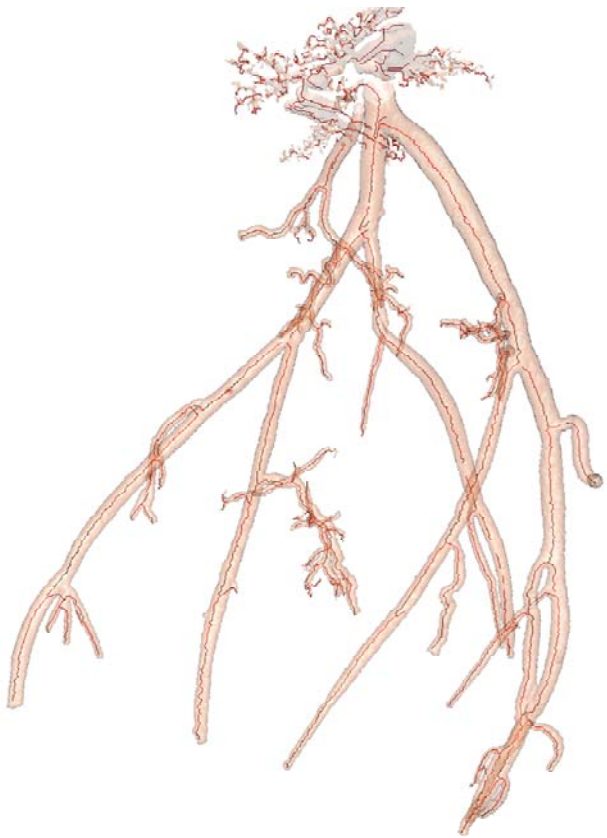


Control2: Problems eliminated (list in Tree Diagnostician)

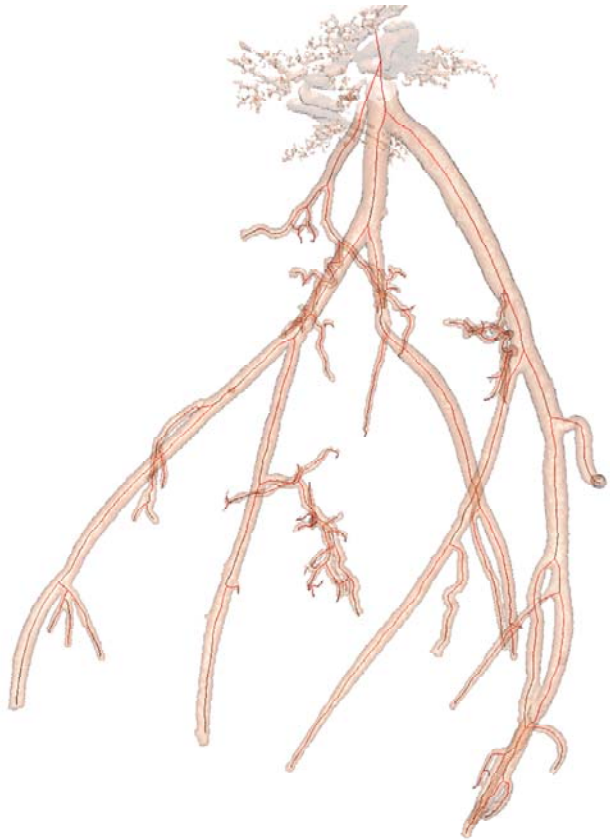
- Took two hours of user interaction
- Number of generations increased from 14 (previous work) to 25

Error	**Number**
Branch Breaks	60
Trifurcations	5
Loops	5
Small Trees	31

Experimental Results – H61 case



(a)



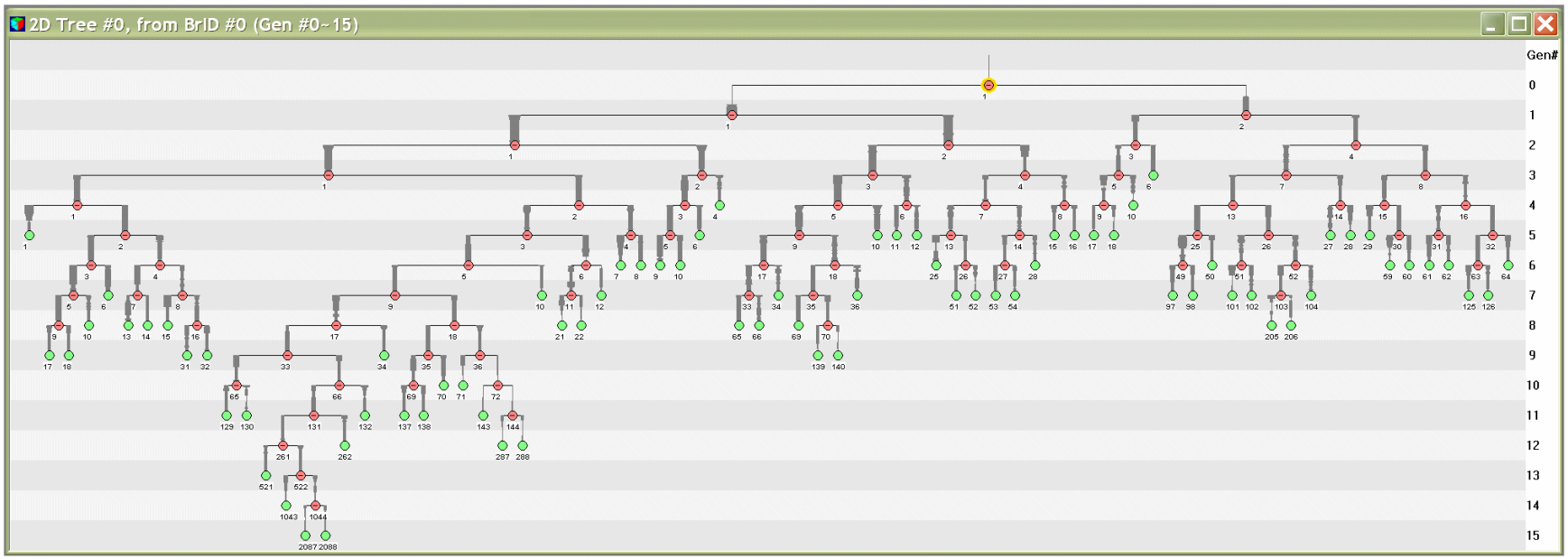
(b)

H61: Problems eliminated
(list in Tree Diagnostician)

- Took two more hours of user interaction
- Number of generations 15
- Computer identified extra branches at generations 12-15 that the human did not measure

Error	**Number**
Trifurcations	12
Loops	14
Small Trees	1

2D Tree Map of H61



Conclusion

- Complete procedure for defining correct branching-tree structure in large 3D CT image
- Graphical tools allow user to interrogate and fix tree defects
- Enable precise geometric tree definition, so that quantitative assessments can be made.
- A more systematic use of tools is required
- Semi-automatic tools are vital to speed up the interactive process

Acknowledgements

This work was partially supported by NIH grants #EB00305 and #CA74325 and CA91534.