



# 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



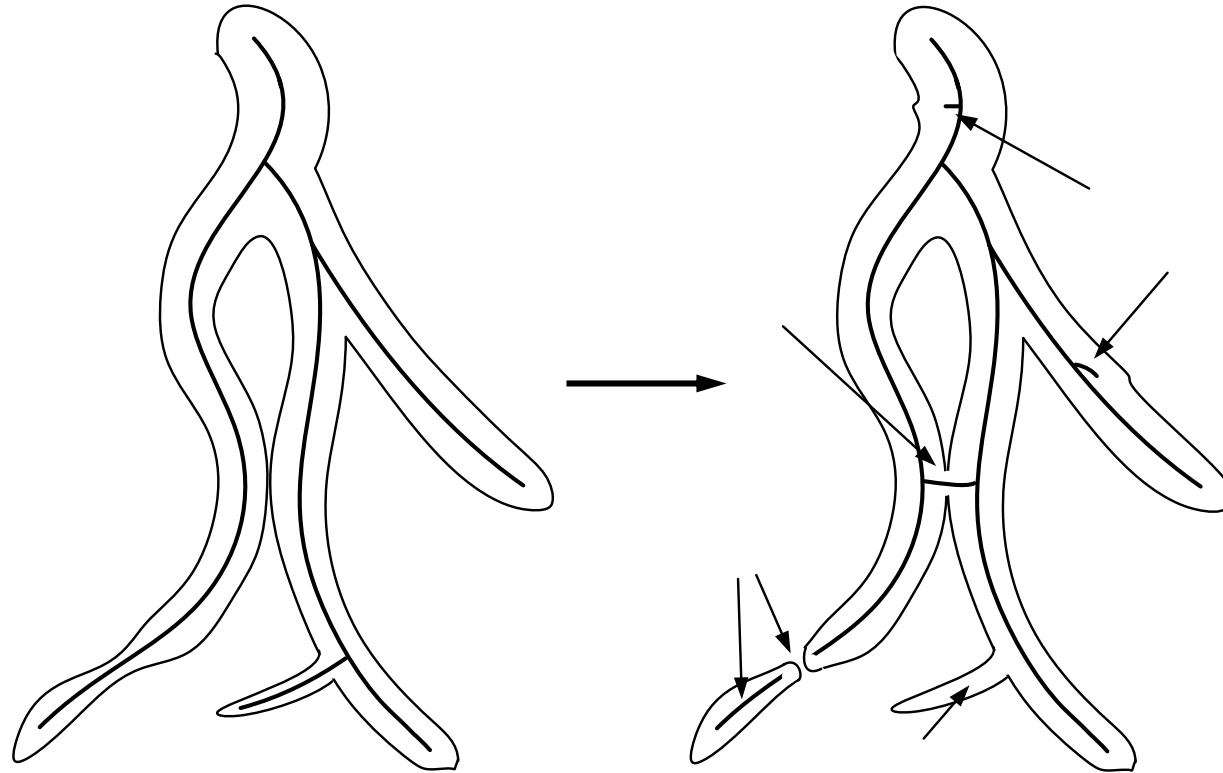
# Outline

- 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

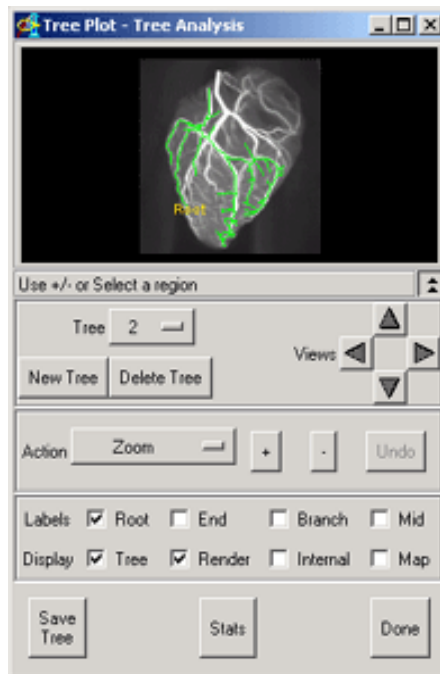


- Branches are missed
- Branches break, creating overly short branches and forming new false branches
- Extra spurious branches arise, causing false bifurcations
- Anatomically implausible loops occur

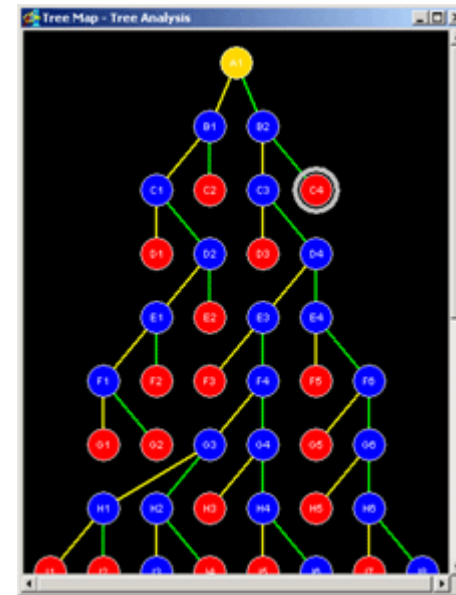
# Interactive System: Tree Analysis Module for Analyze 4.0

- 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, Delete Point, Add Point, Insert Point, and Move Point.

## ■ Map



Rendering and Editing



Map

# The goal of this paper

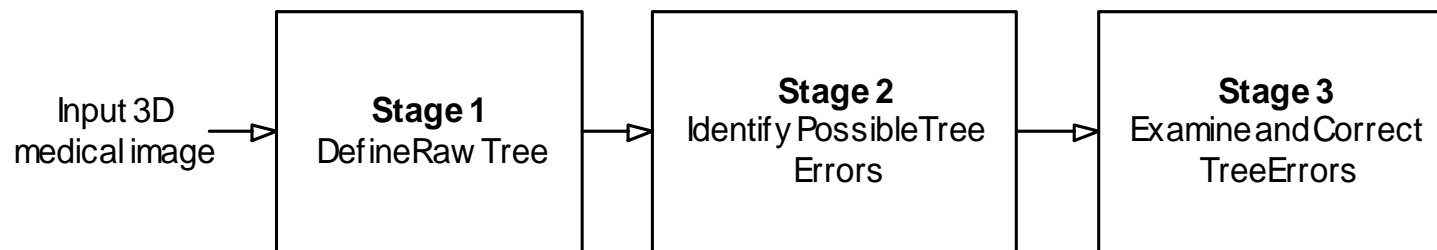
- Develop methods for defining accurate 3D tree structures and accompanied quantitative descriptions.
- Satisfy the following requirements to be useful
  - Reasonable amount of human interaction
  - Computationally efficient
  - Function effectively over a wide range of anatomical and data variations



# 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

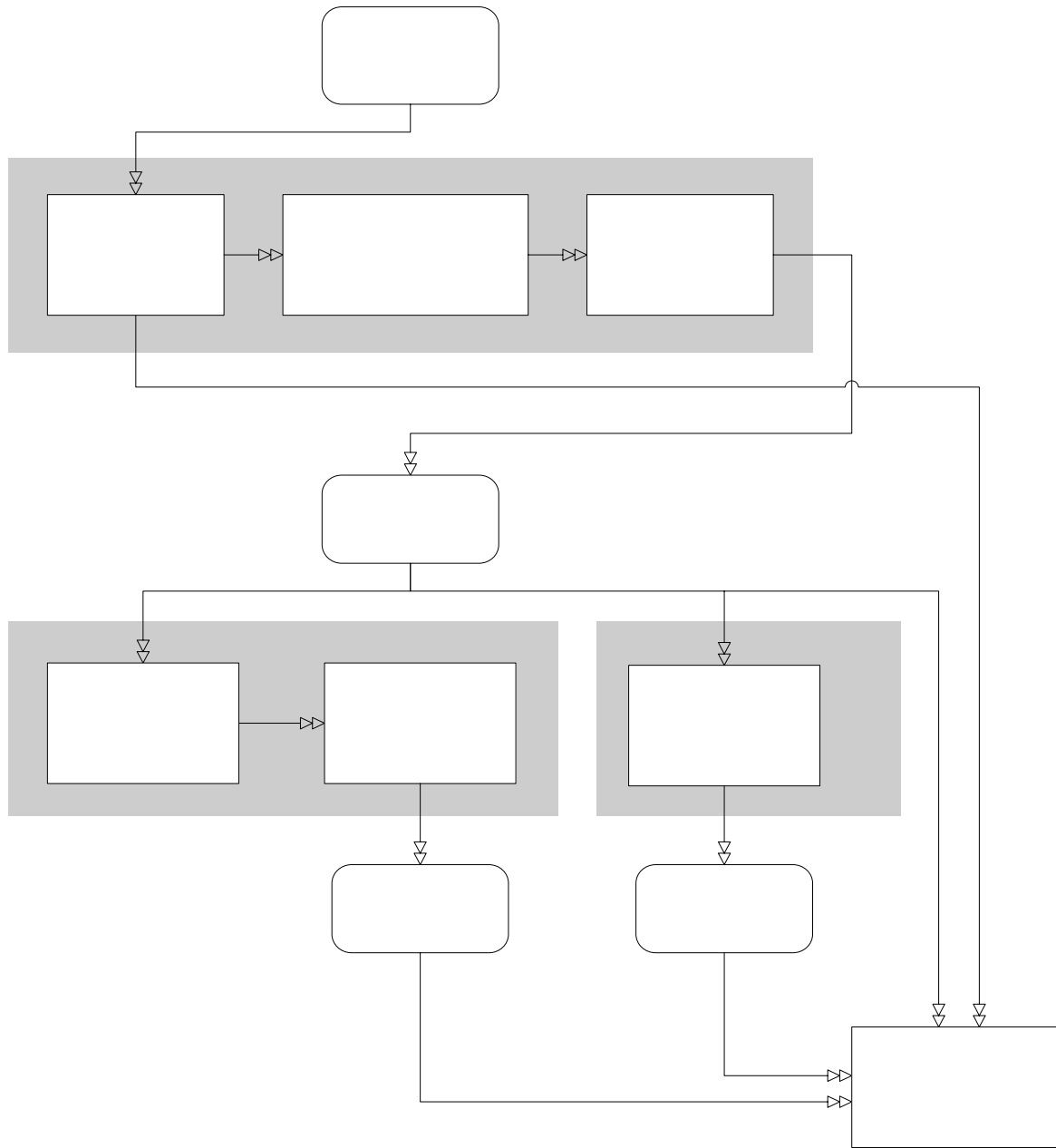
# Three-stage approach



- 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

The screenshot shows the 'Tree Diagnostician' window with the following settings:

- Break**
  - Break (\*) 2 Voxel(s): 0.04 mm
  - Breaks bwt 2 trees(\*) 10 Voxel(s): 0.2 mm
  - End to End Point  End 2 Interior  Interior 2 Interior
  - Short End-branch (\*) 1 Voxel(s): 0.02 mm
  - Small Tree 10 Voxel(s): 0.2 mm
  - Close Bifurcation (\*) 2 Voxel(s): 0.04 mm
  - Loop  Trifurcation/More (\*)  Mark Point  Segment
- Camera**
  - All  Selection Mode (w/ \*)
  - Fixed  Move Focus  Details
- List**
  - Buttons: Refresh, Close, Undo, Reset
  - Table:

Type	Information
Close x-furcation	Tr#0, Br#255 (Length: 1.41421)
Close x-furcation	Tr#0, Br#262 (Length: 1.73205)
Close x-furcation	Tr#0, Br#296 (Length: 1.41421)
Close x-furcation	Tr#0, Br#301 (Length: 1.73205)
Close x-furcation	Tr#0, Br#337 (Length: 1.41421)
Close x-furcation	Tr#0, Br#352 (Length: 1.41421)
Loop	BranchIDs (in Tr#0): 123, 131
Loop	BranchIDs (in Tr#0): 195, 196, 198
Loop	BranchIDs (in Tr#0): 191, 193, 194, 195, 199, 201, 203
Loop	BranchIDs (in Tr#0): 223, 224, 225, 226
Loop	BranchIDs (in Tr#0): 157, 158, 162, 163, 165, 167, 168
Trifurcation/More	Trifurcation: (149,96,246)-(Tr#0,Br#23,Vx#3)
Trifurcation/More	Trifurcation: (110,80,330)-(Tr#0,Br#51,Vx#13)
Trifurcation/More	Trifurcation: (175,60,333)-(Tr#0,Br#90,Vx#1)
Trifurcation/More	Trifurcation: (92,72,416)-(Tr#0,Br#194,Vx#22)
Trifurcation/More	Trifurcation: (212,104,270)-(Tr#15,Br#6,Vx#4)
Short Tree	Tr#4 (Length: 9.38891)
Short Tree	Tr#5 (Length: 2)
Short Tree	Tr#9 (Length: 6.65685)
Short Tree	Tr#19 (Length: 7.70674)
Short Tree	Tr#28 (Length: 5.4641)

## 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

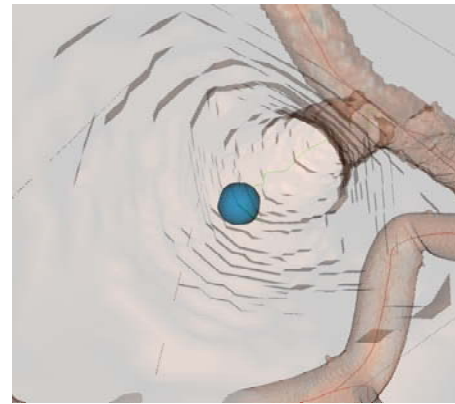
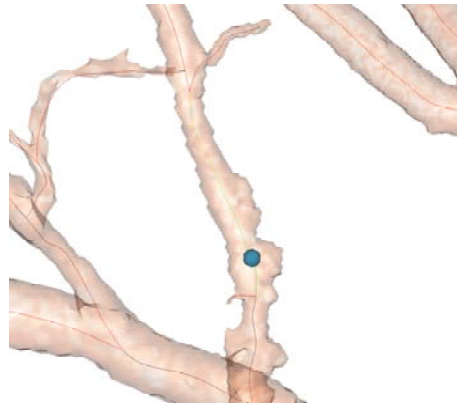
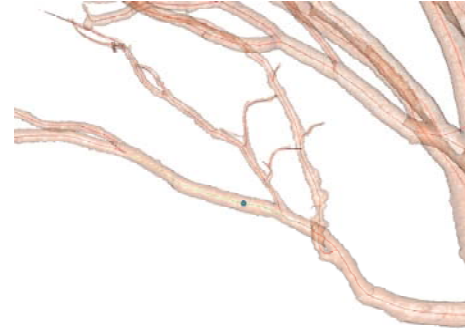
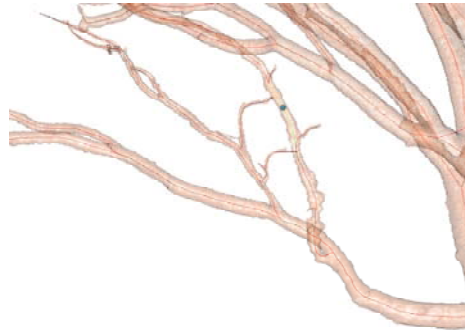
# 3D Rendering System

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

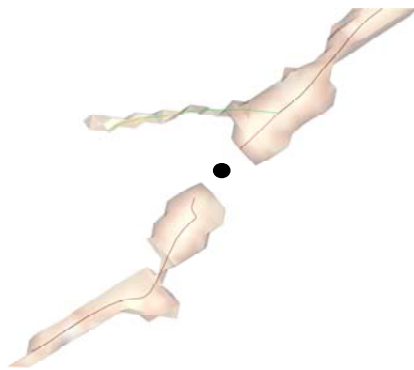
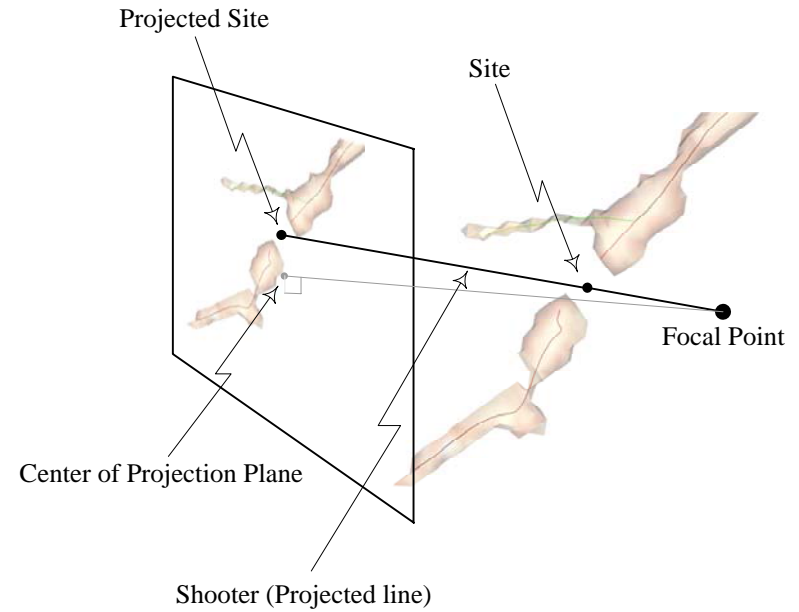
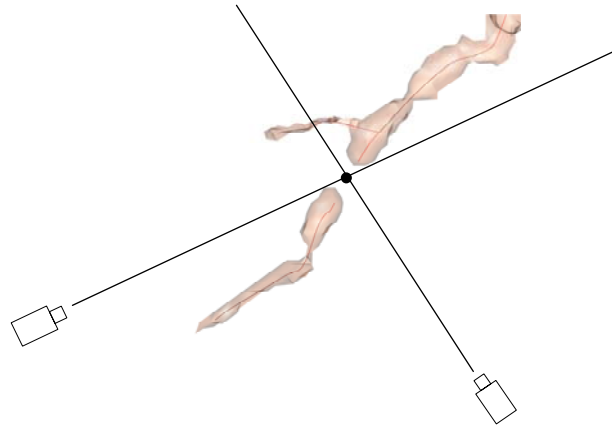


# Locator Tool 1 - Skeleton Picker

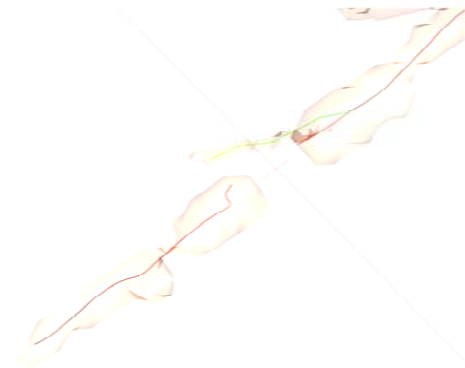
Four visualization modes for picker control



# Locator Tool 2 - 3D Site Locator (Shooter)



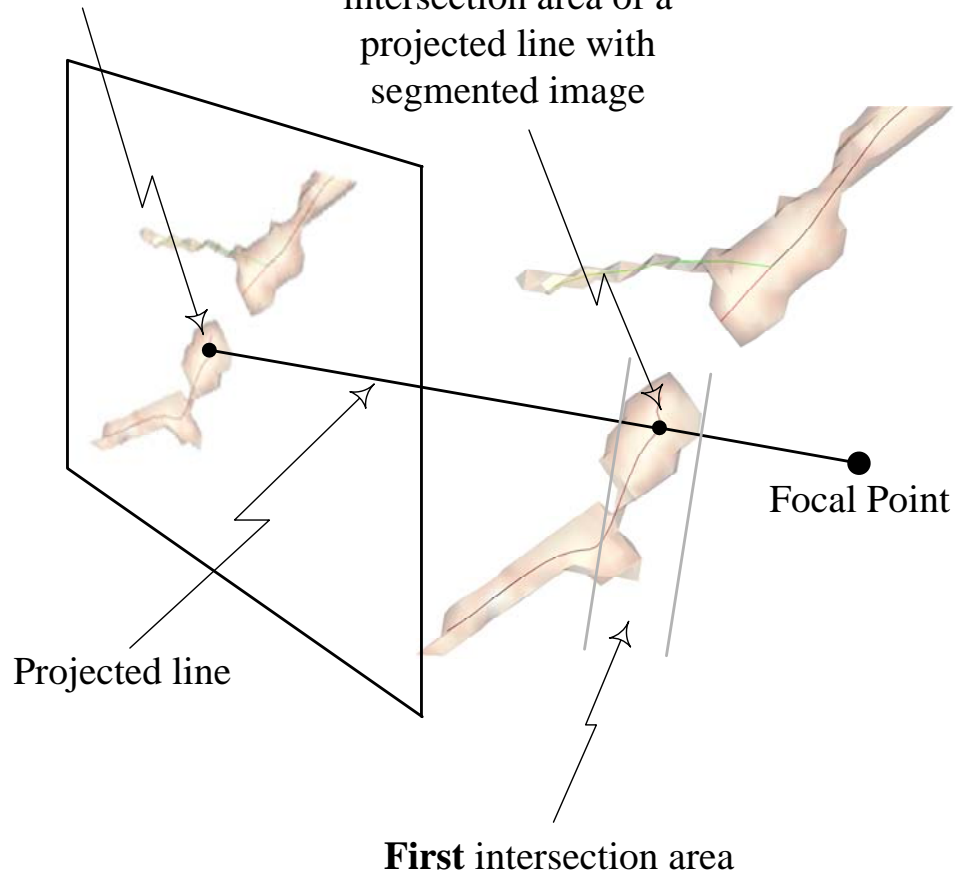
→  
Move/Rotate  
Camera



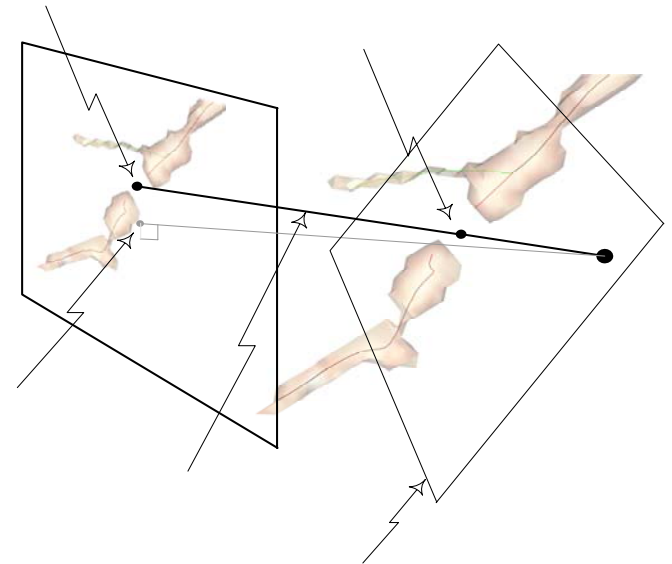
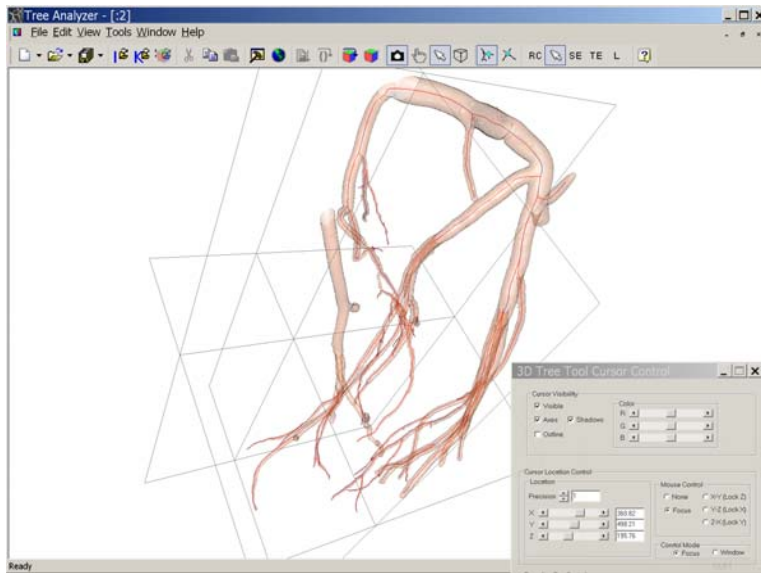
# Locator Tool 3 - Intersection Center

The projection of the intersection center

Site is the center of intersection area of a projected line with segmented image

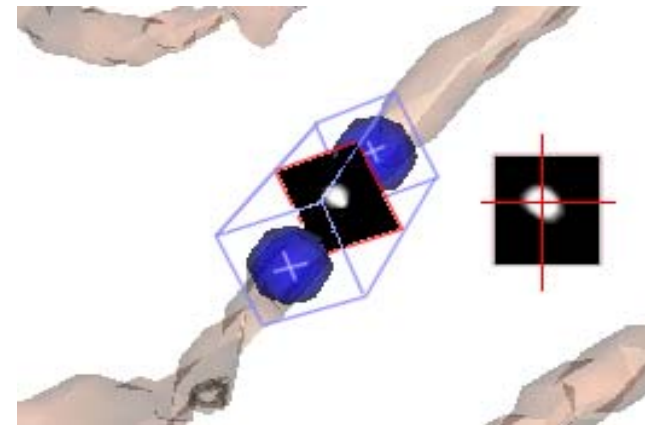
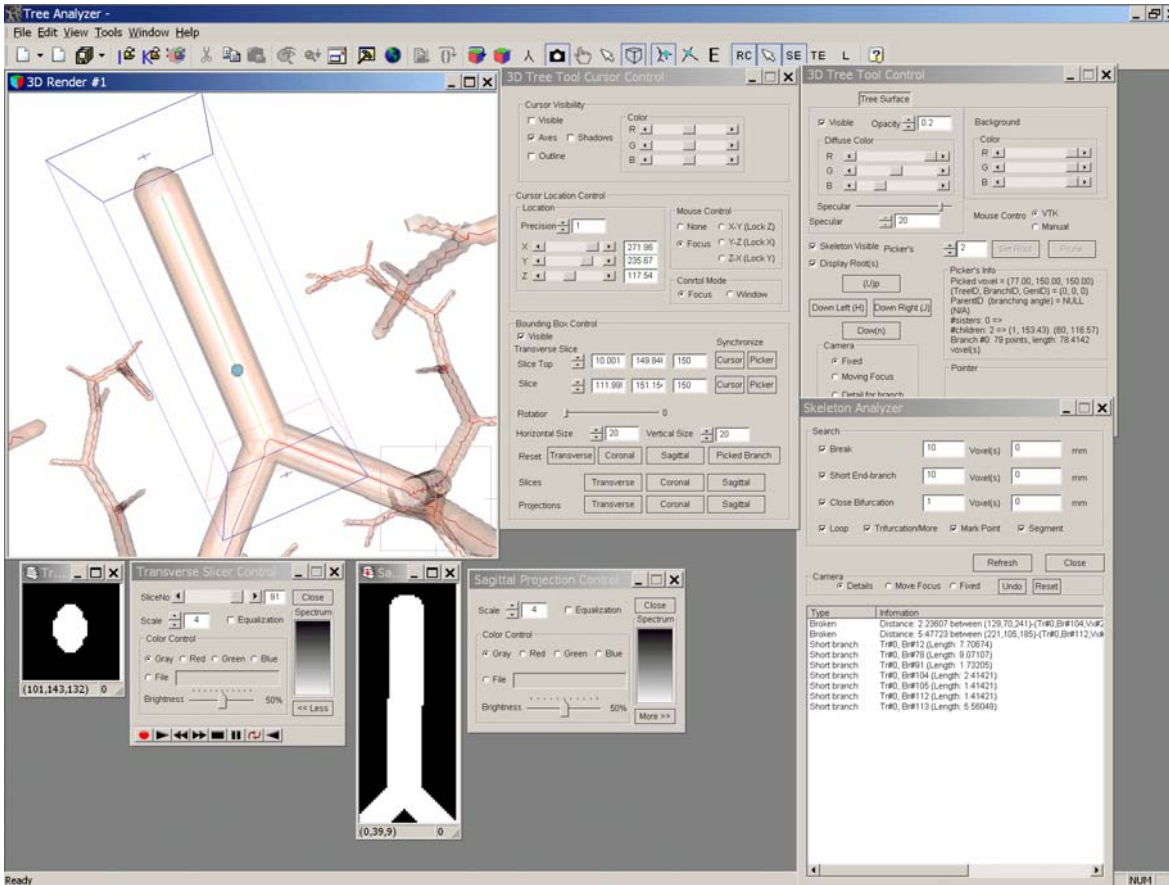


# Locator Tool 4 - 3D Cursor



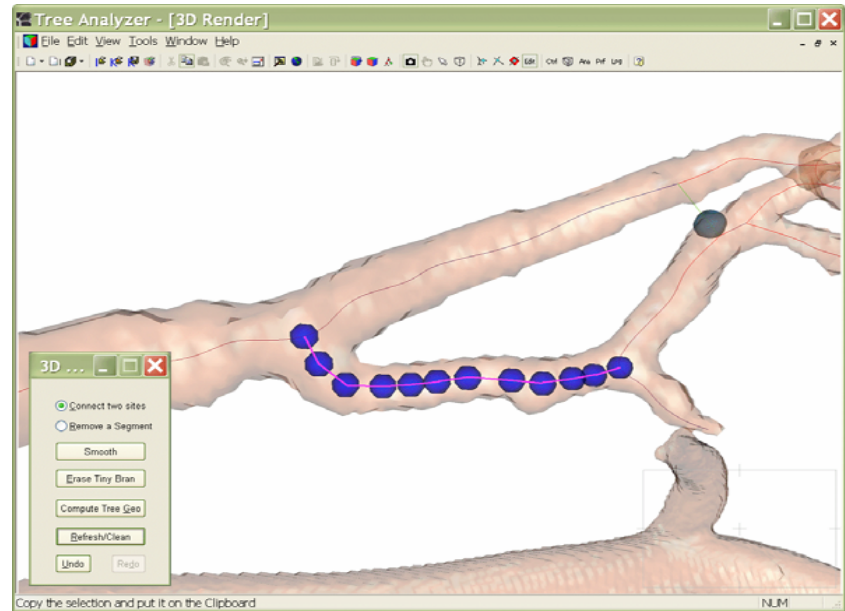
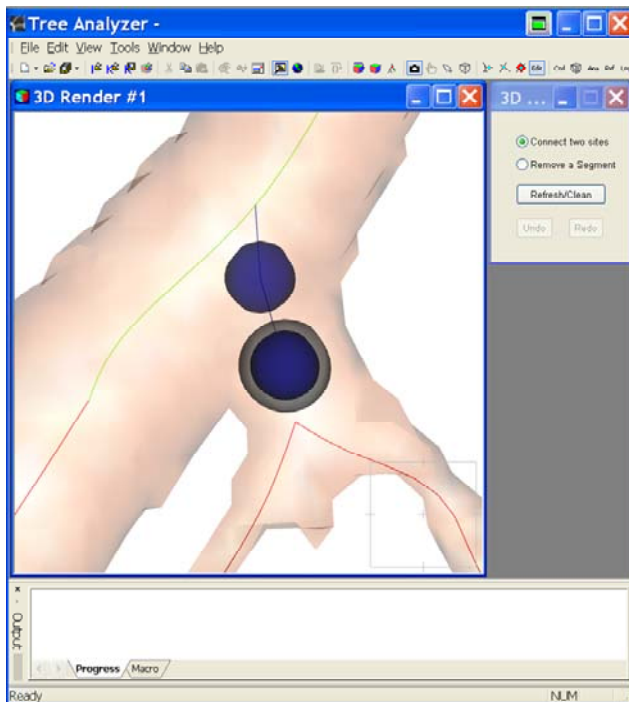


# Site Bounding Box



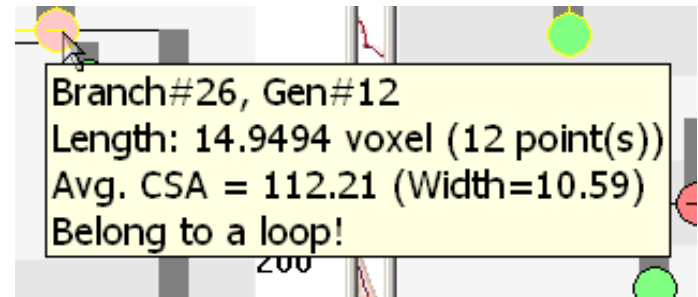
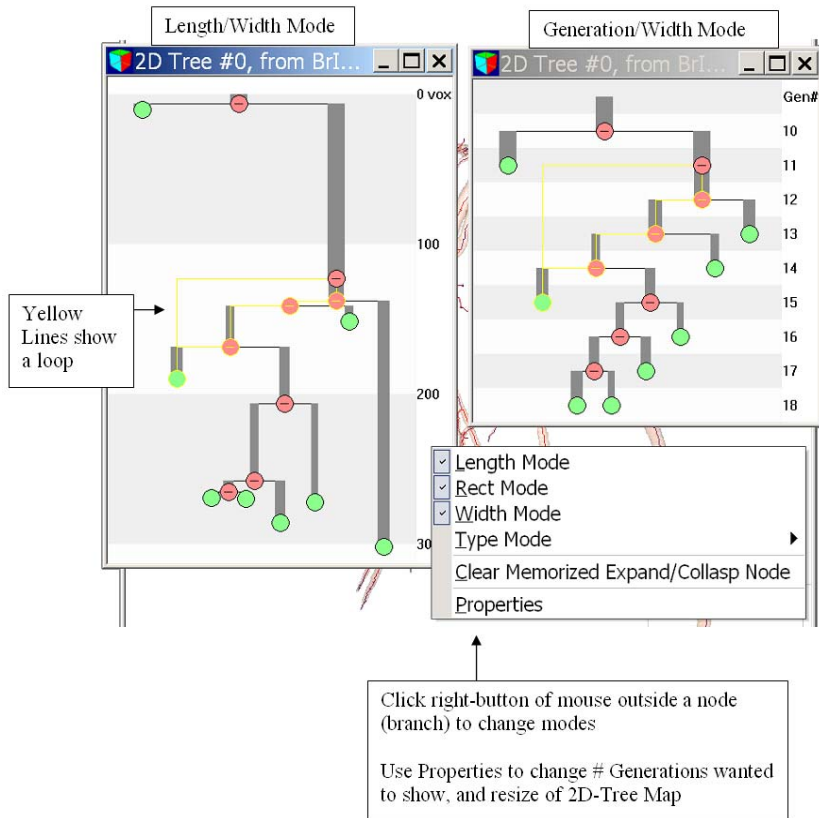
# Tree Editing Tools

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

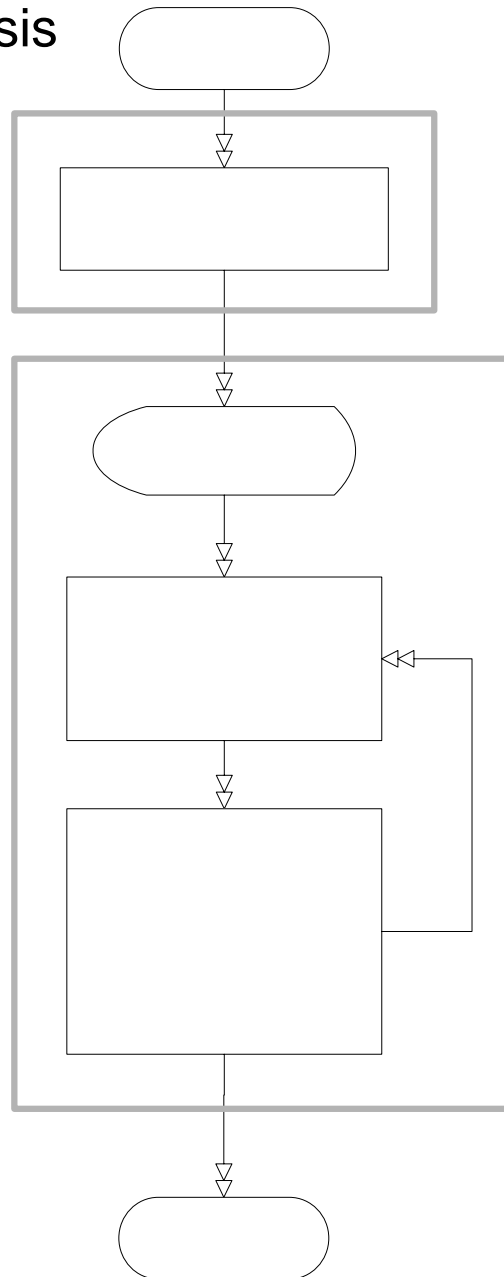


# 2D Tree Map

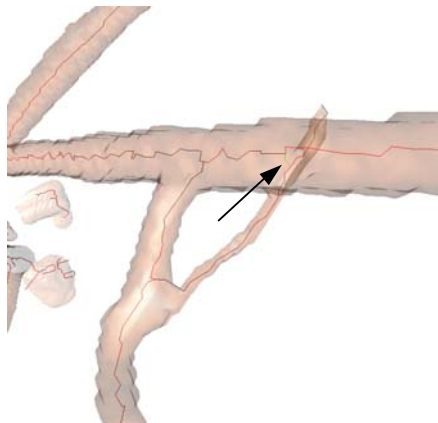
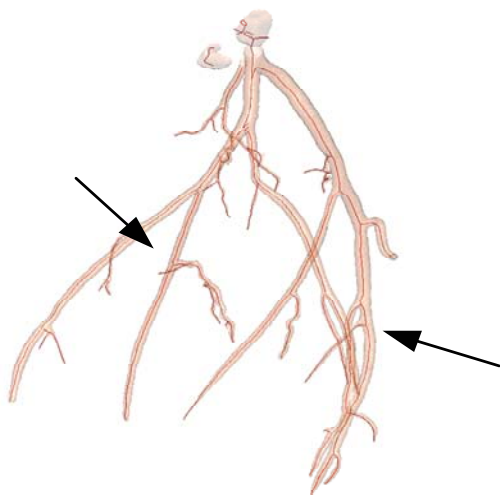
## Zoom in/out and Detail-on-demand



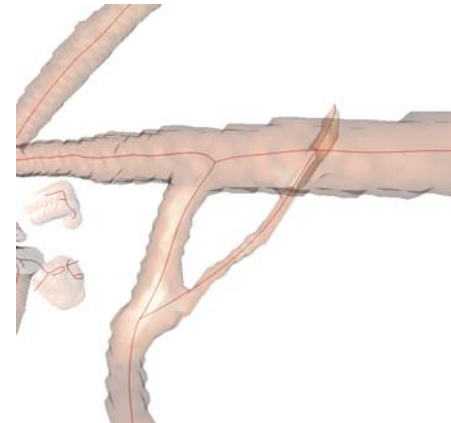
# Flow Chart of Tree Analysis



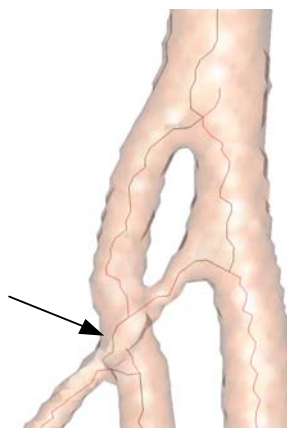
# Example of loop editing



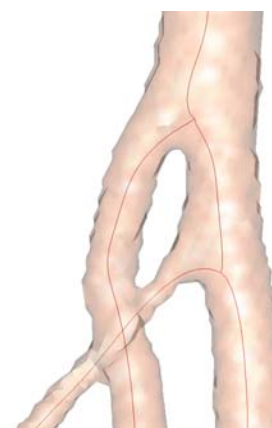
(b) connected-branch case



(c) refined skeleton

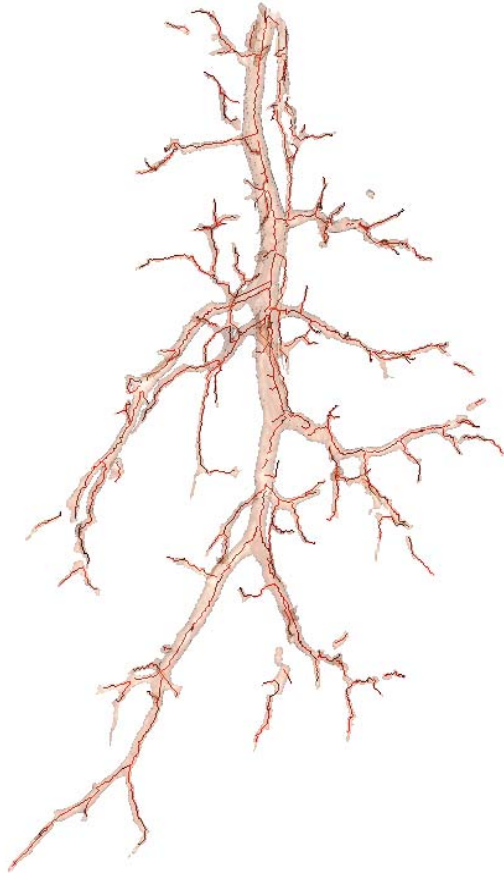


(d) shared-branch case

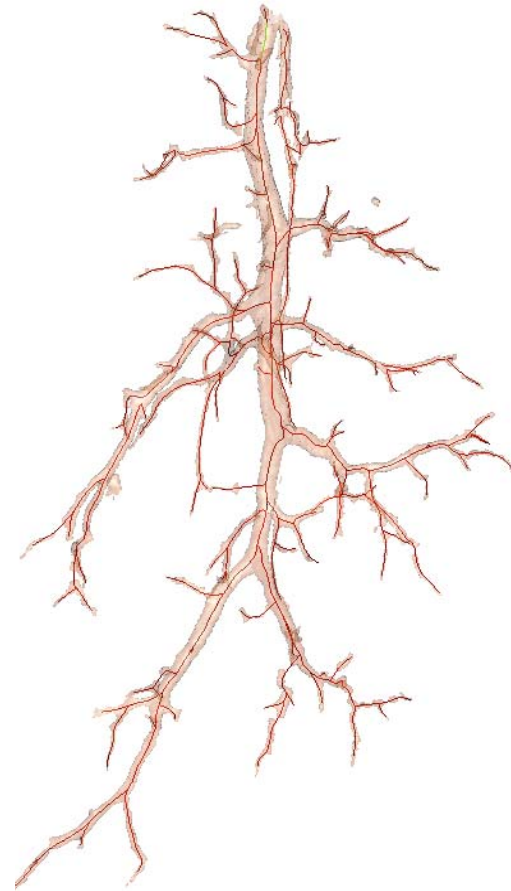


(e) refined skeleton

# Experimental Results - Control2 case (Hepatic vasculature)

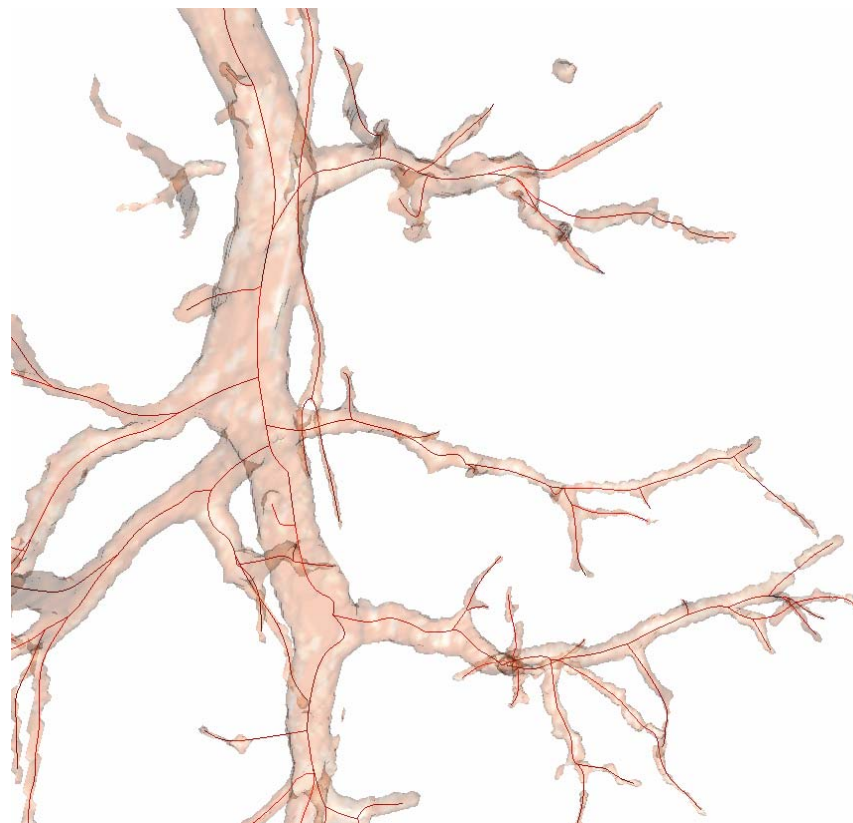
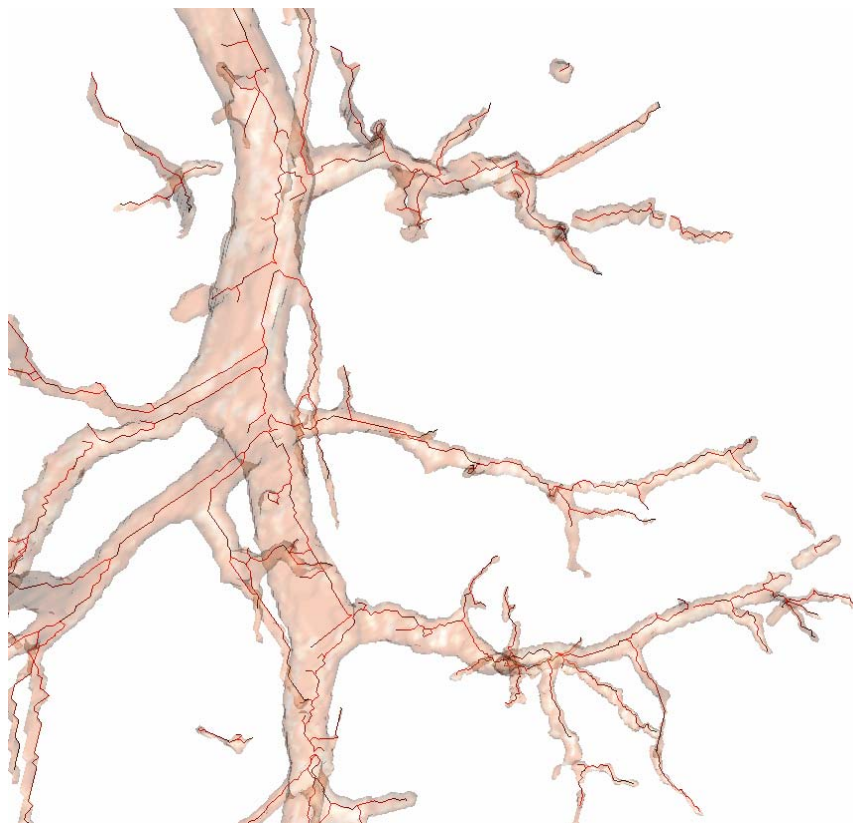


(a)



(b)

# A close look at Control2 case



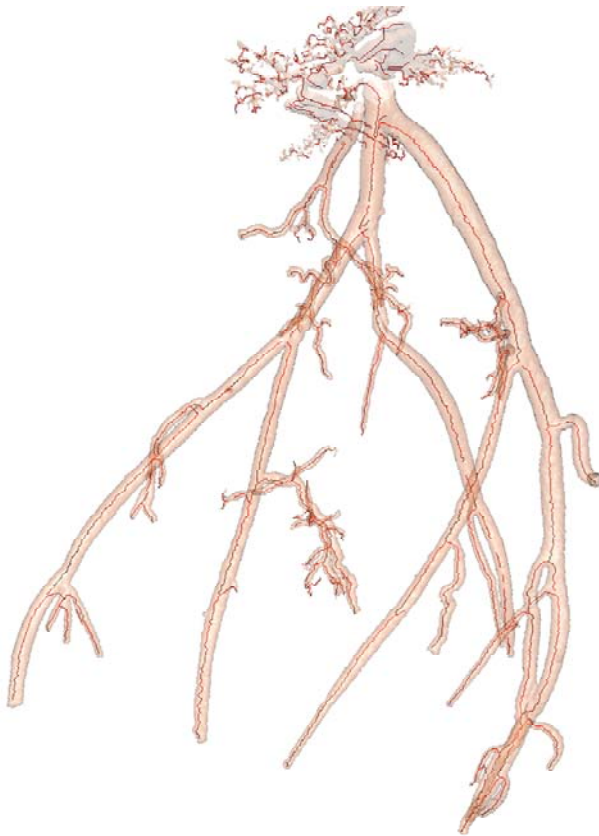
## Control2: Problems eliminated (list in Tree Diagnostician)

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

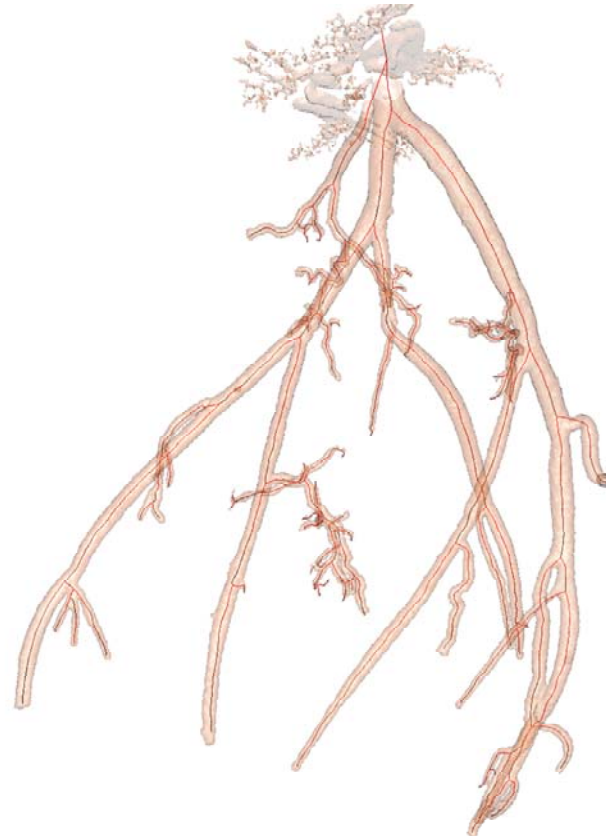
<b>Error</b>	<b>Number</b>
Branch Breaks	60
Trifurcations	5
Loops	5
Small Trees	31



# Experimental Results – H61 case



(a)



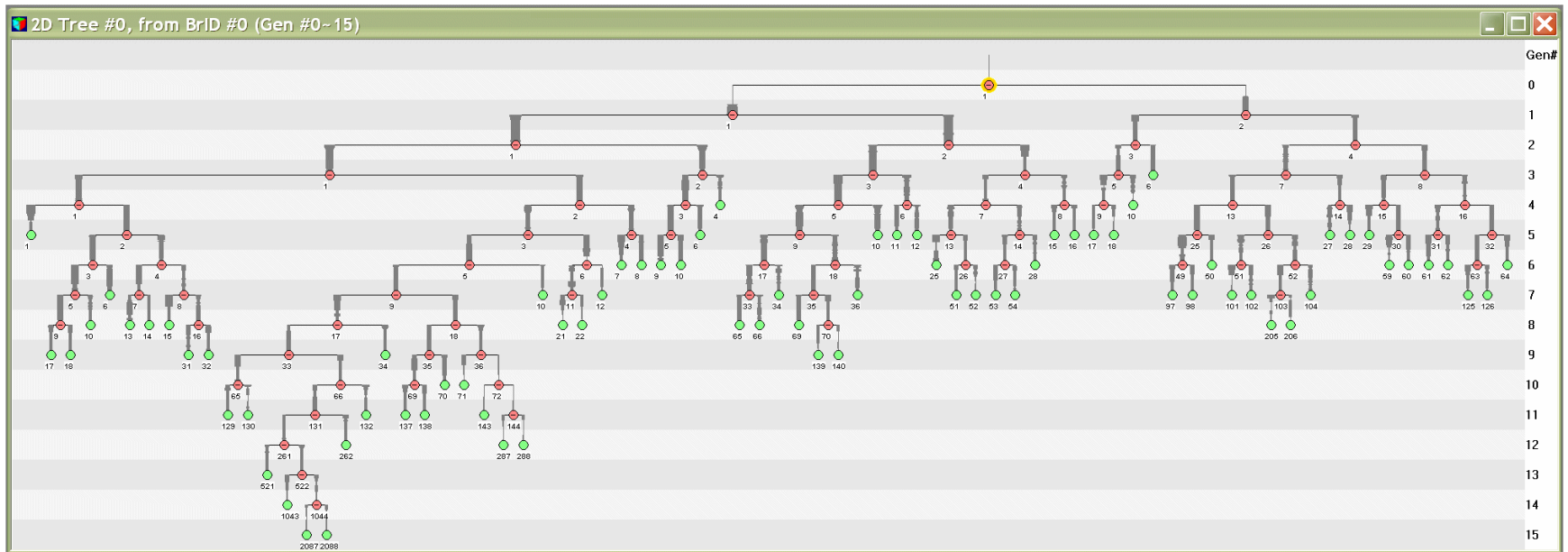
(b)

## 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

<b>Error</b>	<b>Number</b>
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.