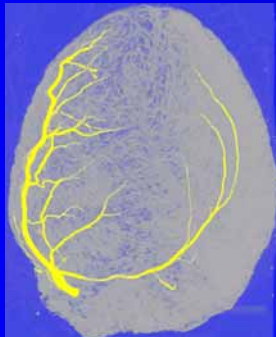
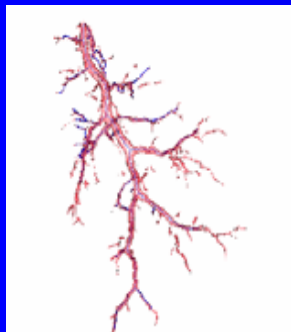
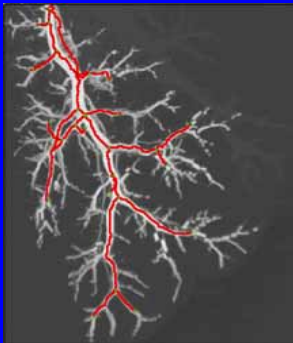


Multigenerational Analysis And Visualization of Large 3D Vascular Images



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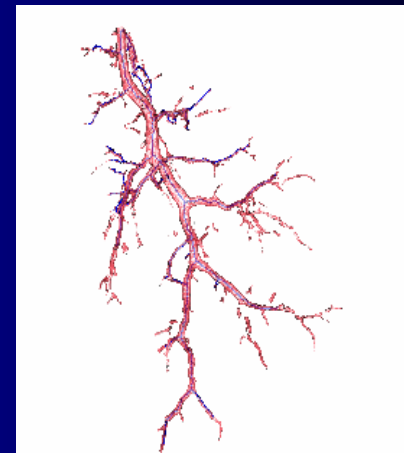
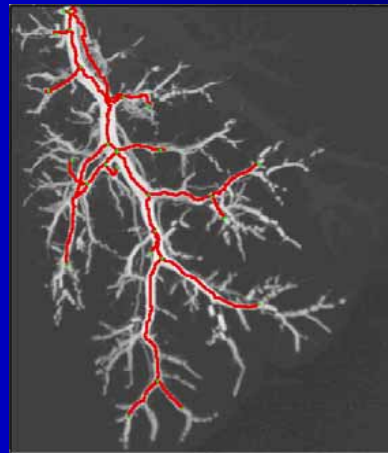
Department of Electrical Engineering, Pennsylvania State University, USA

Problem Statement

Extract embedded geometrical information in large 3D medical images containing vascular networks to perform physiological studies and identify the abnormal.



Analysis
visualization



Branching Geometric Information

- Retrieval of Analysis Statistics
- Vasculature manipulation
- Guided Navigation for Education and Surgery

Challenges

- Manual analysis is time-consuming
- Automatic analysis requires considerable
 - storage & processing space
 - computation
- Efficient network representation is critical
- Root identification
- 3D Visualization to interact with extracted information



Control1

- Size: 80.2 MB (16-bit)
- Subject: rat liver, bile ducts
- Dimensions: 399×215×491
- Voxel resolution: $\Delta x = \Delta y = \Delta z = 21 \mu\text{m}$



Control2

- Size: 114.4 MB (16-bit)
- Subject: rat liver, bile ducts
- Dimensions: 400×400×375
- Voxel resolution: $\Delta x = \Delta y = \Delta z = 21 \mu\text{m}$



Control3

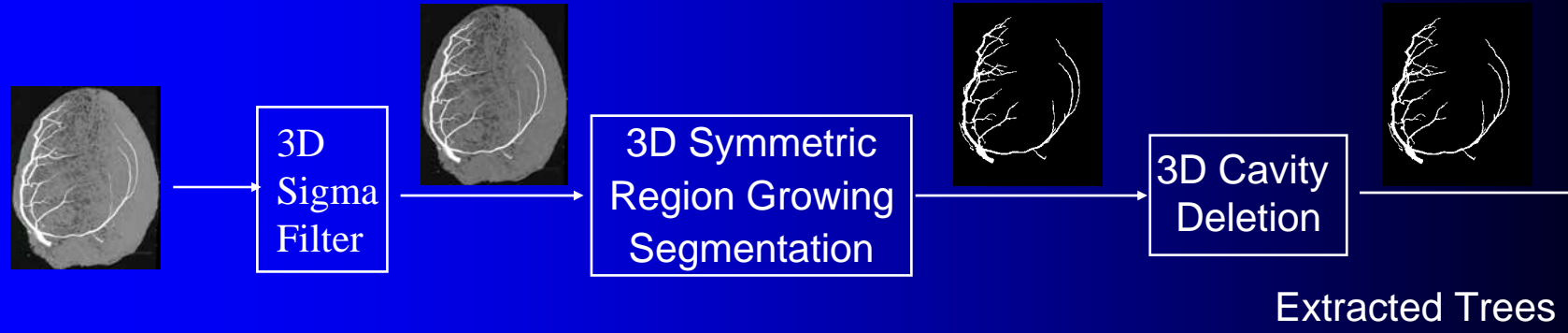
- Size: 73 MB (16-bit)
- Subject: rat liver, bile ducts
- Dimensions: 319×247×487
- Voxel resolution: $\Delta x = \Delta y = \Delta z = 21 \mu\text{m}$

Specific Aims

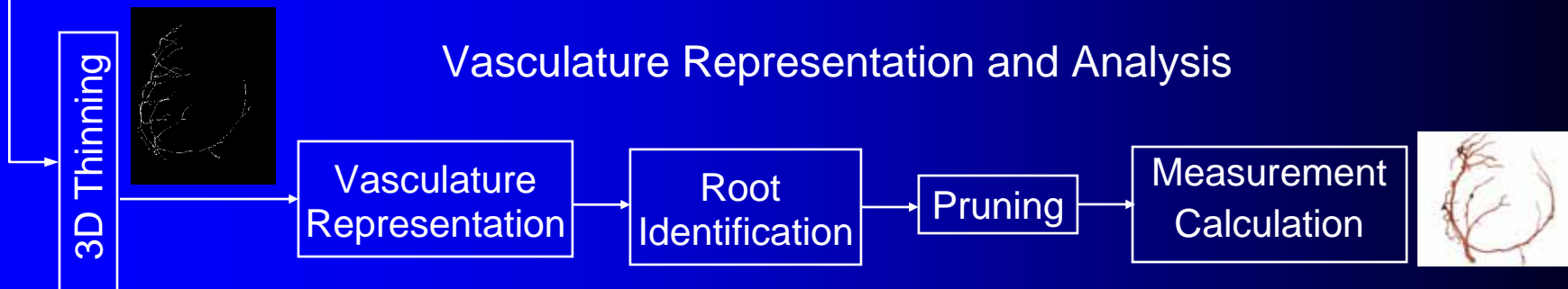
1. Devise efficient individual algorithms and integrated analysis procedure for large 3D branching networks.
2. Construct visualization tools to interact with the extracted image information.
3. Validation.

Analysis Procedure for 3D Vascular Images

Extraction of Regions of Interest



Vasculature Representation and Analysis



Generational Analysis of Control1

Generation Information -- control1

Number of Tree Objects = 1

Generation-Level Summary

[GenID] Generation ID
 [NumBr] Number of Branches
 [AvgBrLen] Average Branch Length
 [NumCS] Number of Cross Sections (CS)
 [AvgCSA] Average CSA of all CS in this generation
 [DevCSA] CSA deviation among CSs
 [AvgBrCSA] Average CSA of Branches in this generation
 [DevBrCSA] CSA deviation among Branches
 [AvgSurf] Average Surface Area of branches
 [DevSurf] Surface Area Deviation
 [AvgVol] Average Volume of branches
 [Avg2Root] Average Distance from Root to Branches
 [Dev2Root] Deviation of the Distance from Root to Branches

Tree# 0

GenID	NumBr	AvgBrLen	NumCS	AvgCSA	DevCSA	AvgBrCSA	DevBrCSA	AvgSurf	DevSurf	AvgVol	DevVol	Avg2Root	Dev2Root
0	1	4.00	5	36.80	10.09	36.80	0.00	106.54	0.00	184.00	0.00	0.00	0.00
1	2	44.50	111	177.41	103.40	179.14	64.21	2514.78	404.37	9846.00	3295.00	4.00	0.00
2	4	45.00	232	132.22	128.28	120.61	73.93	2050.86	1113.12	7668.50	5442.53	48.50	1.50
3	4	41.75	221	188.93	151.12	189.10	132.77	2378.57	1367.50	10438.50	8604.58	106.50	17.50
4	4	25.25	134	101.51	191.20	127.70	99.28	1050.46	706.34	3400.75	2440.08	155.50	17.50
5	6	40.83	320	59.49	107.62	89.50	88.37	1257.88	1103.02	3173.00	2779.30	187.33	3.09
6	6	28.17	225	94.55	75.57	87.26	56.36	1186.93	786.66	3545.50	3322.97	208.00	14.17
7	6	46.33	361	87.80	69.57	92.85	53.40	1871.85	1256.47	5282.33	3814.85	231.00	17.11
8	4	22.50	119	103.21	179.31	160.48	159.76	930.49	658.23	3070.50	2324.07	252.50	22.50
9	4	36.75	190	75.58	120.14	91.17	95.83	1201.57	516.41	3590.25	2942.27	262.50	18.50
10	2	28.00	77	88.08	20.71	88.27	14.70	1271.93	90.65	3391.00	522.00	307.00	0.00
11	4	46.00	242	81.55	53.96	67.54	38.37	1812.30	1236.26	4933.75	3880.53	335.00	0.00
12	2	39.00	102	48.25	27.52	48.87	1.50	1222.21	498.93	2461.00	950.00	393.00	0.00
13	2	44.50	127	27.73	11.72	26.06	5.75	1160.10	451.71	1761.00	847.00	449.00	0.00

Branching Analysis of Control1 – an excerpt

Branch-Level Summary

[GenID] Generation ID
 [BrID] Branch ID
 [ParID] Parent ID
 [BrLen] Branch Length
 [NumCS] Number of Cross Sections (CS)
 [AvgCSA] Average CSA of all CS in this branch
 [DevCSA] CSA deviation
 [Len2Dia] $\text{Log}(\text{BrLen}) / \text{Log}(\text{AvgCSA})$
 [Surface] Surface Area of this Branch
 [Volume] Volume of this Branch
 [Dist2Root] Distance from Root to this Branch
 [VolumeLoss] $1 - (\text{Dd1}^3 / \text{Dm}^3) - (\text{Dd2}^3 / \text{Dm}^3) - \dots - (\text{Ddn}^3 / \text{Dm}^3)$

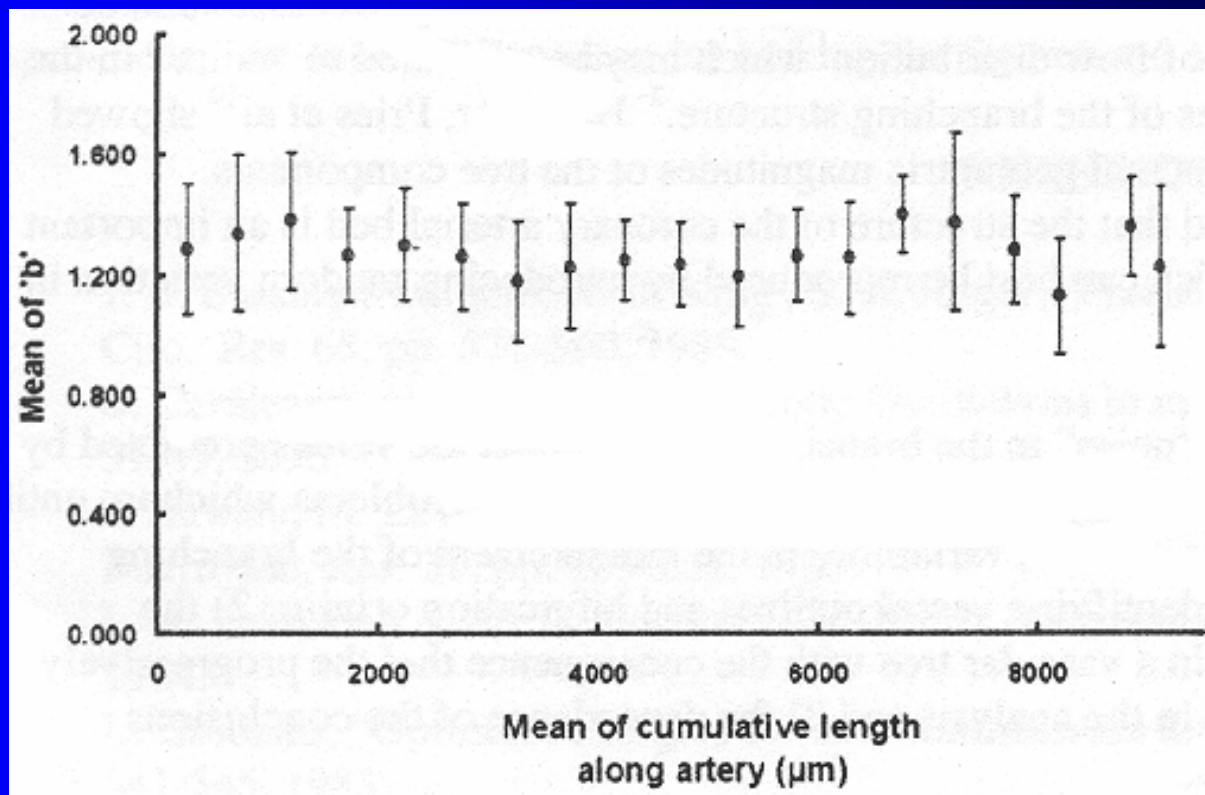
Tree# 0

GenID	BrID	ParID	BrLen	NumCS	AvgCSA	DevCSA	Len2Dia	Surface	Volume	Dist2Root	VolumeLoss
0	0	-1	4	5	36.80	10.09	0.72	106.54	184.00	0.00	-20.58
1	1	0	46	57	114.93	53.65	1.55	2110.41	6551.00	4.00	-0.13
1	46	0	43	54	243.35	101.25	1.32	2919.15	13141.00	4.00	-0.04
2	2	1	74	95	146.88	172.79	1.76	3459.64	13954.00	50.00	-6.17
2	45	1	29	38	39.74	31.92	1.78	790.75	1510.00	50.00	1.00
2	47	46	42	53	228.96	81.10	1.32	2804.96	12135.00	47.00	-0.25
2	50	46	35	46	66.85	77.25	1.72	1148.10	3075.00	47.00	1.00
3	3	2	49	60	368.68	99.42	1.27	4049.17	22121.00	124.00	0.37
3	40	2	14	19	99.05	62.66	1.11	643.56	1882.00	124.00	-0.28
3	48	47	61	83	29.99	25.72	2.35	1495.08	2489.00	89.00	1.00
3	49	47	43	59	258.68	79.72	1.30	3326.46	15262.00	89.00	1.00
4	4	3	10	12	291.75	305.21	0.80	661.72	3501.00	173.00	-0.36
4	31	3	17	23	73.96	39.65	1.27	675.30	1701.00	173.00	-0.20
4	41	40	51	64	114.59	87.09	1.62	2272.65	7334.00	138.00	0.63
4	44	40	23	35	30.49	41.83	1.86	592.16	1067.00	138.00	1.00
5	5	4	6	7	285.57	20.75	0.61	419.05	1999.00	183.00	0.20
5	30	4	116	151	61.40	83.37	2.33	3649.03	9271.00	183.00	1.00
5	32	31	33	43	62.60	16.22	1.60	1195.00	2692.00	190.00	-1.39
5	37	31	22	27	39.04	31.08	1.64	557.87	1054.00	190.00	-0.23
5	42	41	34	44	55.36	47.08	1.74	1054.47	2436.00	189.00	1.00

More analysis not shown

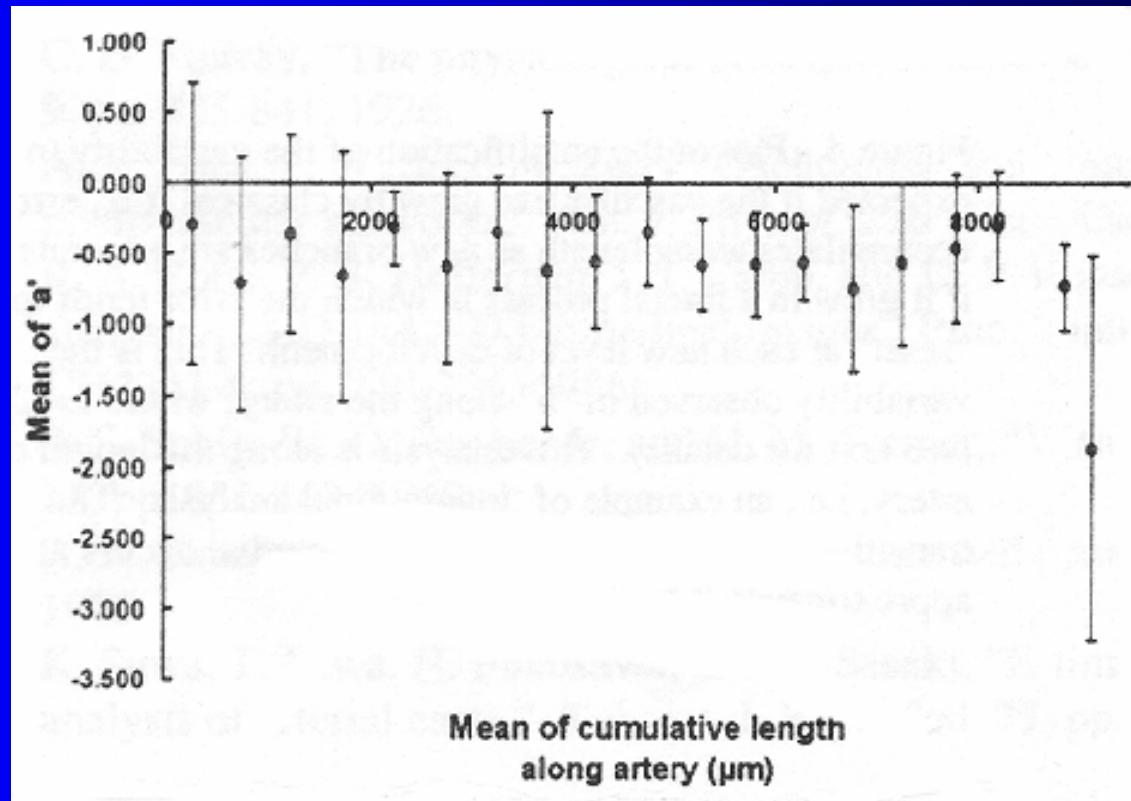


Variation of Branch Diameters vs. Cumulative Lengths



$$L = cD^b$$

Volume Loss Analysis



$$1 - (D_{d1}^3/D_m^3 + D_{d2}^3/D_m^3) = a$$

Problems With Traditional Image Viewing

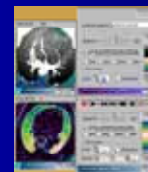
- Only Two-Dimensional Views
- Restricted Viewing Directions
- Can't Retrieve Extracted and Computed Geometrical Information
- Lack of Global Views of the Vasculature

Visualization of Geometrical Information

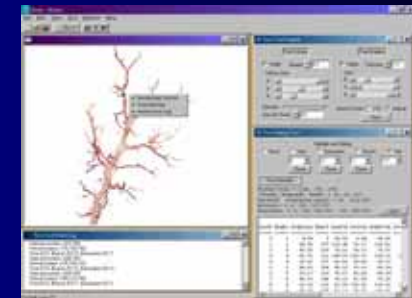
- Determine intensity range of regions of interest
- Estimate root location of the branching structure
- Display quantitative analysis results
- Dynamically interact with the extracted vasculature

1. 3D Viewers

- 3D Slicer Tools
- 3D-to-2D Projection Tools



2. 3D Tree Tool



2D Slicer Tools

Transverse Slicer Control

Transverse Slicer

SliceNo 78

Scale 1.0

Equalization

Color Control

Gray Red Green Blue

File E:\Database\Demo\Rainb

Brightness 50%

Spectrum

Navigation buttons: Red circle, Left arrow, Double left arrow, Double right arrow, Square, Vertical bar, Refresh, Right arrow

(125,198,78) 1

histogram equalization

color table selection

point of selection
and its gray-level
value

Transverse Projection Control

Transverse Projec...

Scale 1.0

Equalization

Color Control

Gray Red Green Blue

File E:\Database\Demo\Split.256

Brightness 50%

Spectrum

Navigation buttons: Red circle, Left arrow, Double left arrow, Double right arrow, Square, Vertical bar, Refresh, Right arrow

(184,167,0) 255

Projection Method Maximum Intensity

Apply

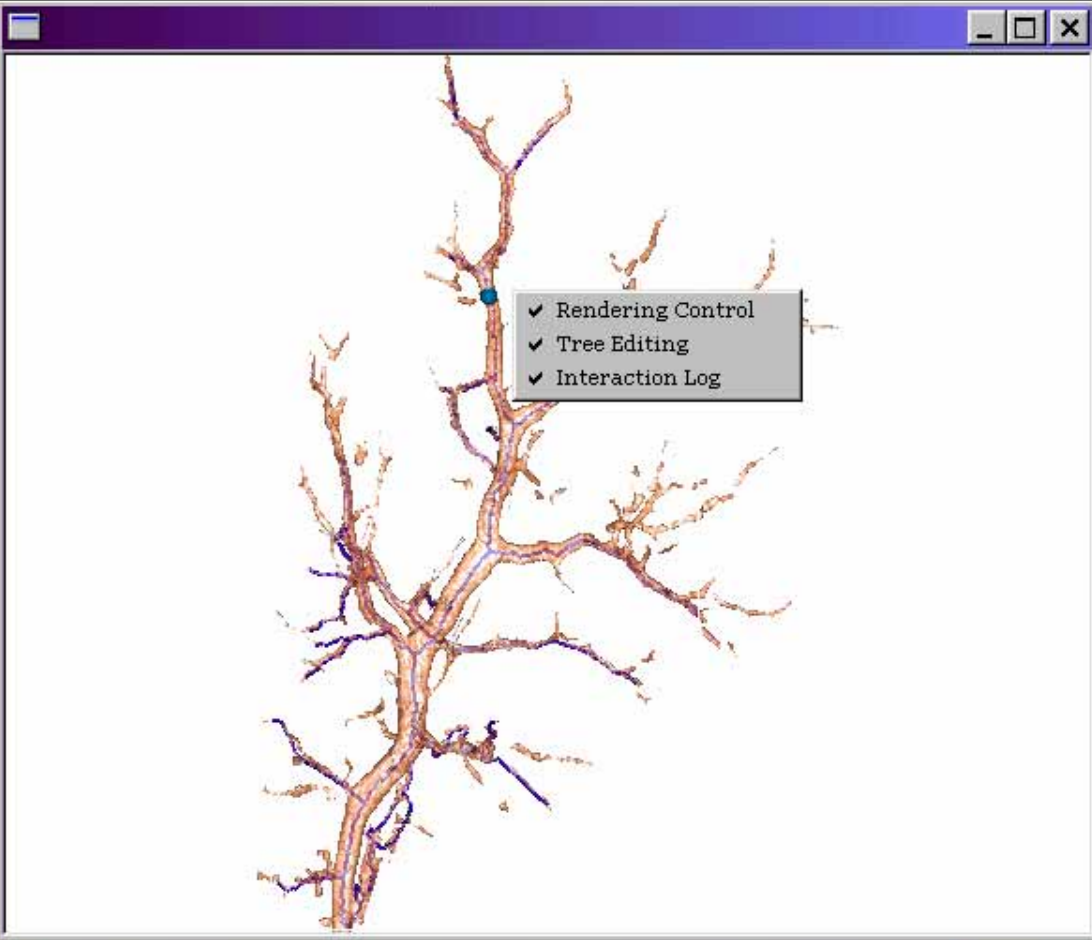
color table entry# 0

color table entry# 255

3D-2D Projection Tools

SD Studio - Studio1

File Edit View Tool Window Help



3D Tree Tool Control

Tree Surface

Visible Opacity

Diffuse Color

R

G

B

Specular

Specular Power

Tree Skeleton

Visible Thickness

Color

R

G

B

Specular

Specular Power

Specular

Specular Power

Mouse Control VTK Manual

Close

3D Tree Editing Tool

Highlight and Editing

None Tree Generation Branch Site

Prune Prune Prune

Tree Geometry

Picked voxel = (140, 133, 145)
 (TreeID, BranchID, GenID) = (0, 11, 11)
 ParentID (branching angle) = 10 (111.26)
 #sisters: 1 => (16, 117.65)
 #children: 2 => (12, 103.26) (15, 143.41)

<<Less

GenID	NumBr	AvgBrLen	NumCS	AvgCSA	DevCSA	AvgBrCSA	Dev
0	1	4.00	5	28.60	6.44	28.60	
1	2	44.50	107	118.48	72.17	120.61	
2	4	45.00	220	76.21	76.71	76.01	
3	4	41.75	212	149.05	130.75	150.61]
4	4	25.25	127	62.01	39.89	66.63	
5	6	40.83	304	49.22	70.35	66.54	
6	6	28.17	214	76.67	66.64	69.94	
7	6	46.33	346	76.23	51.99	78.20	
8	4	22.50	110	67.58	158.55	130.22]
9	4	36.75	178	55.11	76.67	63.81	

Tree Tool Event Log

Selected position: (310,304)
 Picked location: (178,130,190)
 [Tree ID] 0, [Branch ID] 19, [Generation ID] 11
 Selected position: (256,342)
 Picked location: (125,143,127)
 [Tree ID] 0, [Branch ID] 15, [Generation ID] 12
 Selected position: (254,330)
 Picked location: (140,133,145)
 [Tree ID] 0, [Branch ID] 11, [Generation ID] 11

For Help, press F1

Summary and Future Work

1. 3D image processing and analysis procedure
2. Perform comprehensive generational analysis on networks contained in 3D images
3. Visualization tools
 - ❖ Offer global view of extracted branching structures
 - ❖ Display branching geometric information
 - ❖ Interactively edits of the branching structures
4. Java implementation of the analysis system
5. Studies on Medical Education and Image-Guided Surgery
6. Improvements on the 3D Rendering Tools.



Thank you !