Vessel tree modelling and 3D analysis

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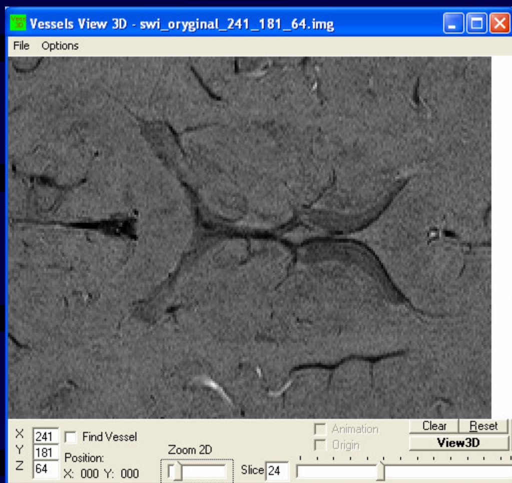
Collaborative research (Bergen, Jena, Lodz)

- Vascular tree growth simulation
- Modelling viscosity, blood flow, pressure drop and drug delivery
- Segmentation and visualization of vasculature from real and simulated data
- Vessel tracking and volume estimation
- 3D texture
- Perfusion
- Verification on phantom data

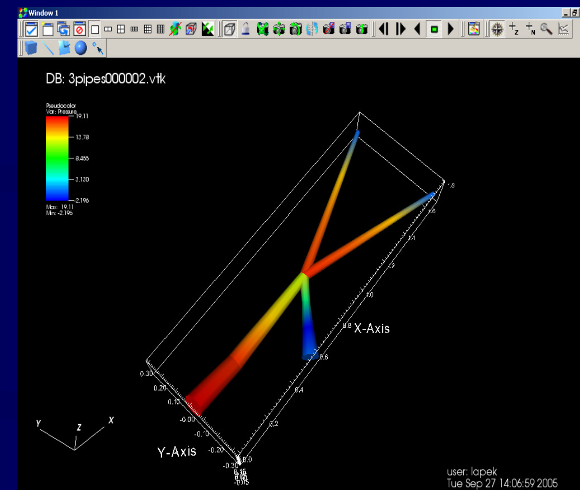
Topics example

3D MRI Data



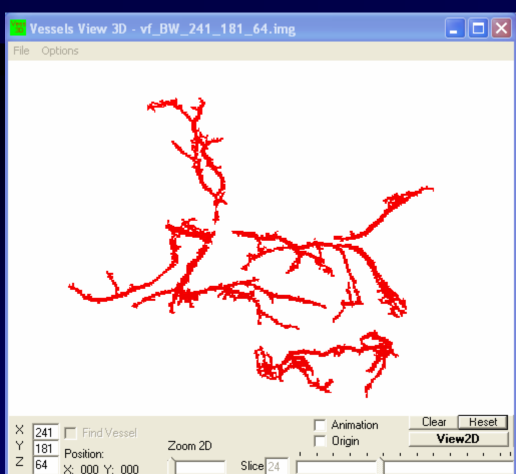
comparison

Pressure drop & flow simulation

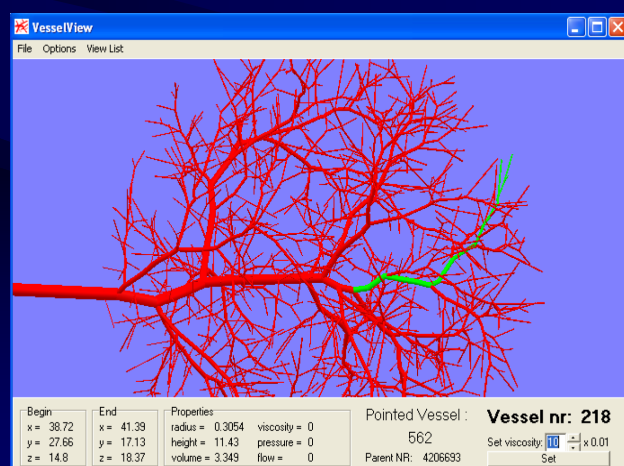


Vascular Tree Generation

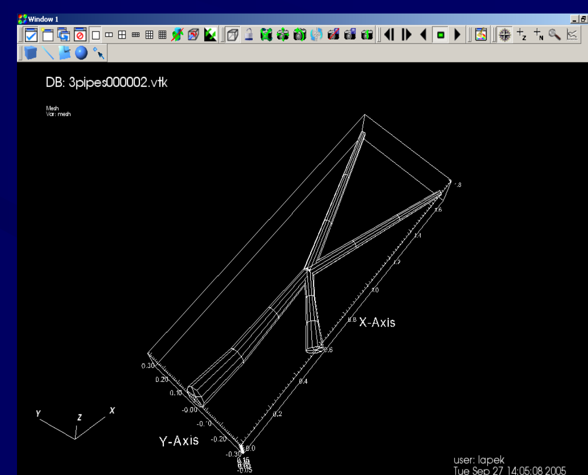
(geometry, flow, pressure drop, viscosity)



3D segmentation of a vessel



3D model of a vessel



Mesh generation

COST presentations

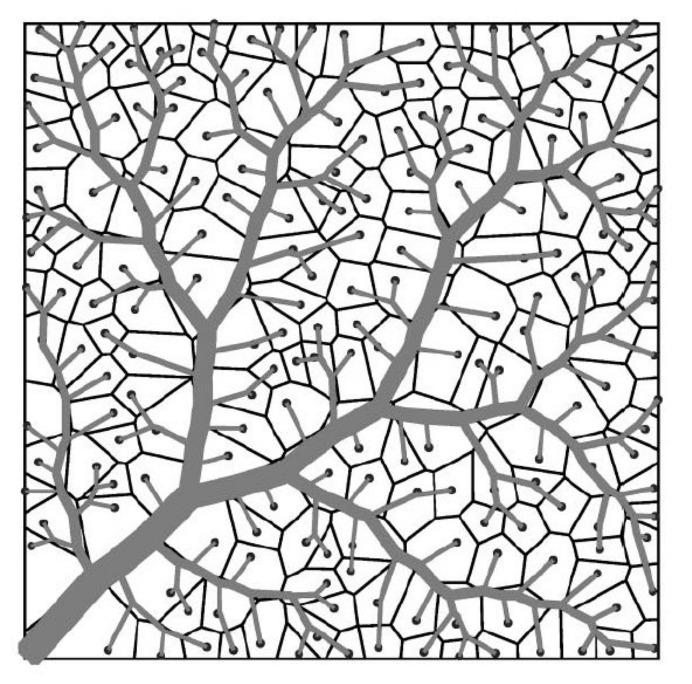
- Computer modelling of vascular tree growth and drug release simulation *(Kocinski, Dundee 2004)*
- Venous vessel extraction from high-resolution MRI data *(Deistung, Lodz 2005)*
- Vascular model generation *(Lundervold, Lodz 2005)*

3D texture of tree data

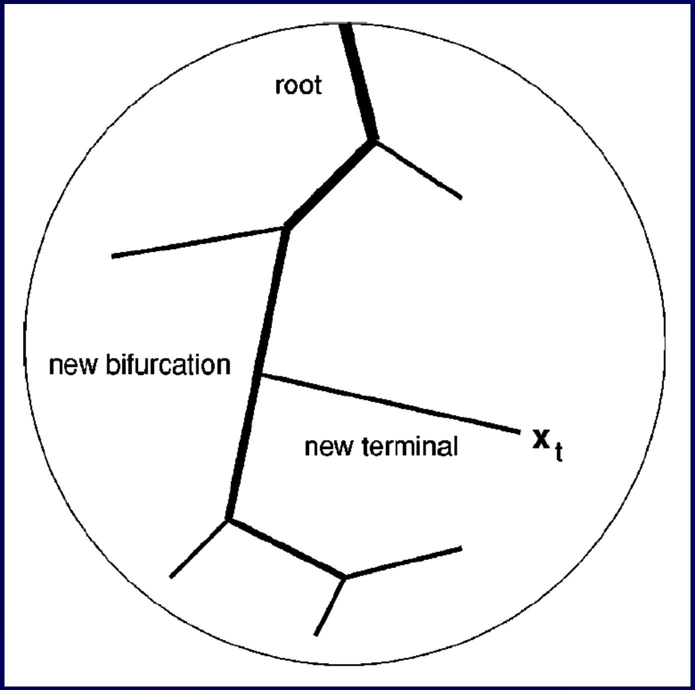
- Parameterised vessel tree simulation *(vectors in 3D)*
- Tree volume discretization *(3D grey level images)*
- 2D & 3D texture of images *(correlation with tree parameters)*

Vascular tree modelling

Universite de Rennes, France



University of Vienna, Austria



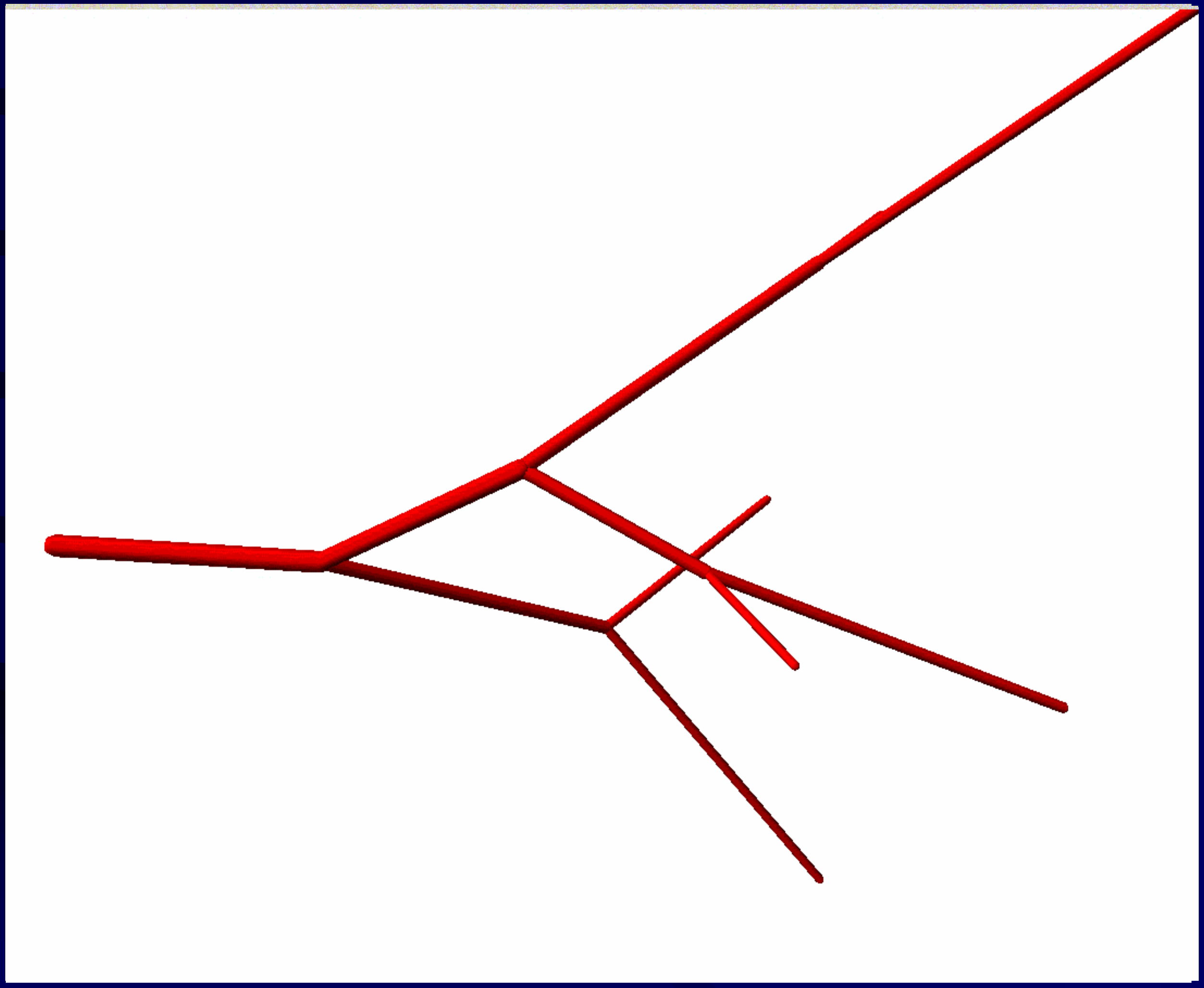
Based on R. Karch, *Voronoi Polychedra Analysis of Optimised Arterial Tree Models*

When organ reaches its adult shape

Stop

After adding specified number of branches

Adding new terminal point

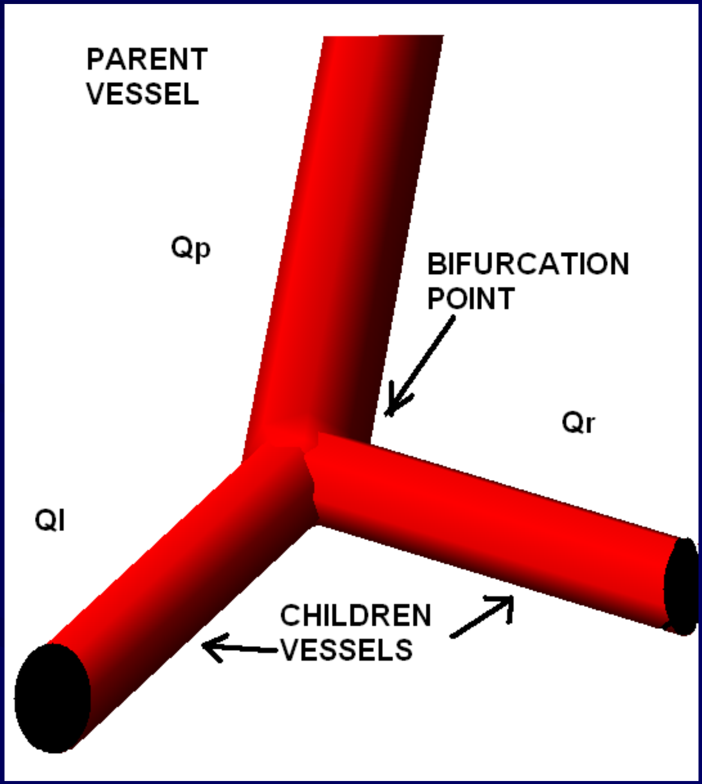


Physical laws

- Matter preservation law

$$Q_p = Q_l + Q_r$$

Q_p –blood flow in the parent vessel
$Q_{r,l}$ – blood flows in the left and right children branches

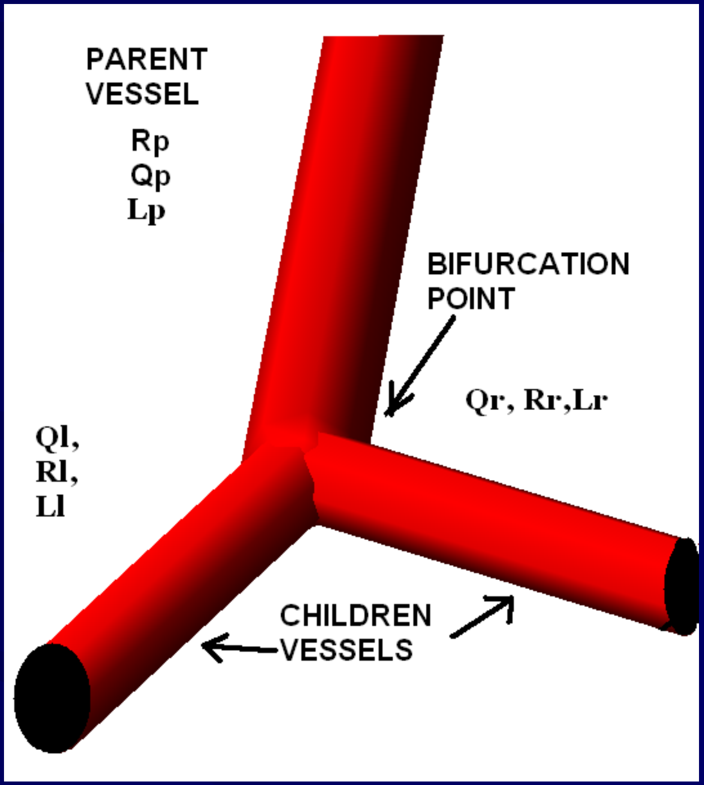


Physical laws

- Poiseuilles law

$$\Delta P = Q \cdot \frac{8 \cdot \mu \cdot l}{\pi \cdot R^4}$$

  - μ blood viscosity
  - Q blood flow in vessel
  - l - vessel length
  - R – vessel radius



- Bifurcation law

$$R_b^{\gamma} = R_r^{\gamma} + R_l^{\gamma}$$

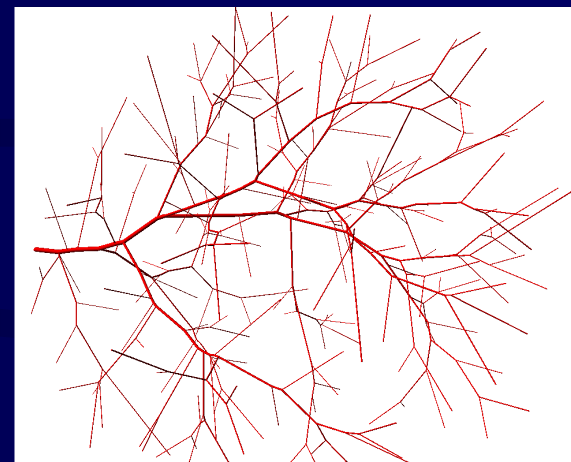
  - γ =2.55,...,3 – bifurcation exponent

Vascular tree growth inside specified volume

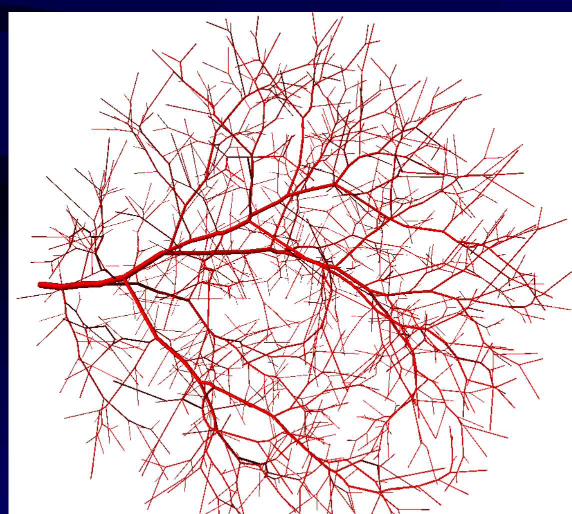
Perfusion pressure

Perfusion flow

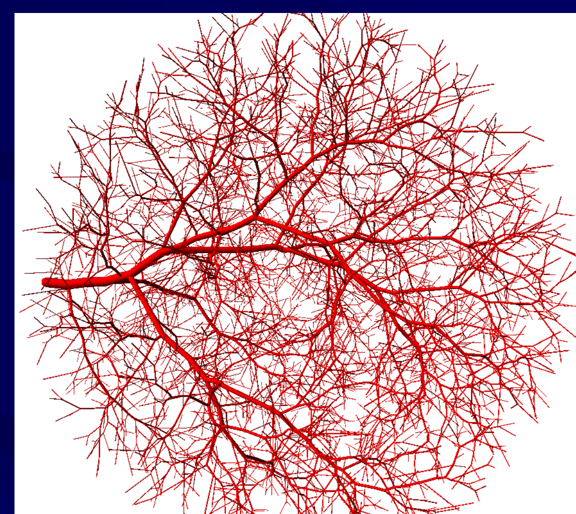
20 terminal branches



200 terminal branches



1000 terminal branches



4000 terminal branches

Terminal pressure

Tree parameters example

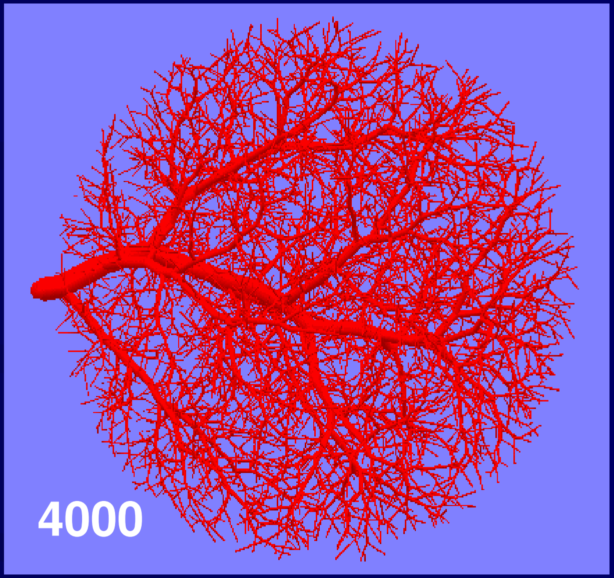
V_{perf}	Perfusion volume	100 cm^3
p_{perf}	Input pressure	100 mmHg
p_{term}	Output pressure	60 mmHg
Q_{perf}	Input flow	0.5 l/min
N_{term}	Terminal branches count	4 000
Q_{term}	Output flow	0.125 ml/min
η	Viscosity	3.6 cP
γ	Bifurcation exponent	3

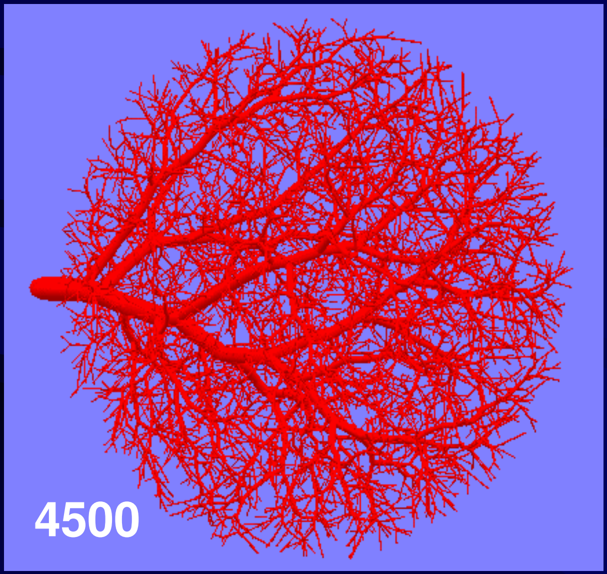
Tree examples

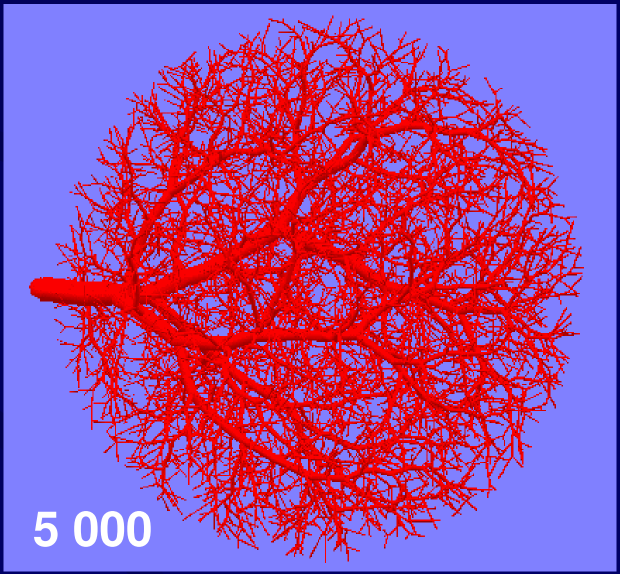
- Terminal branches count
- Viscosity

Trees, Q_{term} = 0.125 ml/min

Terminal count	Input flow
4 000	0.500
4 500	0.562
5 000	0.625

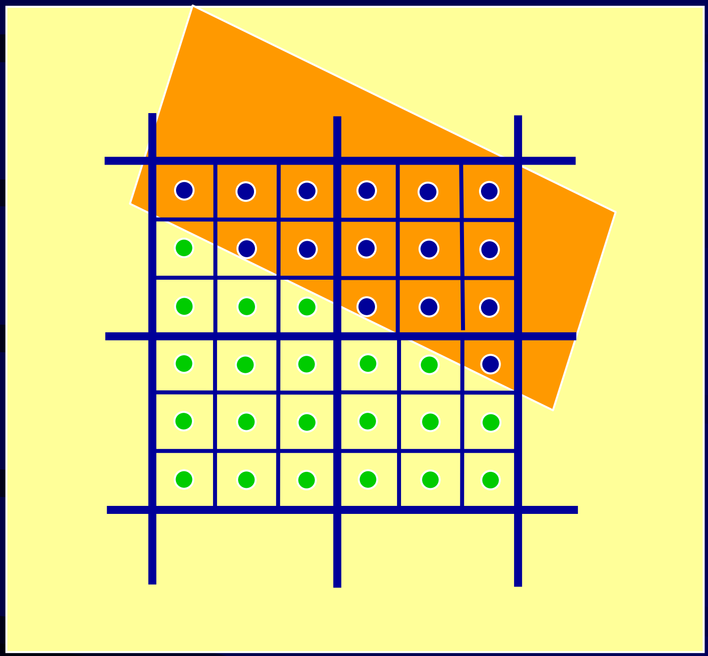


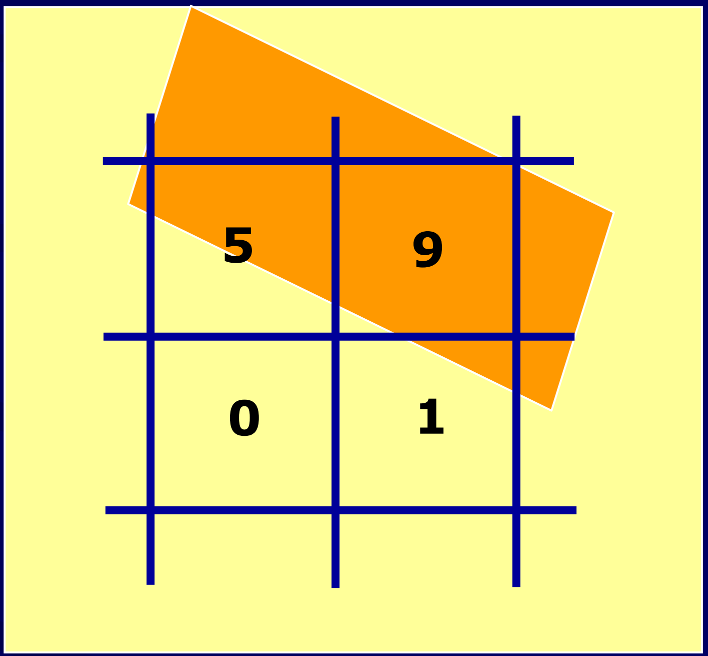




Viscosity = 3.6 cP

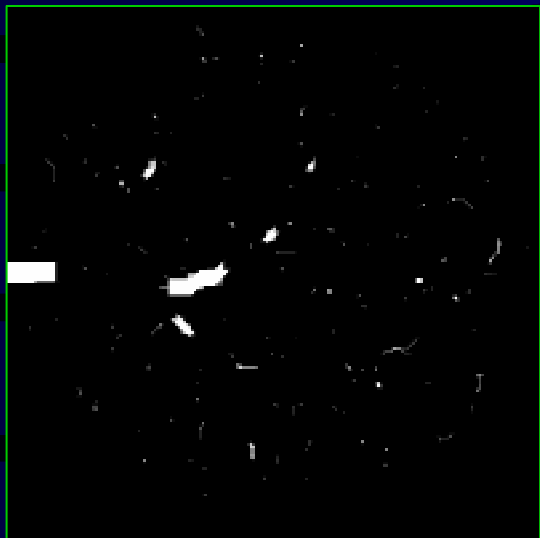
Discretization – box counting

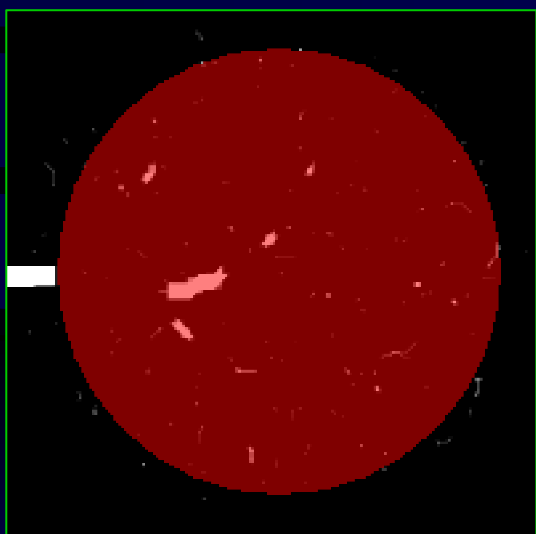


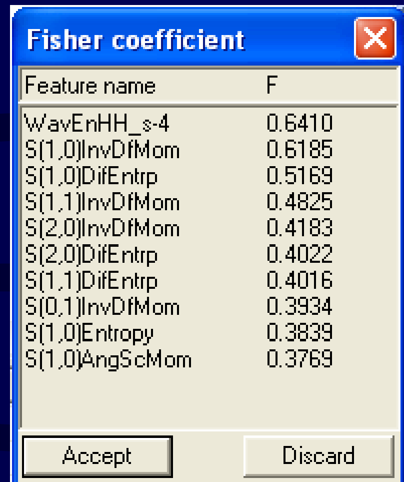


- 2D: 0,1,…,9
- 3D: 0,1,…,27

2D texture







Fisher coefficient

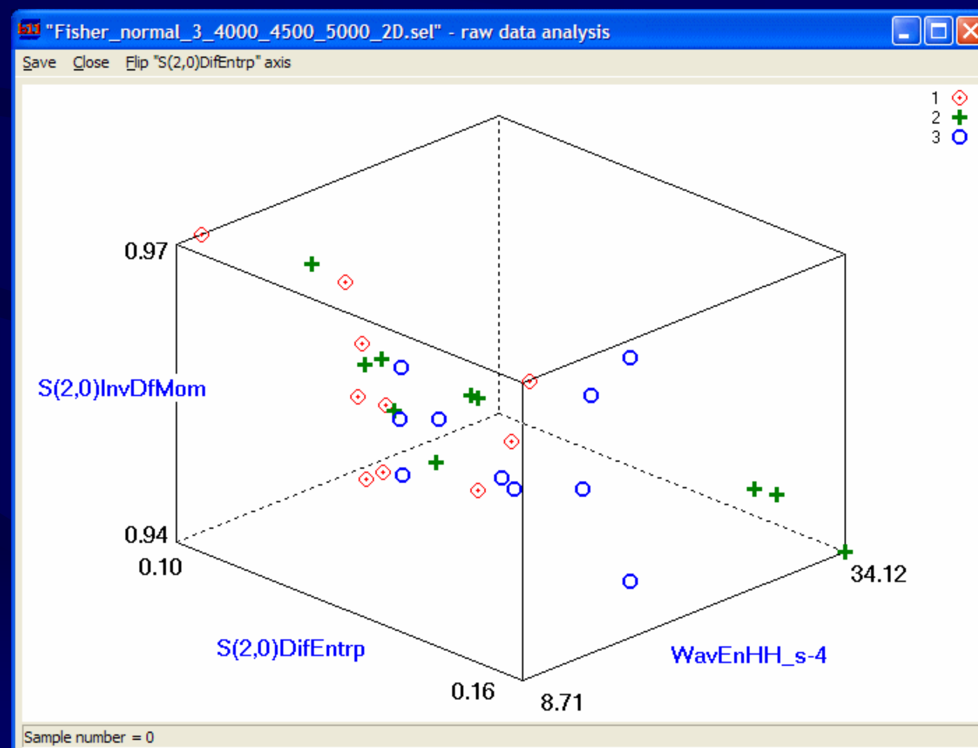
Feature name	F
WavEnHH_s-4	0.6410
S(1,0)InvDfMom	0.6185
S(1,0)DifEntrp	0.5169
S(1,1)InvDfMom	0.4825
S(2,0)InvDfMom	0.4183
S(2,0)DifEntrp	0.4022
S(1,1)DifEntrp	0.4016
S(0,1)InvDfMom	0.3934
S(1,0)Entropy	0.3839
S(1,0)AngScMom	0.3769

Accept Discard

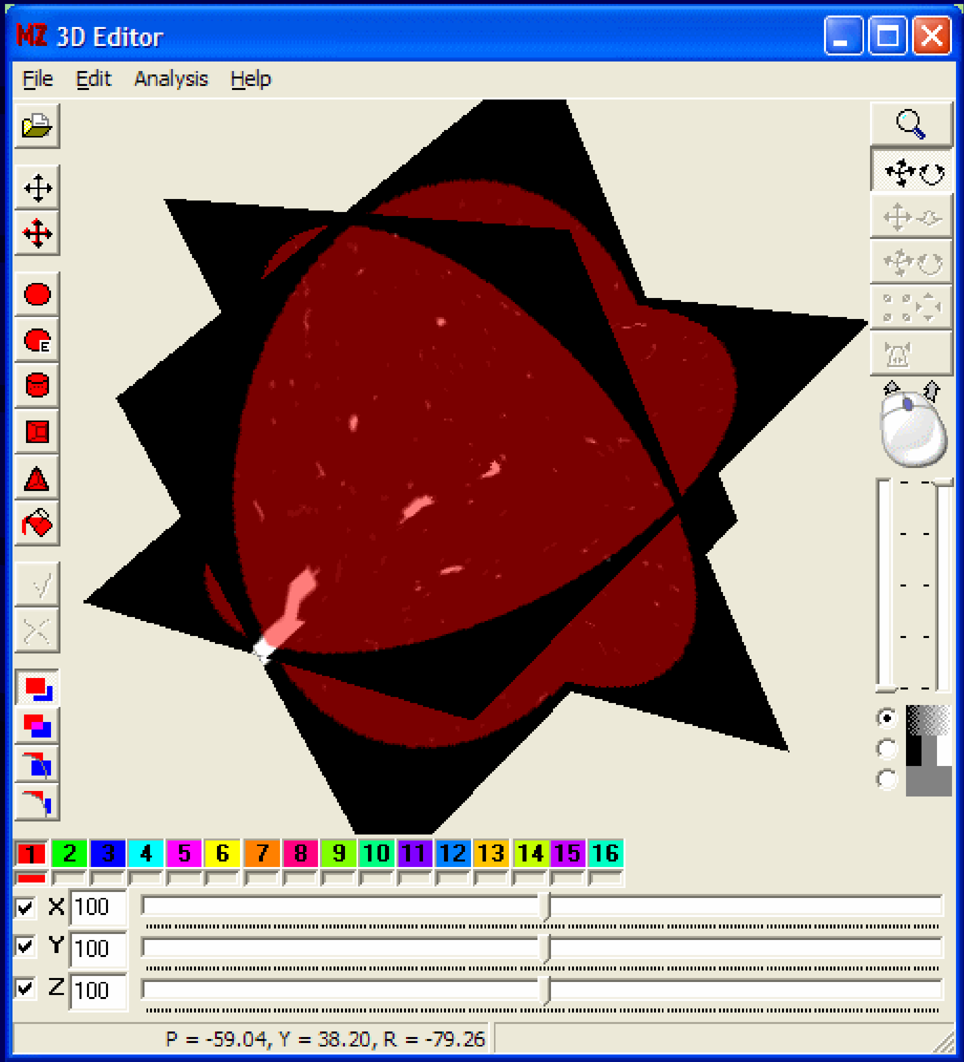
N = 4000, 4500, 5000

Qterm = 0.125 ml/min

1-NN error rate = 17/30



3D texture



3D Editor
File
Edit
Analysis
Help
1
2
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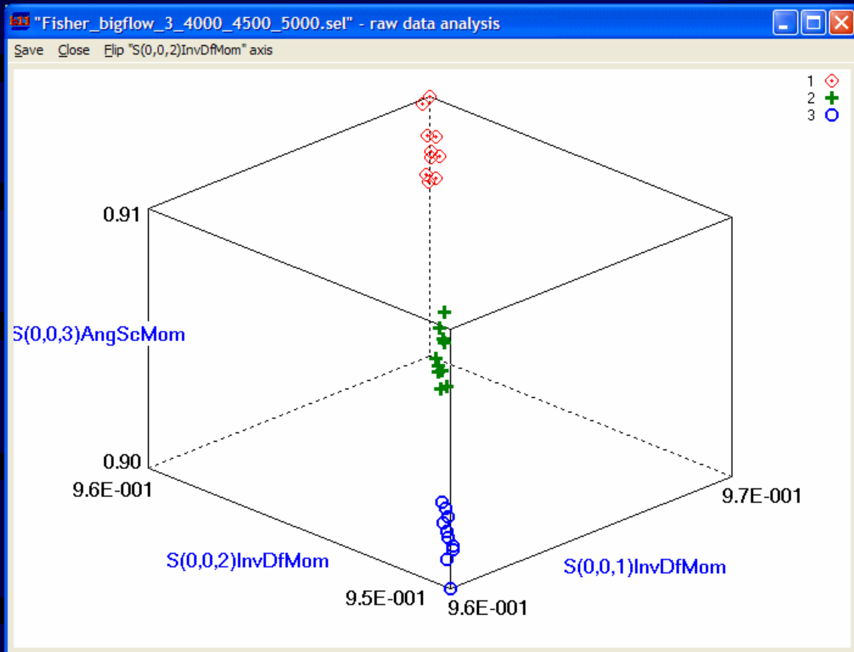
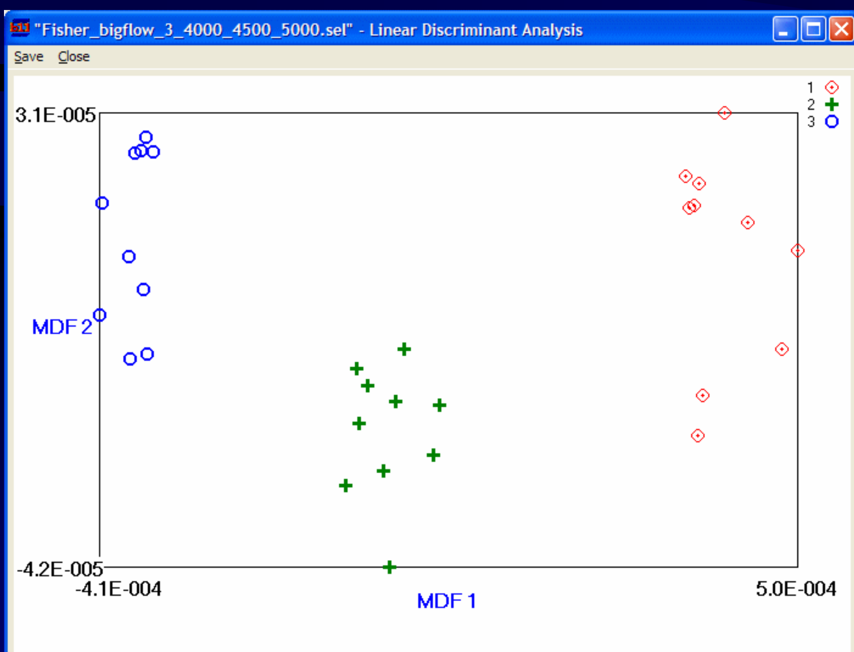
15
16
X 100
Y 100
Z 100
P = -59.04, Y = 38.20, R = -79.26

3D texture





N = 4000, 4500, 5000

Qterm = 0.125 ml/min

Fisher coefficient

Feature name	F
S(0,0,3)InvDfMom	125.1067
S(0,0,4)InvDfMom	115.7743
S(0,0,2)InvDfMom	115.2718
S(3,3,0)InvDfMom	114.6140
S(0,0,1)InvDfMom	112.2724
S(0,0,3)AngScMom	111.6212
S(4,4,0)InvDfMom	110.7589
S(0,0,5)InvDfMom	109.7422
S(0,0,4)AngScMom	108.3557
S(2,2,0)InvDfMom	106.8670

Accept Discard

1-NN error rate = 0/30

Trees, Q_{perf} = 0.5 l/min

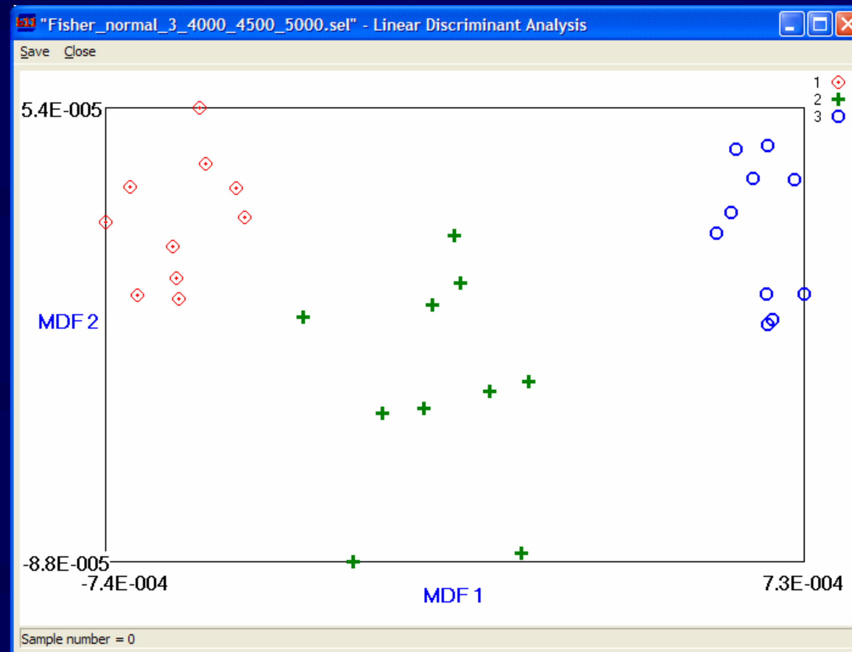
Fisher coefficient

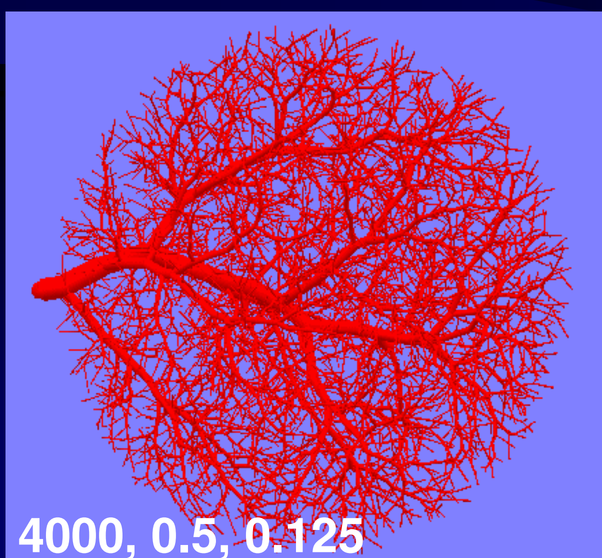
Feature name	F
S(0,0,3)DifEntrp	55.4535
S(0,0,5)DifEntrp	53.9816
S(0,0,2)DifEntrp	53.8931
S(0,0,4)DifEntrp	53.4033
S(0,0,3)InvDfMom	52.6955
S(0,0,2)InvDfMom	51.7798
S(0,1,0)InvDfMom	51.7406
S(1,0,0)InvDfMom	50.9022
S(1,1,0)InvDfMom	50.3863
S(2,2,0)DifEntrp	50.0553

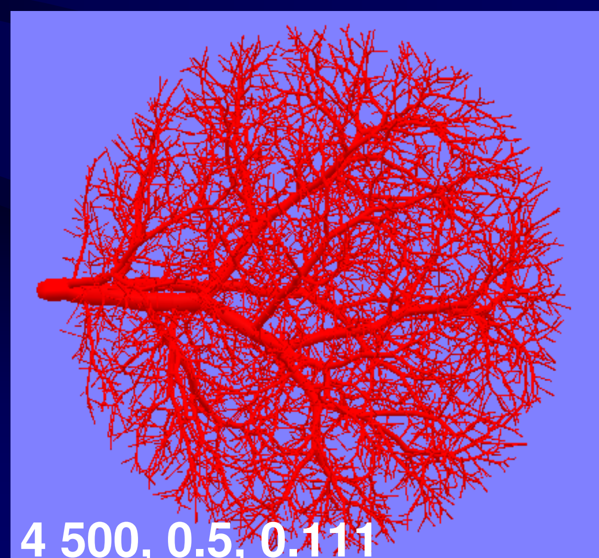
Accept   Discard

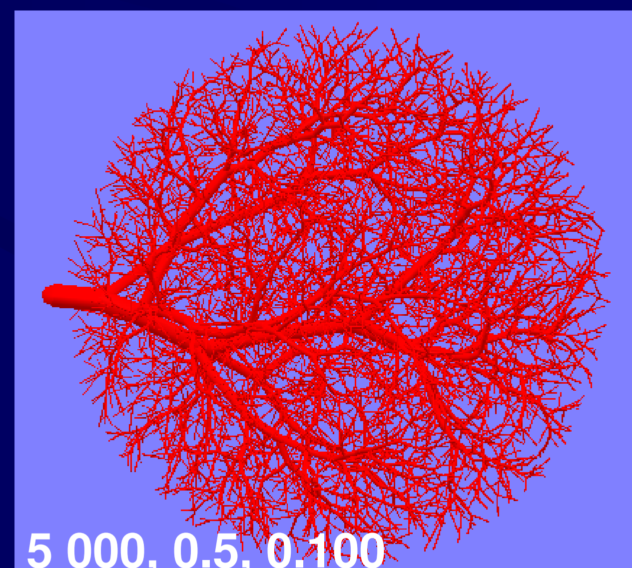
Viscosity = 3.6 cP

1/30
F=67









Trees, 0.5 l/min, noise

$N(0,0)$

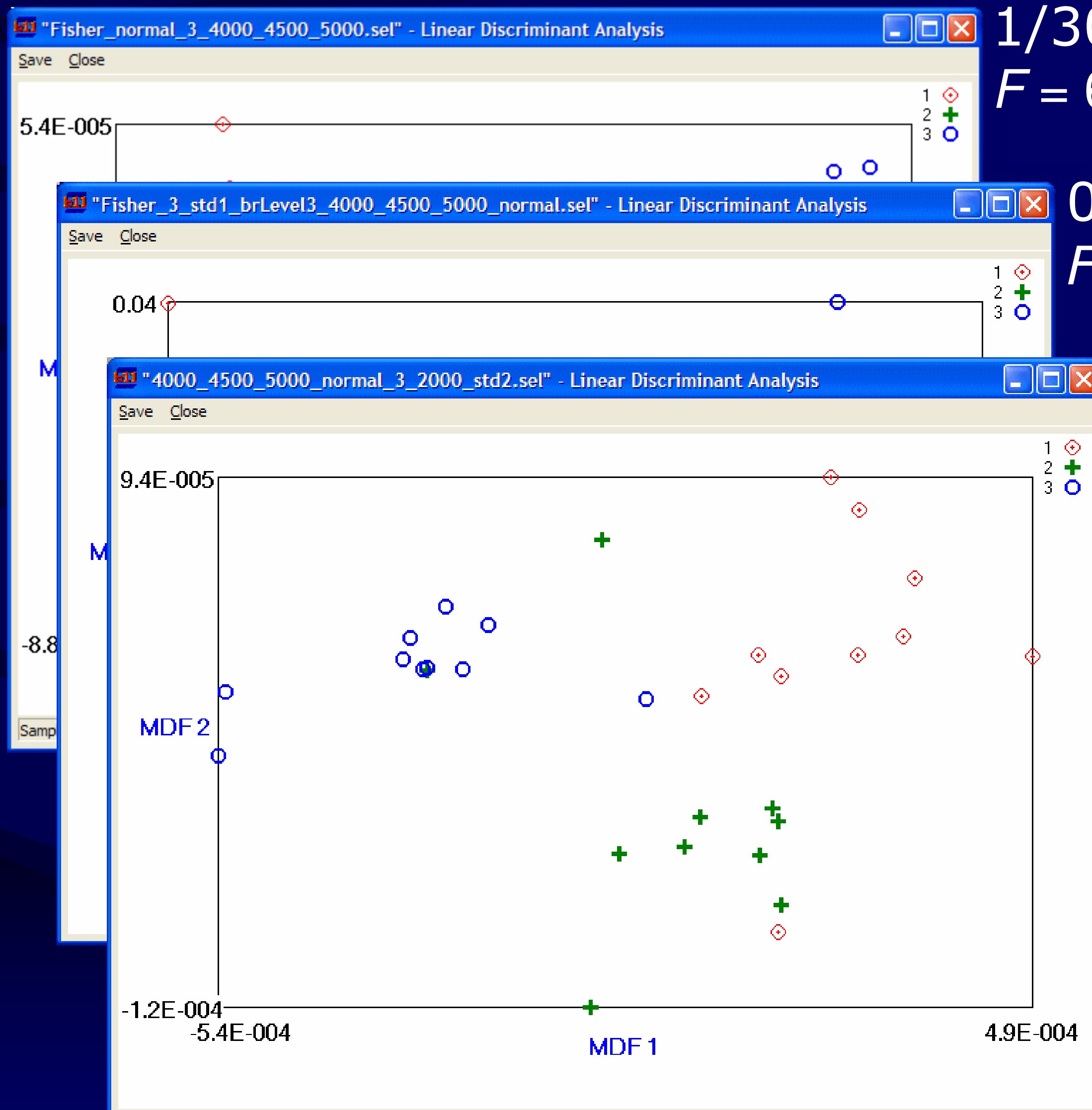
Feature name	F
S[0,0,3]DifEntrp	55.4535
S[0,0,5]DifEntrp	53.9816
S[0,0,2]DifEntrp	53.8931
S[0,0,4]DifEntrp	53.4033
S[0,0,3]InvDfMom	52.6955
S[0,0,2]InvDfMom	51.7798
S[0,1,0]InvDfMom	51.7406
S[1,0,0]InvDfMom	50.9022
S[1,1,0]InvDfMom	50.3863
S[2,2,0]DifEntrp	50.0553

$N(0,1)$

Feature name	F
S[0,0,5]DifVarnc	33.6314
S[0,0,4]DifVarnc	31.3322
S[5,-5,0]DifVarnc	29.8856
S[1,0,0]SumVarnc	28.4549
S[1,-1,0]SumVarnc	27.9490
S[4,-4,0]DifVarnc	27.4311
S[0,0,1]SumVarnc	24.9976
S[0,1,0]SumVarnc	24.8352
S[0,0,3]DifVarnc	23.8348
S[1,1,0]SumVarnc	22.7699

$N(0,2)$

Feature name	F
S[0,4,0]AngScMom	7.8670
S[0,0,5]AngScMom	6.8022
S[4,0,0]AngScMom	6.6704
S[2,2,0]AngScMom	6.6143
S[0,0,3]AngScMom	6.5839
S[3,0,0]AngScMom	6.3336
S[5,5,0]AngScMom	6.3292
S[0,0,1]AngScMom	6.2274
S[3,-3,0]AngScMom	6.0705
S[5,-5,0]AngScMom	6.0698



1/30 $F = 67$

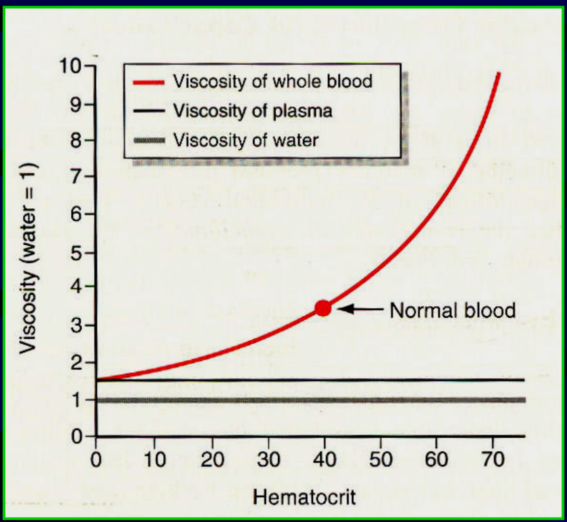
0/30 $F=47$

9/30 $F=8$

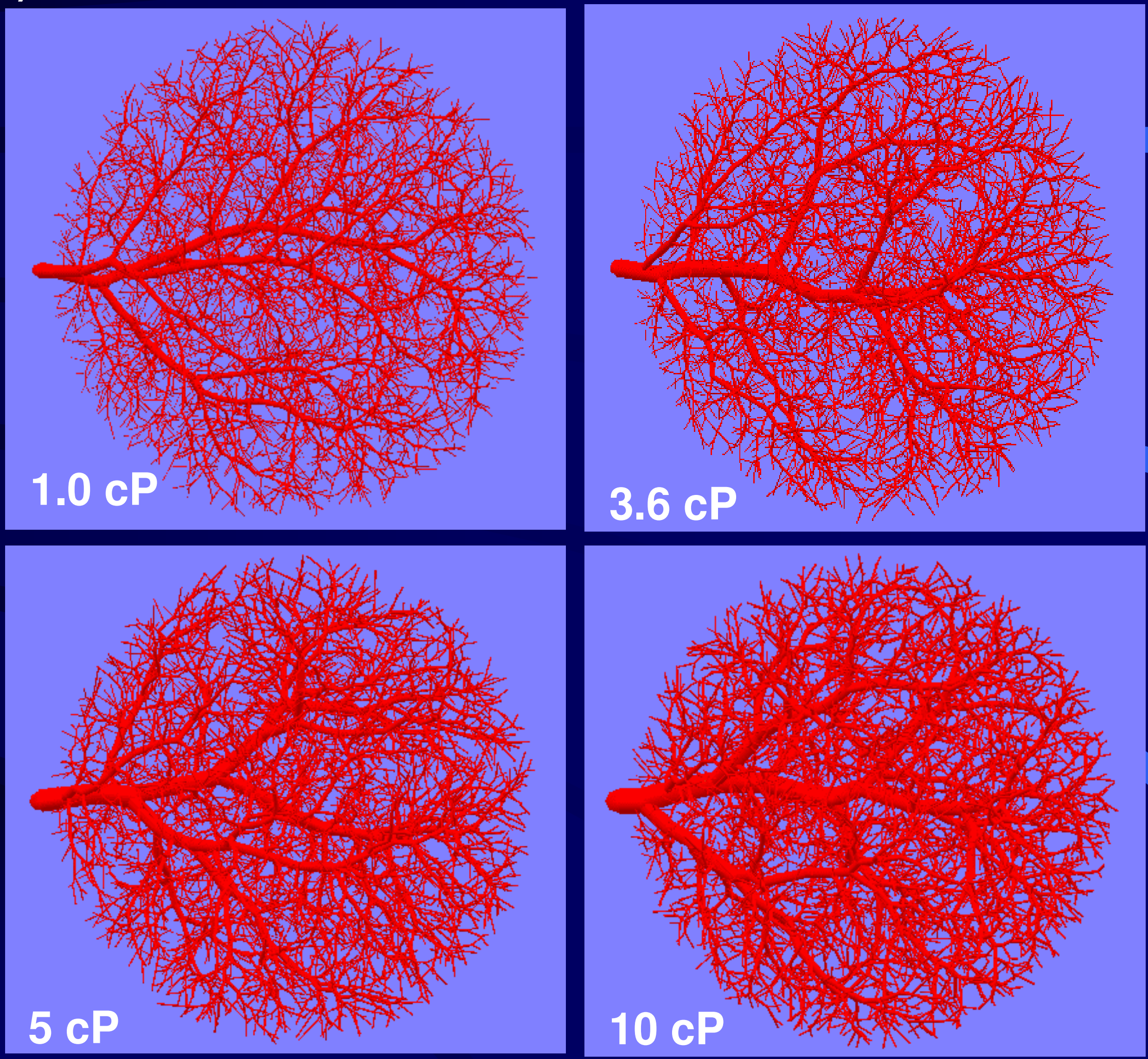
Reduced number of distinct classes

Terminal count = 4000
Input flow = 0.5 l/min
Ouput flow = 0.125 ml/min

Trees – viscosity

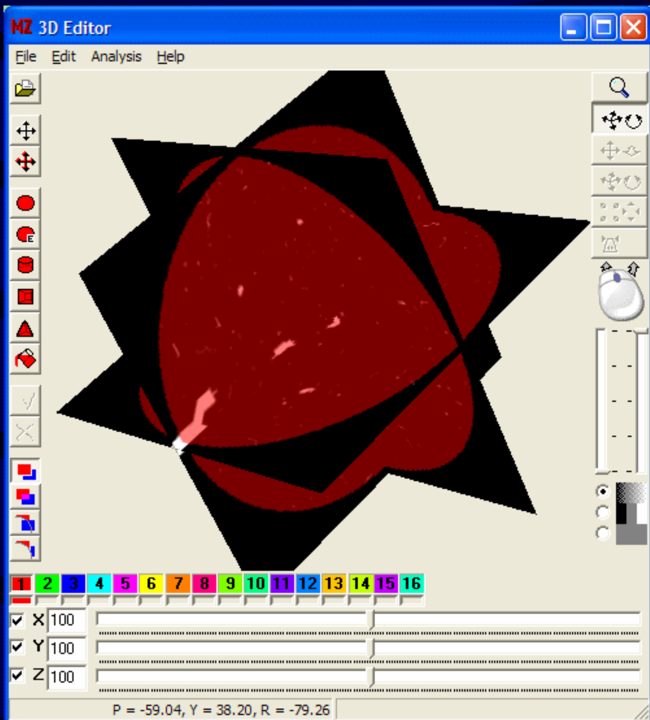


A.C. Guyton, J.E. Hall,
Textbook of medical physiology,
W.B.Saunders, Philadelphia 2000



3D texture – viscosity

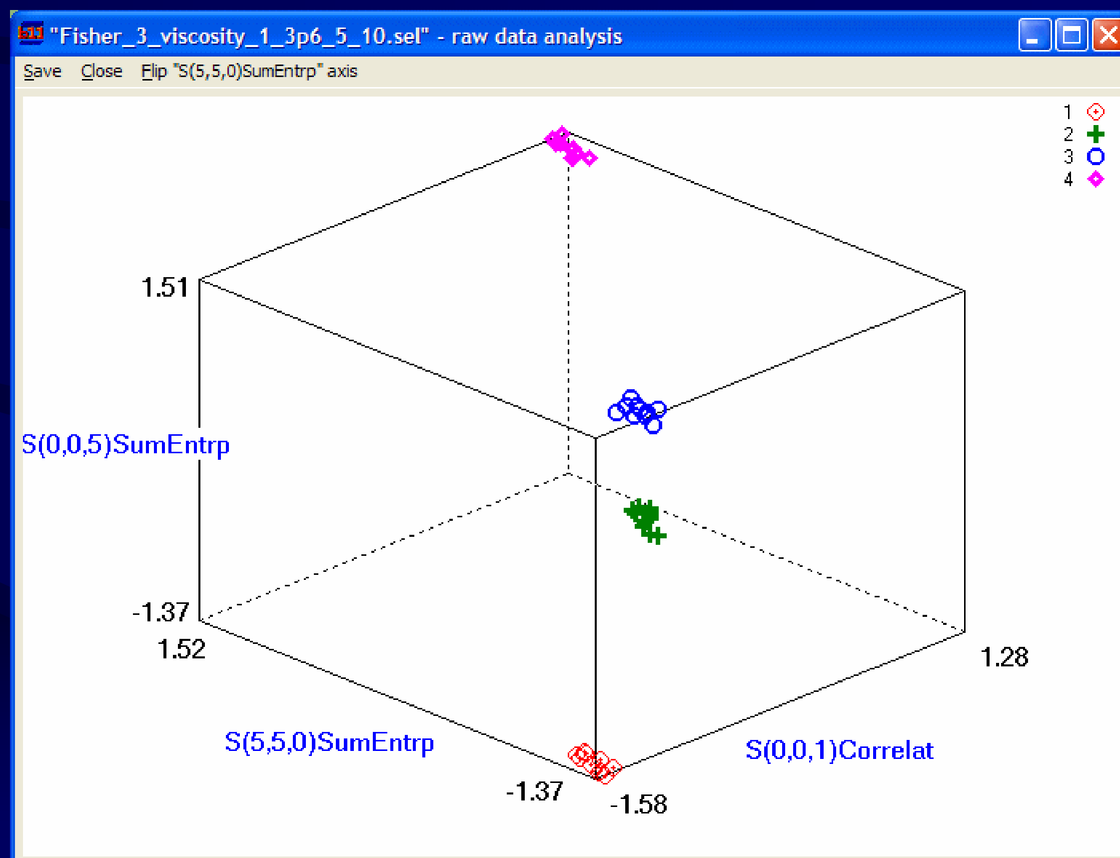
η = 1, 3.6, 5, 10 cP



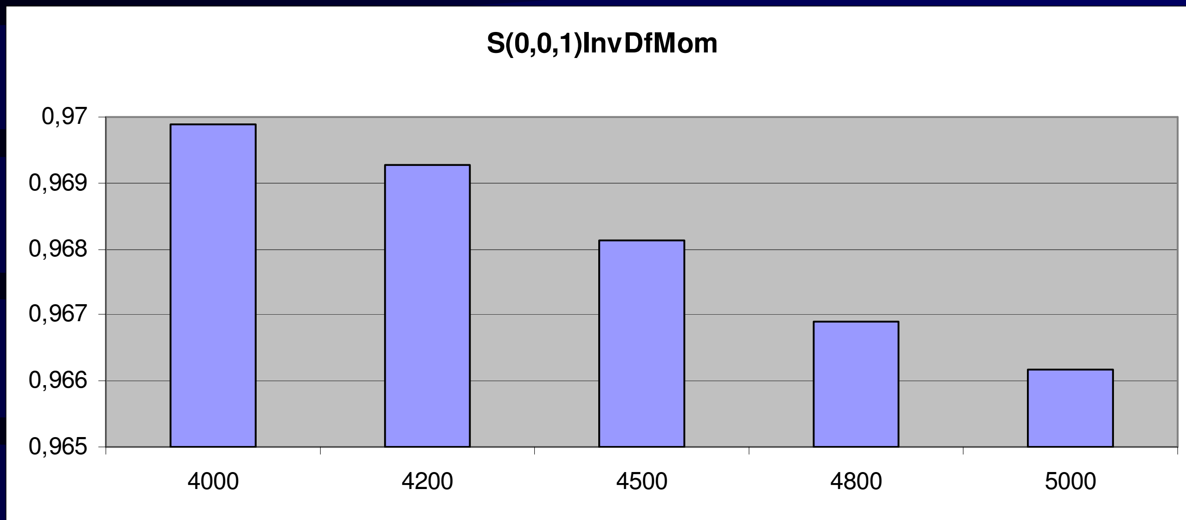
Fisher coefficient

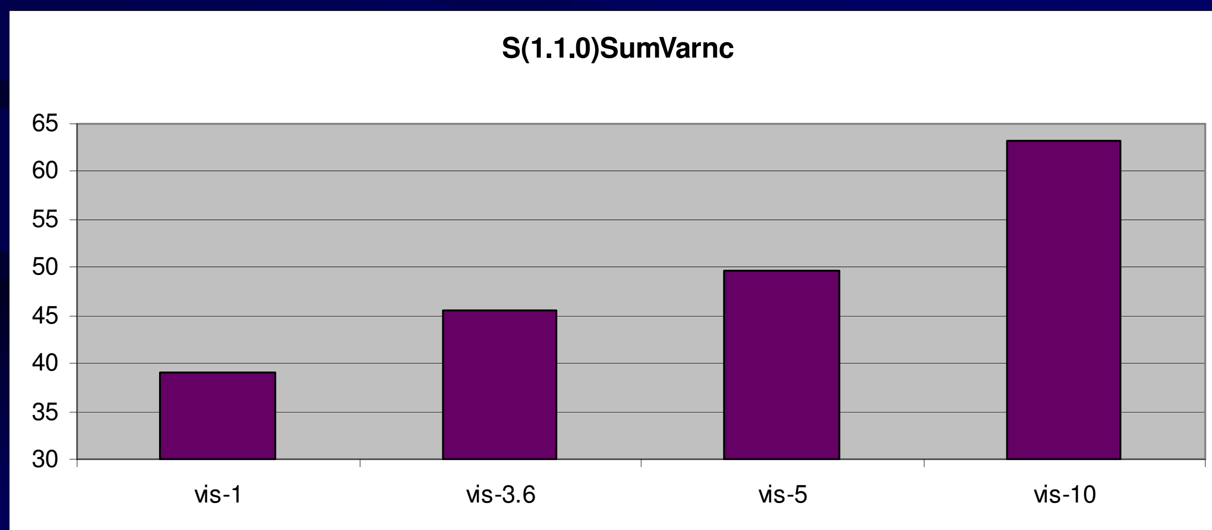
Feature name	F
S(0,0,1)Correlat	1079.9084
S(5,5,0)SumEntrp	1054.7678
S(0,0,5)SumEntrp	1043.0749
S(4,4,0)SumEntrp	1038.8688
S(4,4,0)DifEntrp	1038.1272
S(3,3,0)SumEntrp	1036.5638
S(3,3,0)Entropy	1036.3652
S(5,5,0)Entropy	1035.8374
S(1,-1,0)SumVarnc	1035.6962
S(5,-5,0)SumEntrp	1030.9797

Accept Discard



Texture vs. tree parameters



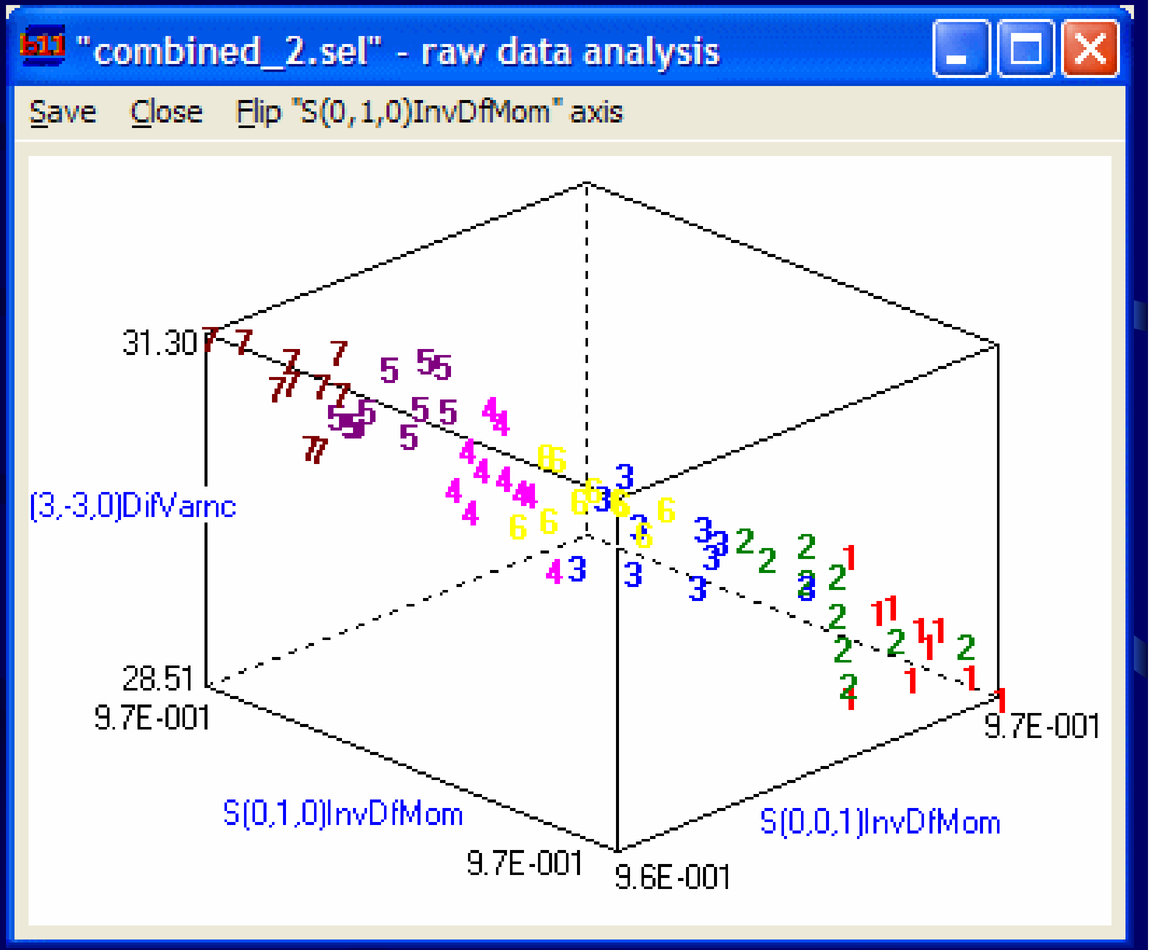


Tree parameter monitoring

3D texture

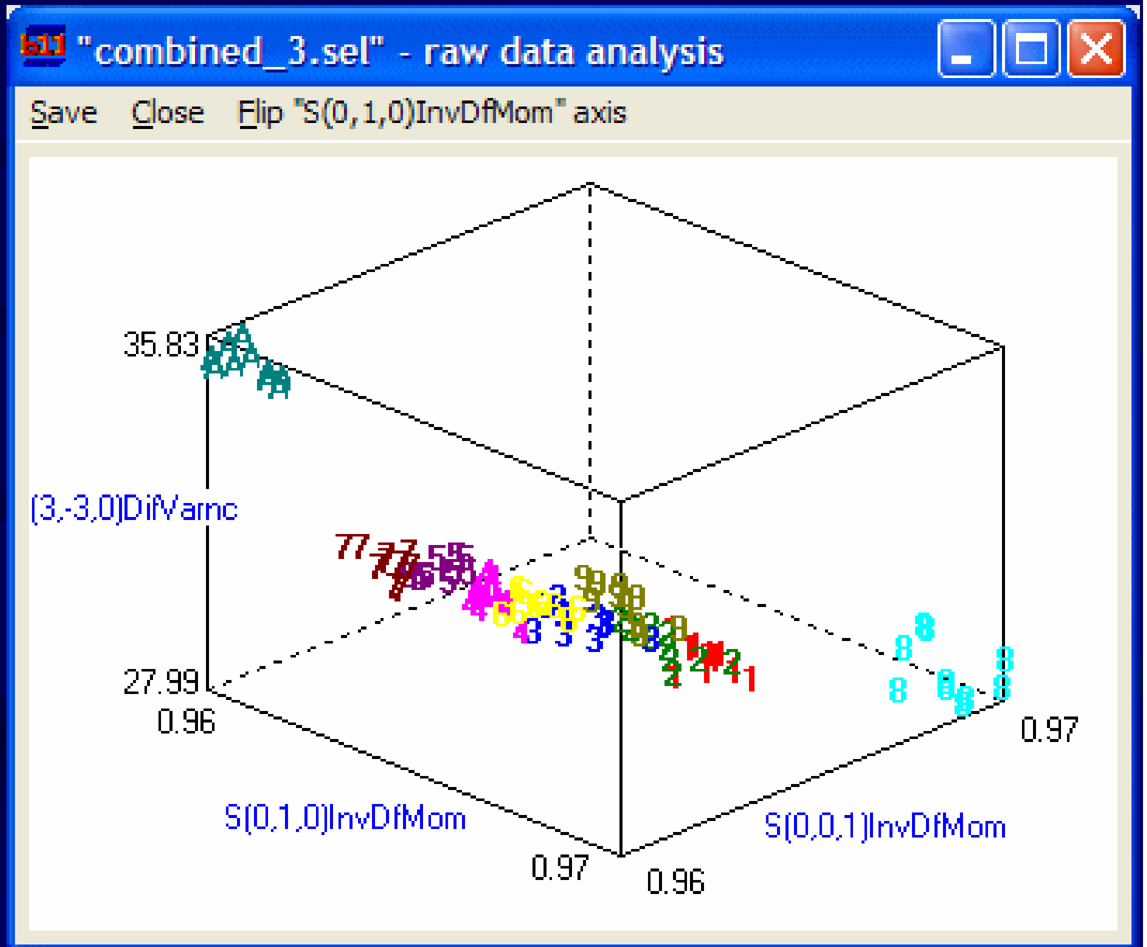
Class	Term. count	Input flow	Output flow
1	4 000	0.500	0.125
2	4 200	0.500	0.119
3	4 500	0.500	0.111
4	4 800	0.500	0.104
5	5 000	0.500	0.100
6	4 500	0.562	0.125
7	5 000	0.625	0.125

Viscosity = 3.6 cP

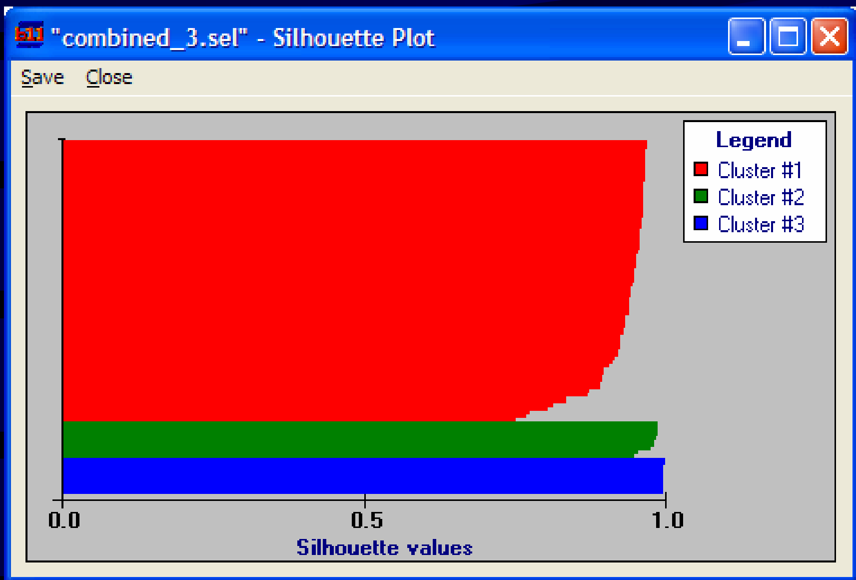


3D texture

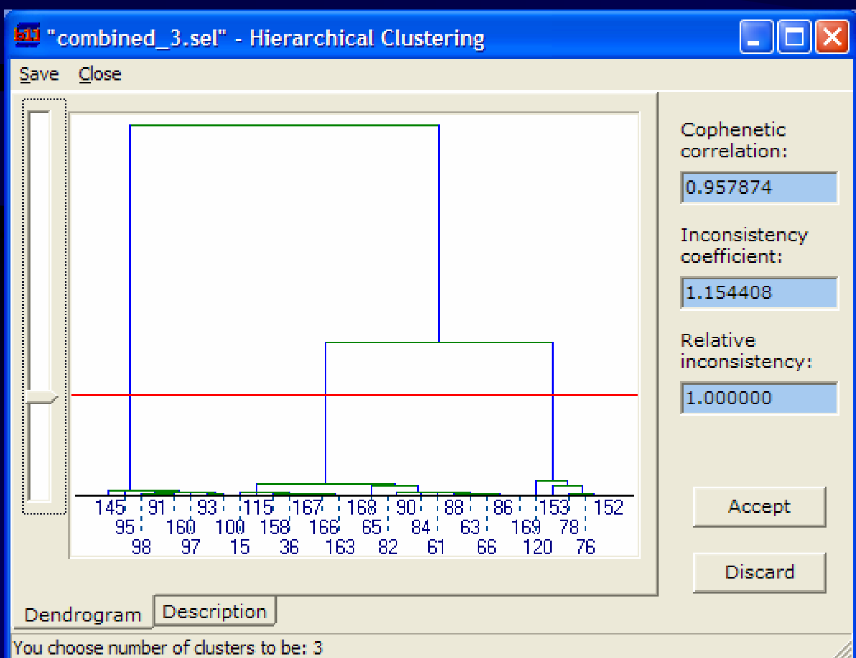
#	N	Qin	Qout	η
1	4 000	0.500	0.125	3.6
2	4 200	0.500	0.119	3.6
3	4 500	0.500	0.111	3.6
4	4 800	0.500	0.104	3.6
5	5 000	0.500	0.100	3.6
6	4 500	0.562	0.125	3.6
7	5 000	0.625	0.125	3.6
8	4000	0.500	0.125	1
9	4000	0.500	0.125	5
A	4000	0.500	0.125	10

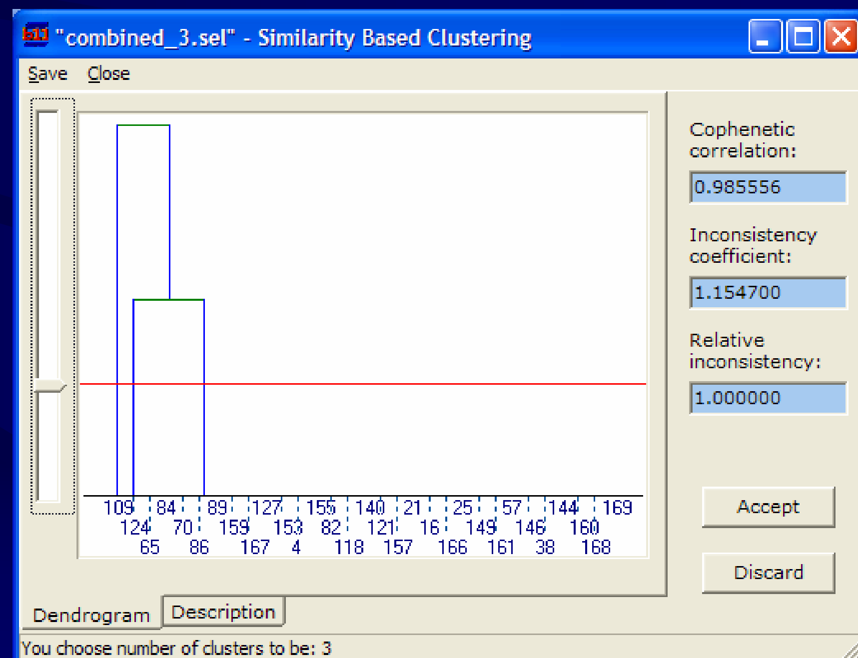


3D texture



viscosity = 1; {3.6,5}; 10





Summary

- 3D texture features of pseudo-RMI images related to simulated vessel tree parameters
- Distinct classes of trees (e.g. large, medium, small viscosity) in 3D texture for diagnosis support
- Number of distinguishable classes decrease with noise
- Slice texture (2D) does not discriminate different vessel trees
- Monotonous dependence of texture features on groups of tree parameters

Future work

- Subvoxel structures modelling (blood vessels, trabecular bones)
- Vessel tracking and volume estimation
- Brain perfusion
- Experimental verification