

# Multimedia and Mathematics 2005



## Deformable Models for Biomedical Image Analysis *from 'snakes' to 'organisms'*

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Simon Fraser University



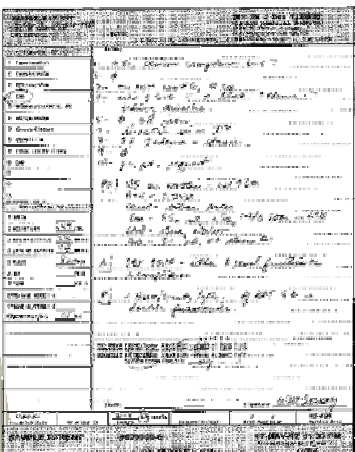
# Talk Overview



- Multimedia patient records
- Medical images
- Medical images analysis
- Image segmentation and registration
- Deformable models: Snakes
- Controlling shape deformation
- Deformable organisms



# Multimedia Patient Record



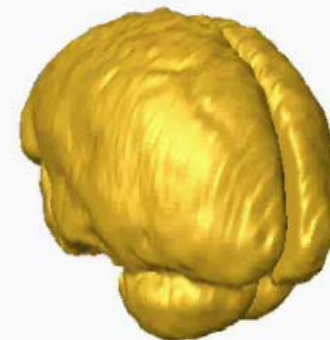
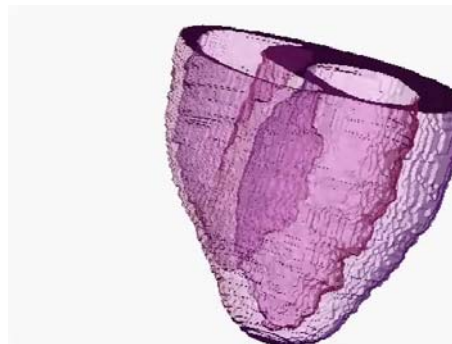
alphanumeric



speech

audio

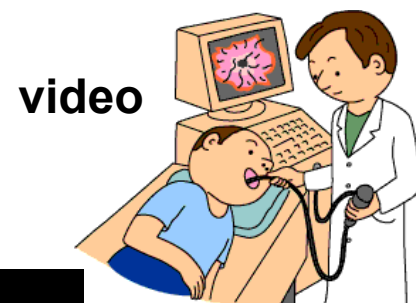
natural language



graphical objects



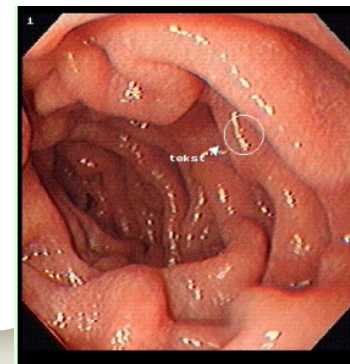
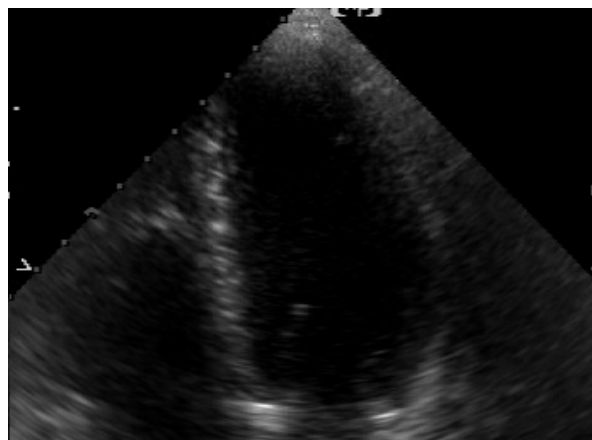
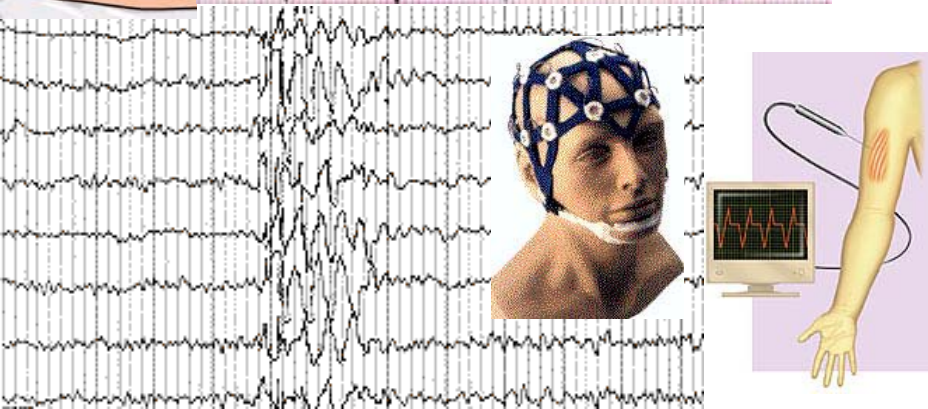
images



video

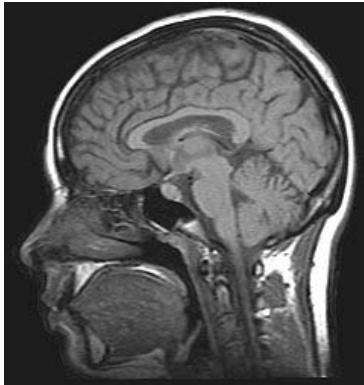


bio-signals





# Medical Images



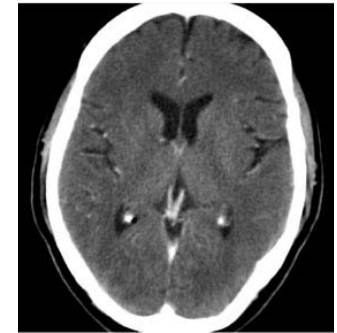
University of Bergen - Norway

**Need to:**  
**Store, Communicate, Visualize, Process, Analyze**

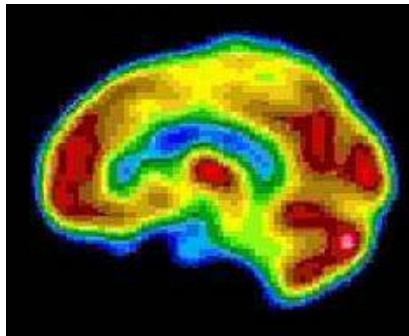
MR, CT, SPECT, MRA, EIT, MRE, hist., optical, PET, DTMRI, fMRI...



University College London



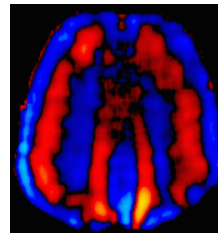
Philips Medical



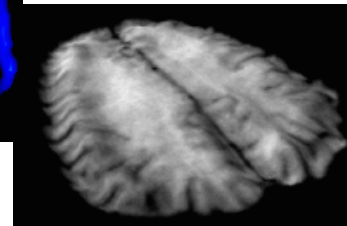
www.Brain-Spect.com



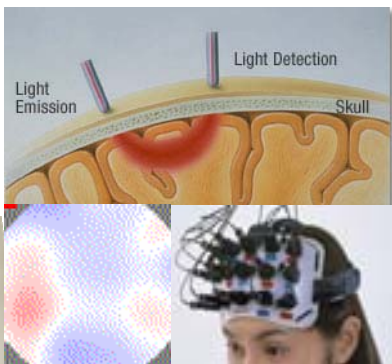
BrighamRAD



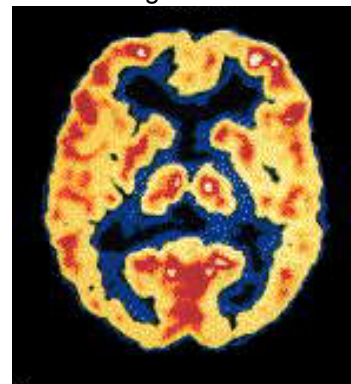
Mayo Clinic



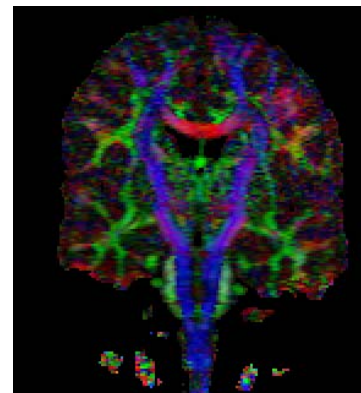
Visible Human



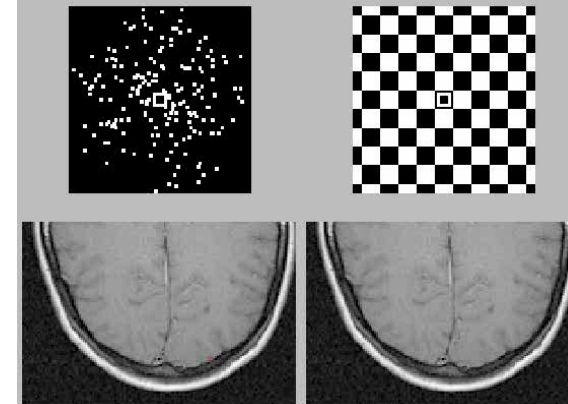
Koizumi, Hitachi



Chudler, U of Washington



Scientific Computing & Imaging, Utah



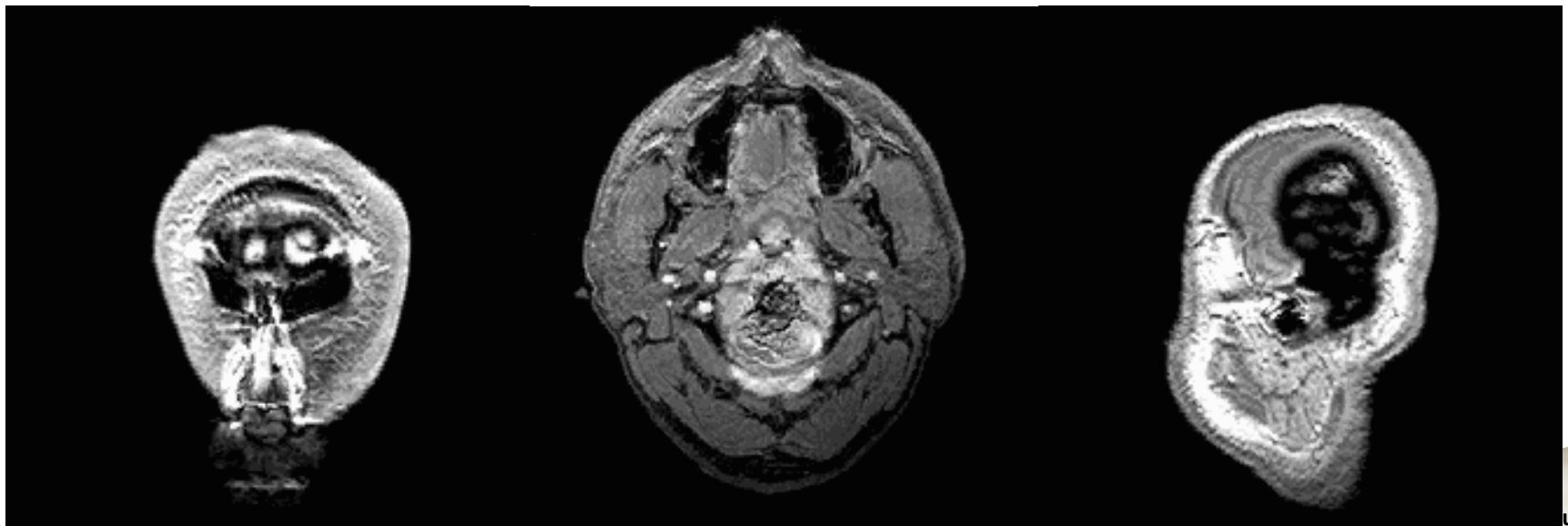
Center for Neural Science at NYU



# Medical Image Analysis



- **Medical Images:** 2D/3D+Time, scalar/vector/tensor fields, non rigid tissue, patient info
- **Manual Analysis:** Tedious. Time consuming. Inter-, intra-operator variability
- **General goals:** Automation. Quantification. Classification. Data reduction. Visualization
- **General Methodologies:** Image restoration. Image enhancement. Visualization techniques, **image segmentation. Image registration. Shape analysis**
- **Mathematics:** Inverse problems, PDEs, transforms, optimization, statistics,...
- **Numerous Applications...** *Computer-aided diagnosis. Computer assisted intervention. Image guided therapy, therapy evaluation. Surgical simulation, planning, and navigation. Image data fusion. Quantitative & time series analysis. Statistical Structural Shape Analysis Anatomical atlases. Virtual, augmented reality. Instrument, patient localization, tracking. Medical tele-presence and tele-surgery. Functional brain mapping. Screening and functional genomics.*

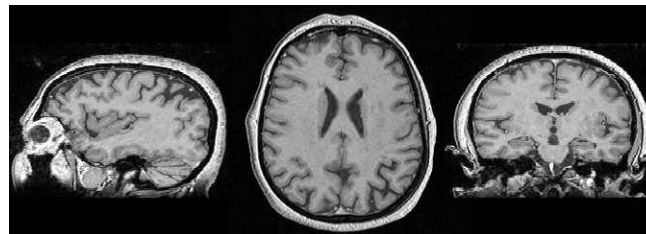
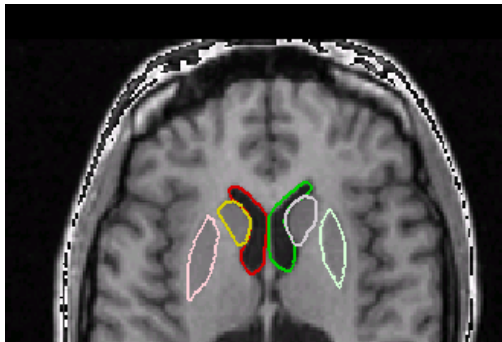
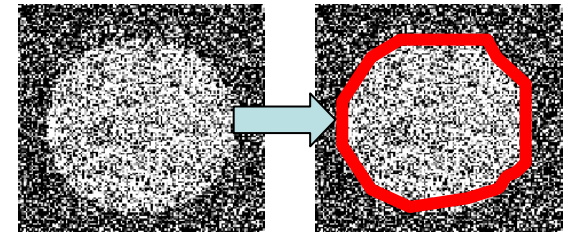




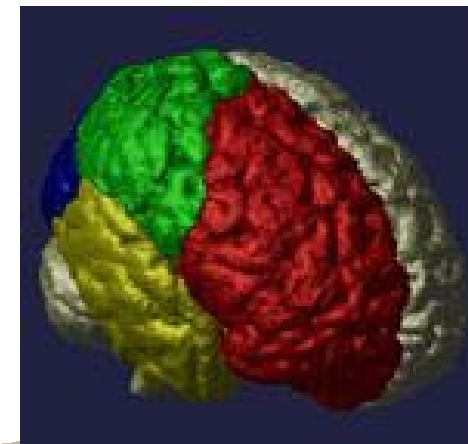
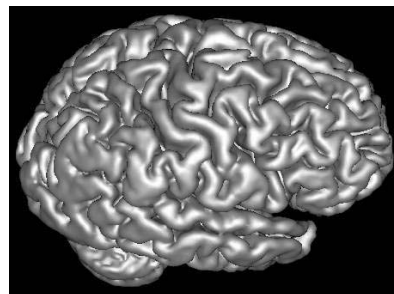
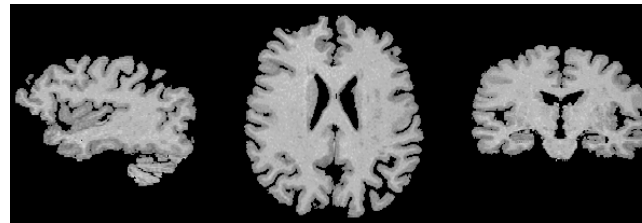
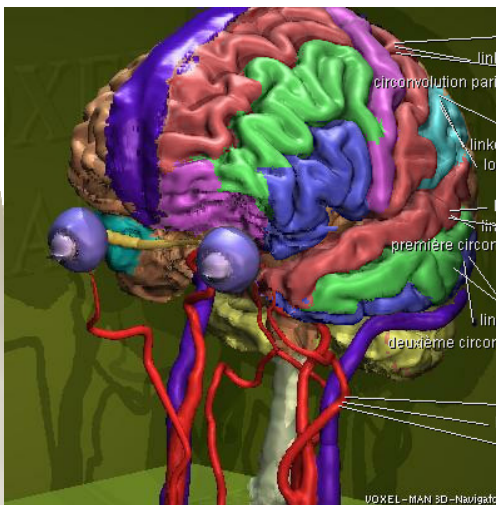
# Image Segmentation



- Partition an image into regions
- Assign labels to pixels (binary/fuzzy)
- Obtain higher-level representation



University Medical Center Utrecht

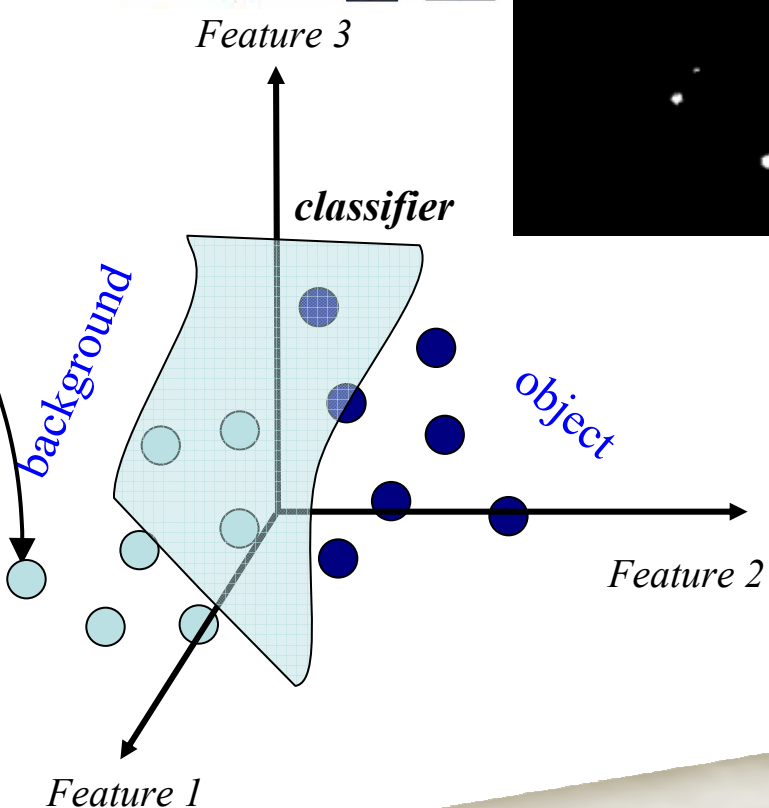
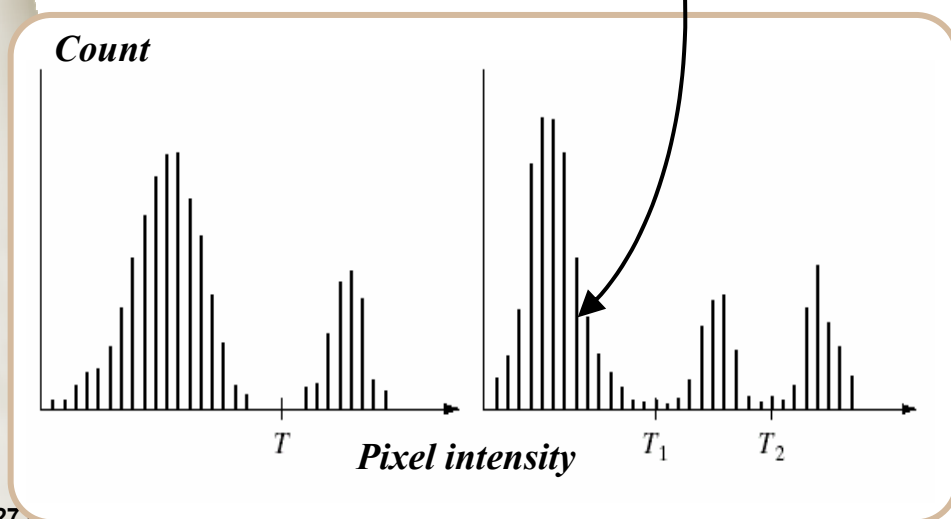
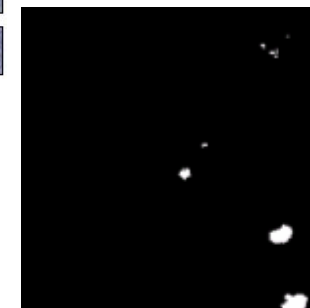
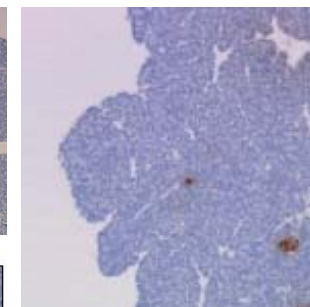
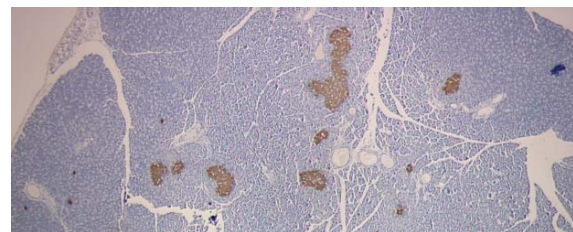
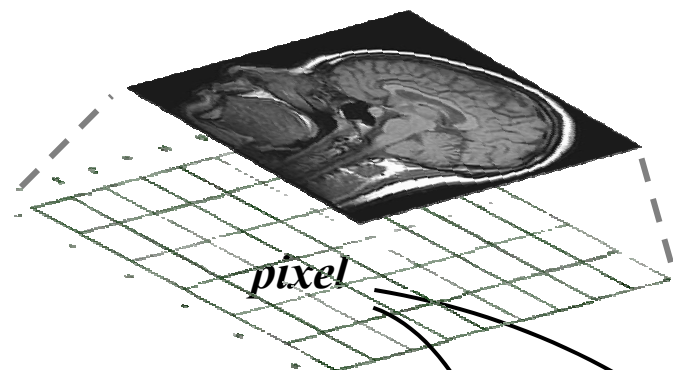


Voxel-Man 3D Navigator

<http://www-dsv.cea.fr>



# Thresholding and Clustering

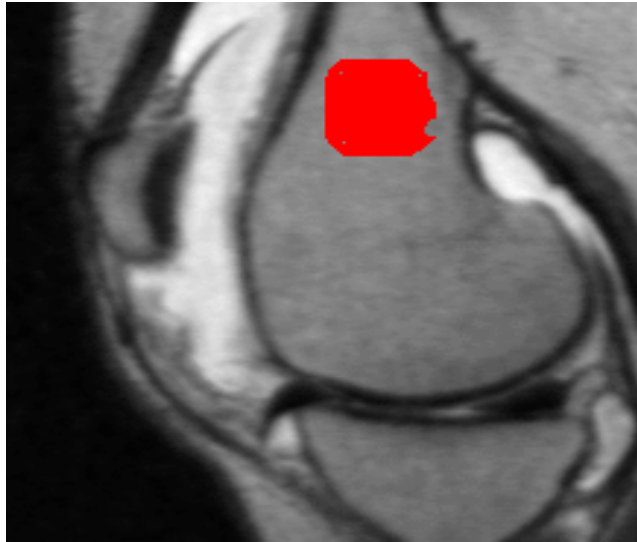




# Region-based Methods



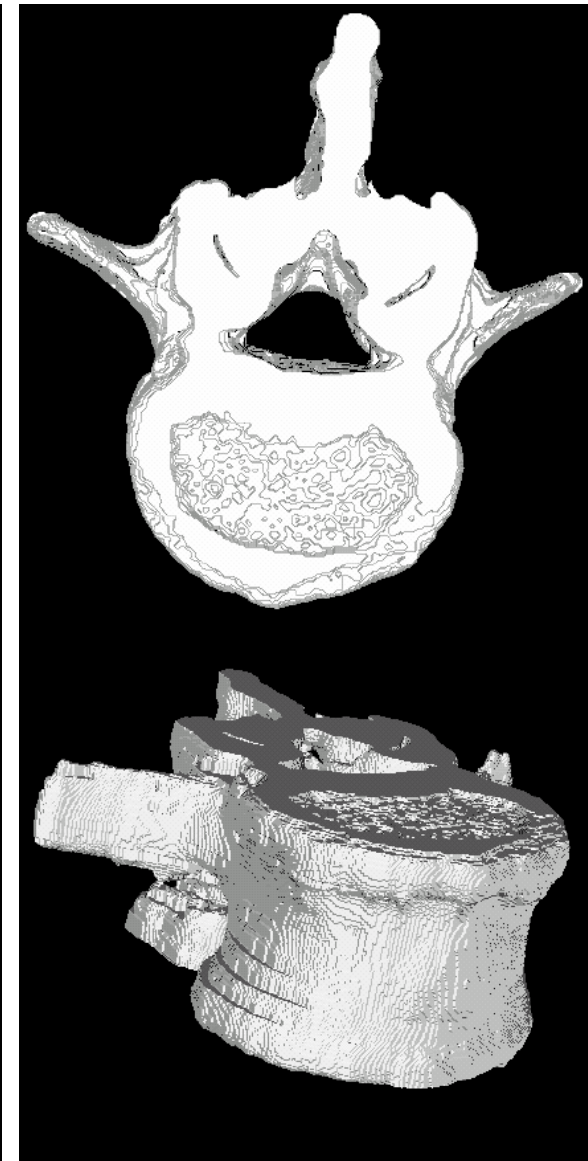
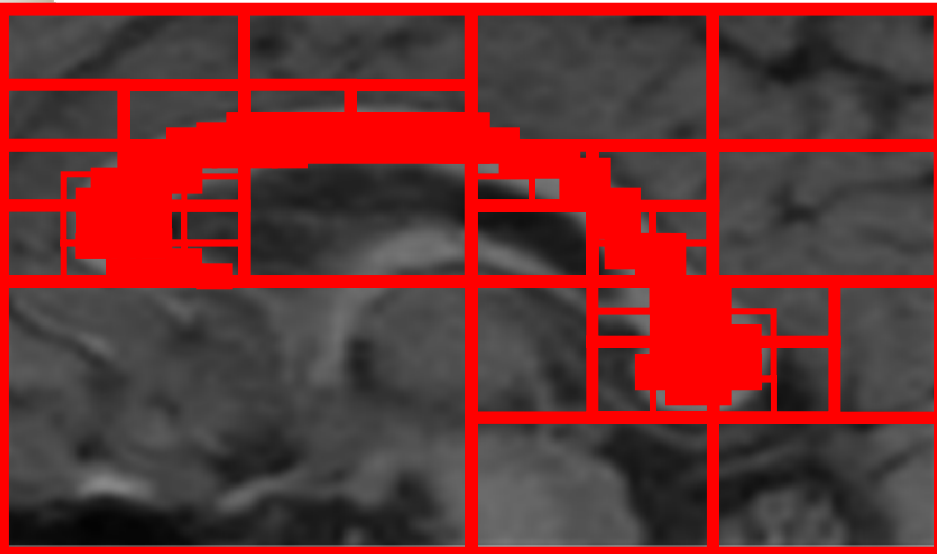
## Growing



Courtesy: Tina Kapur

## ...Merging

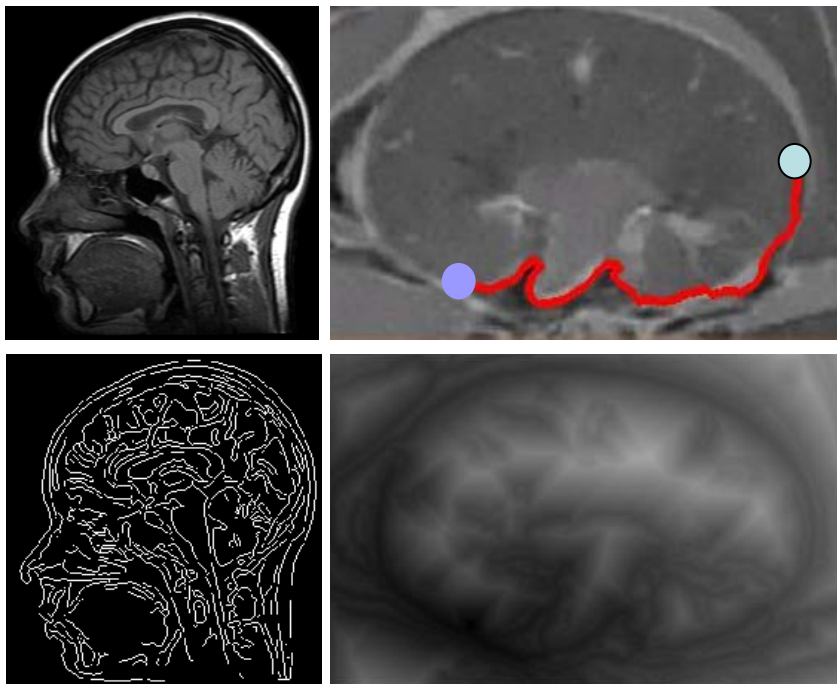
## Splitting







# Edge Detection and Linking...

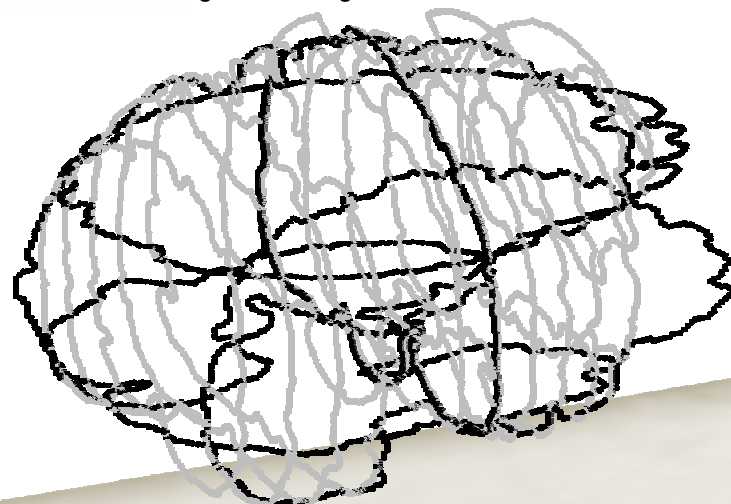
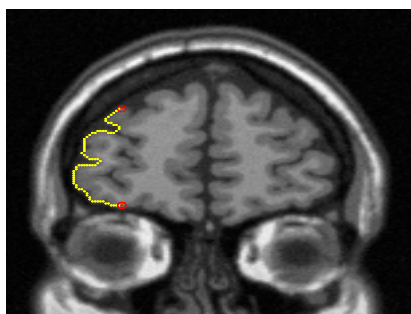
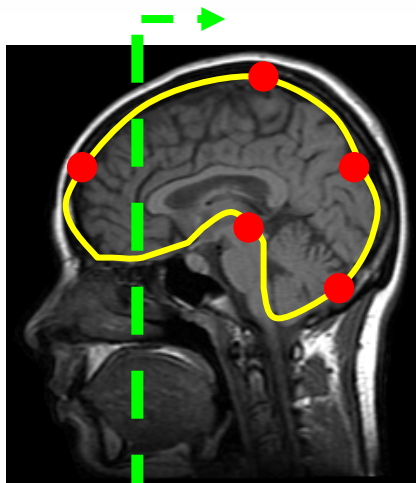


“Livewire”

$$C(p, q) = w_z f_z(q) + w_c f_c(q) + w_G f_G(q) + w_D f_D(p, q)$$

Laplacian zero-crossing, canny-edge, gradient magnitude and direction

2D → 3D

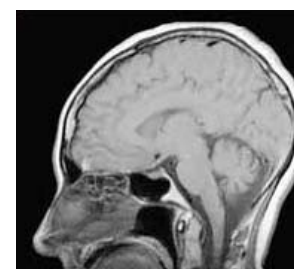
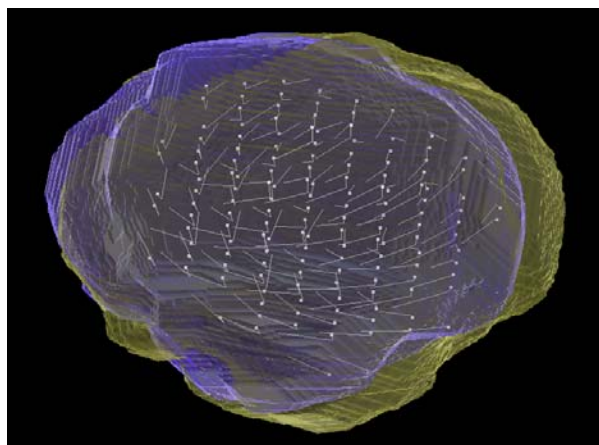
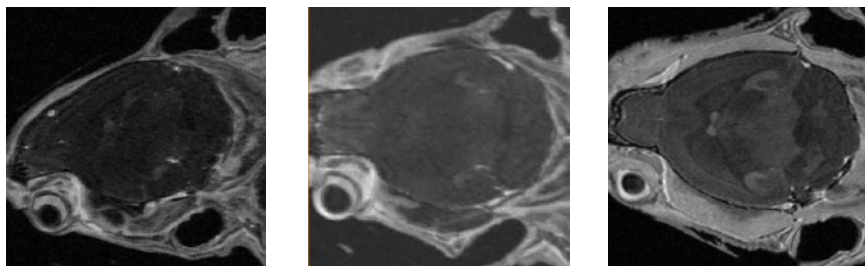
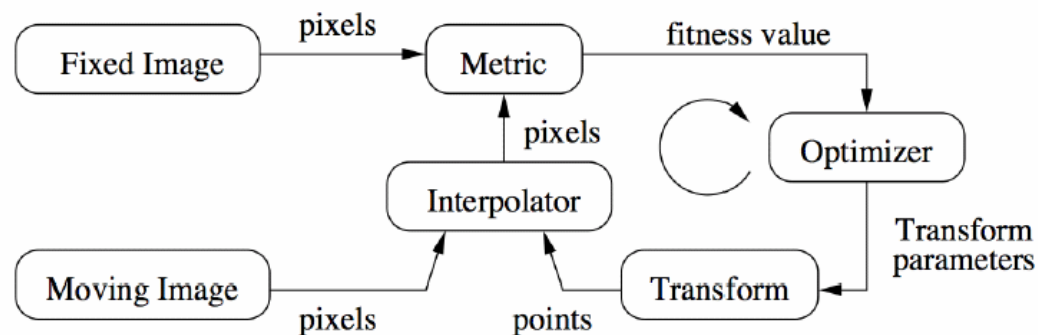




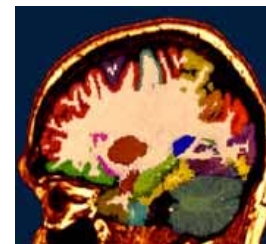
# Image Registration and Atlas-based Segmentation



- **Registration:** Find optimal spatial transformation (warping) of one image to maximize “similarity” to another image
- Segmentation via registration



reference image



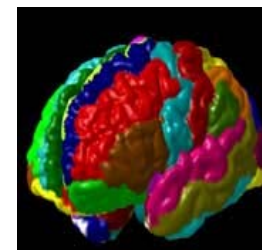
labelled reference (atlas)

register



new image

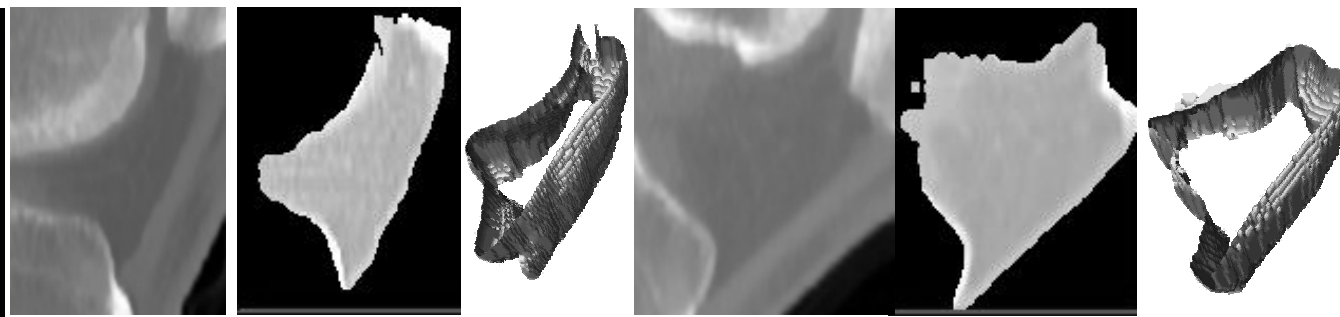
warp labels using same transform



labelled image

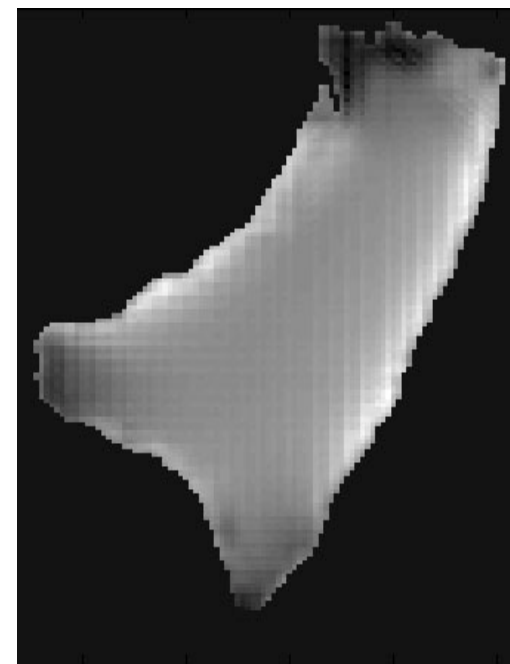
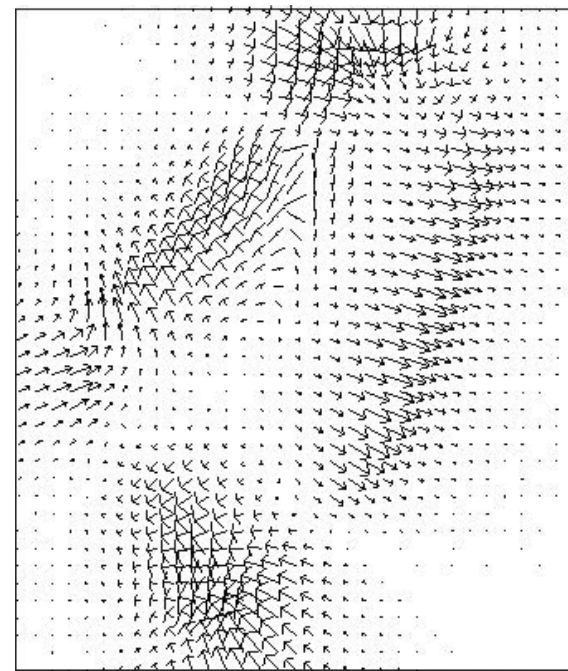
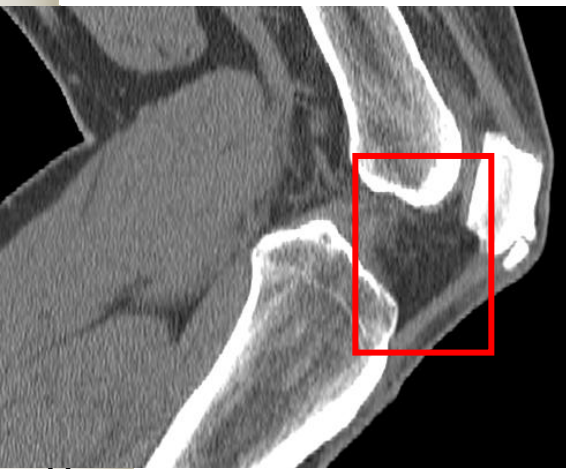


# Registration and deformation analysis



$$d(u, v, w) = \det \{ \nabla [U(u, v, w), V(u, v, w), W(u, v, w)] \}$$

**Extension and Flexion**

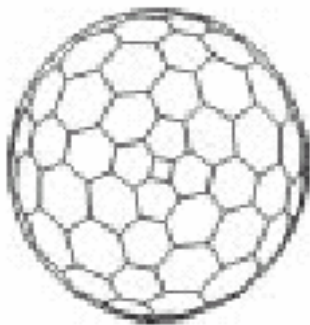




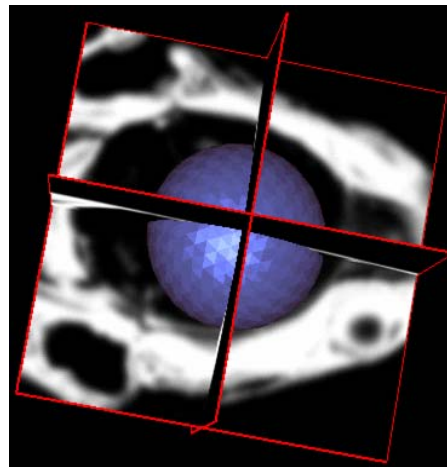
# Deformable Models



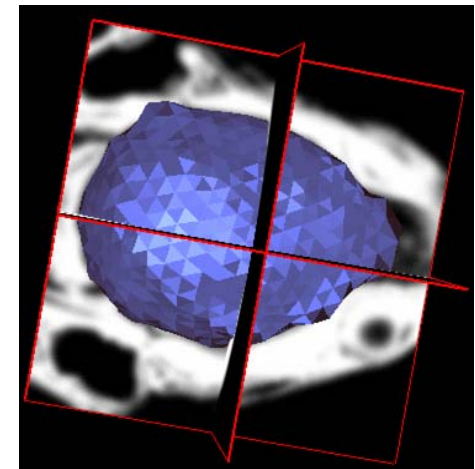
- Contours, surfaces, volumes
- Initialized in the image space
- Deform according to image data
- ... & “shape” constraints
- Originally: 2D semi-automatic tools
- Integrate boundary elements, robust to image noise, boundary gaps
- Implemented on the continuum achieving sub-pixel accuracy



Shape representation



Initialization



Model deformation

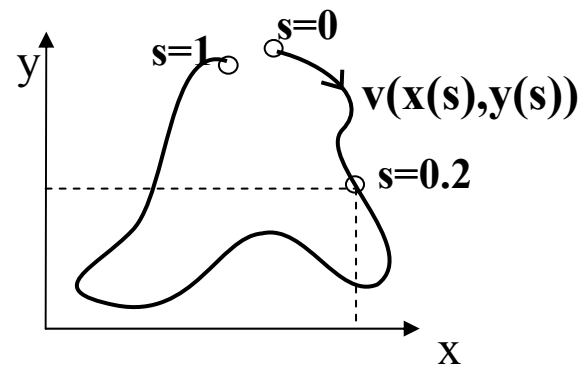


# Classical “snakes”

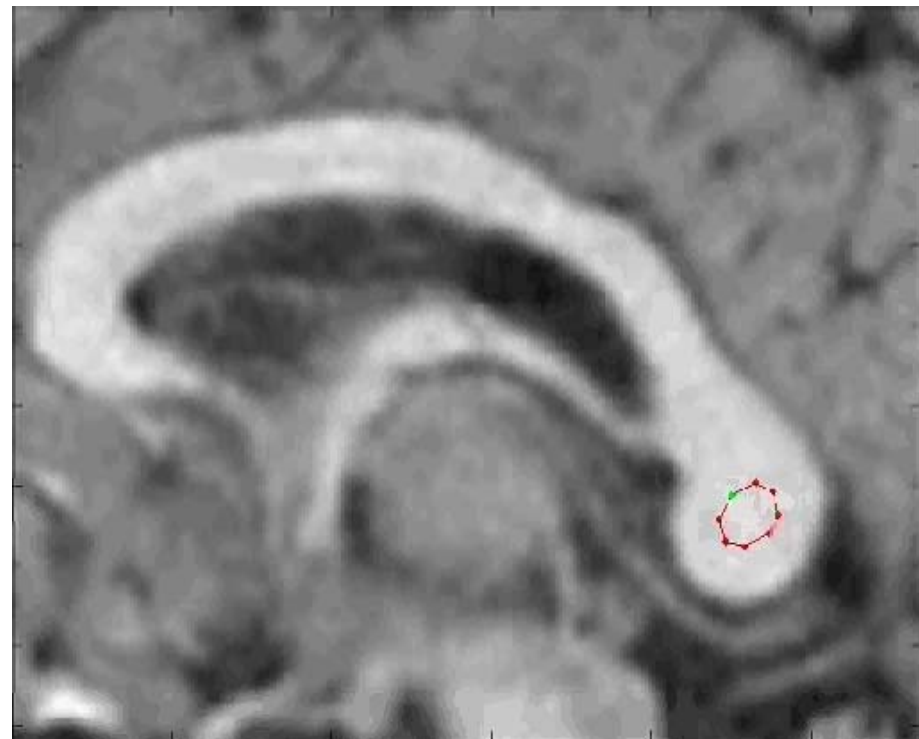
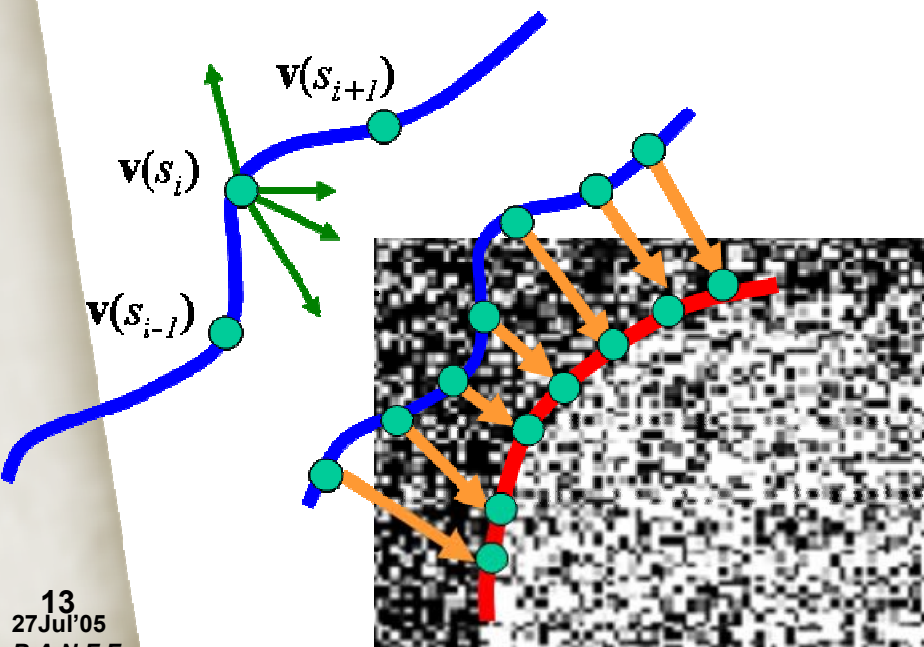


## Snake or Active Contour Models:

Deformable contours, initialized in the image, deform according to internal and external constraints

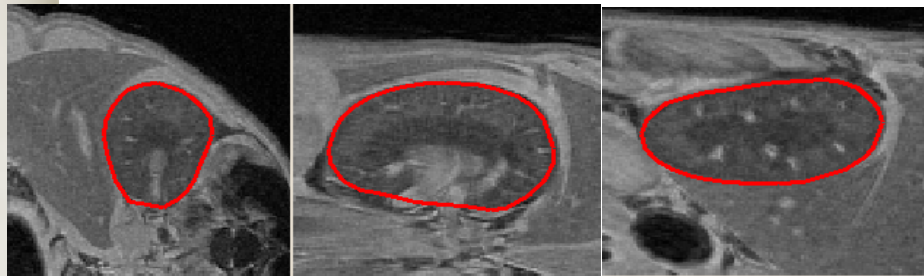
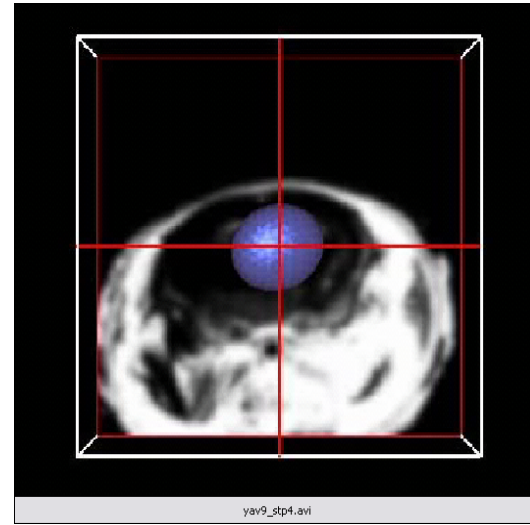
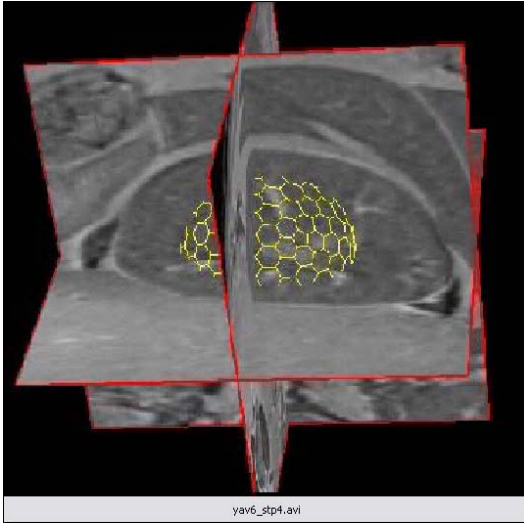


$$\mu \ddot{\mathbf{v}}_i + \gamma \dot{\mathbf{v}}_i + \alpha \mathbf{F}_i^{tensile} + \beta \mathbf{F}_i^{flexural} = \mathbf{F}_i^{external} + \mathbf{F}_i^{inflation}$$

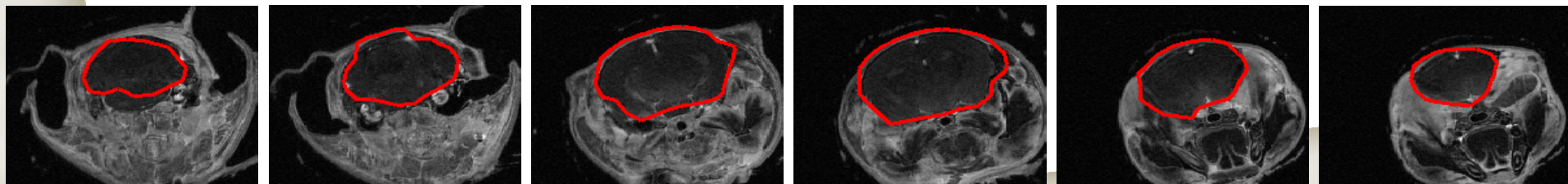




# Deformable Surfaces



$$m \frac{d^2 V_i}{dt^2} + \delta \frac{dV_i}{dt} = \alpha F_{int} + \beta F_{ext}$$





# Some DM Extensions



**Dimensionality:** 2D, 2D+T, 3D, 3D+T, color, stereo...

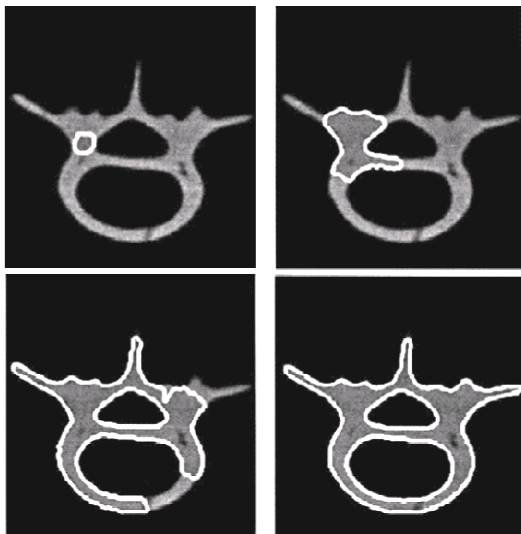
**Framework:** Bayesian, wavefront propagation, geodesic computation

**Shape representations:** Wavelets, Splines, Fourier descriptors,...

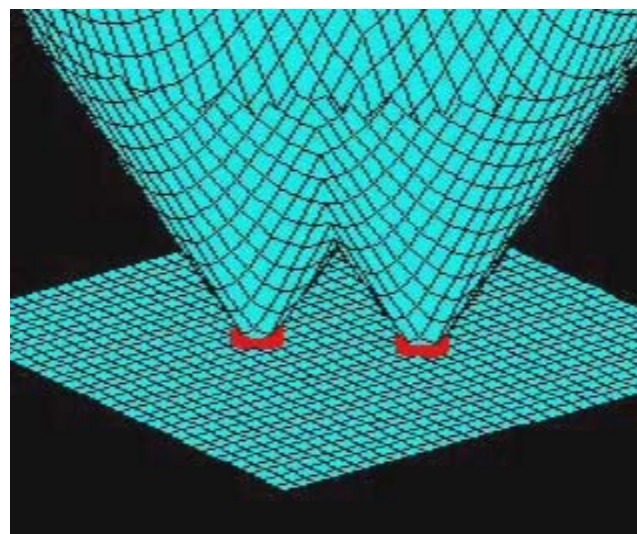
**Energy/forces:** inflation, distance transform, texture/appearance...

**Optimization:** GA, SA, ANN, DP,...

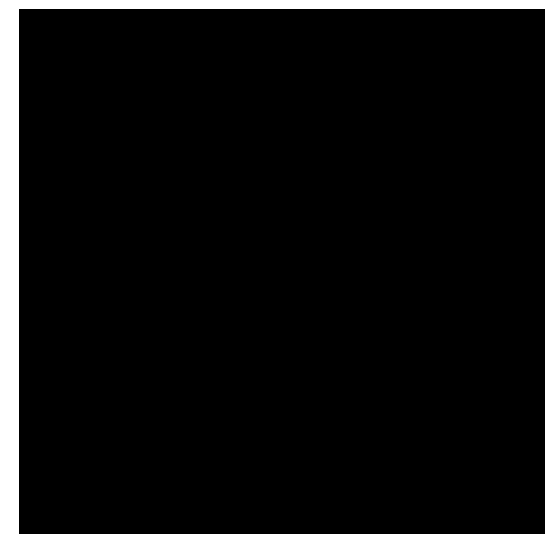
**Topological changes:** T-snakes, Level-sets



McInerney, Ryerson



Sethian, Berkley



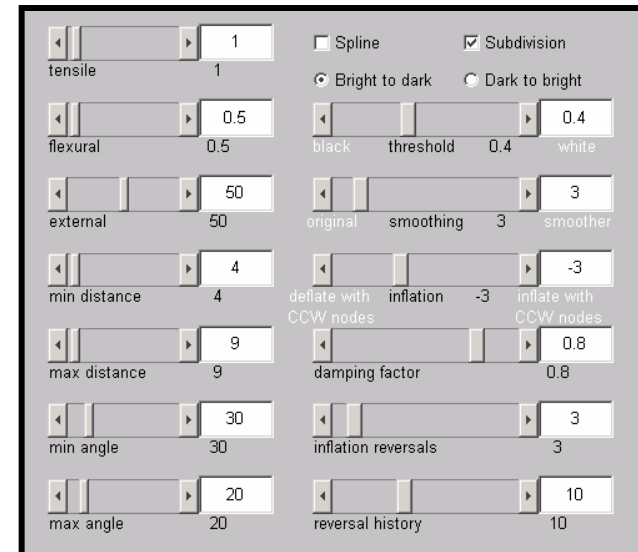
hamarneh@cs.sfu.ca  
<http://www.cs.sfu.ca/~hamarneh>



# DM Problems



- **Leaking** from weak edges
- Low level **parameter** selection problematic
- **Lack of high level control** (rely on human guidance, user interaction)
- **Modest prior** shape knowledge (amorphous shapes, smoothness constraints)
- Sensitivity to **initialization**



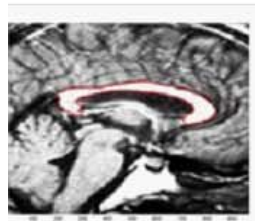




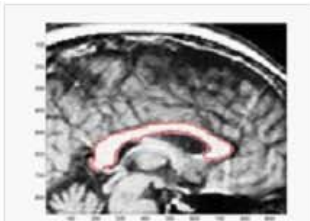
# CC Segmentation for MS



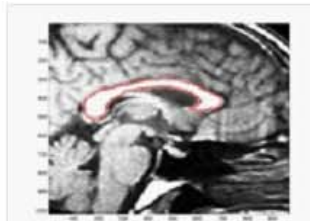
407 images



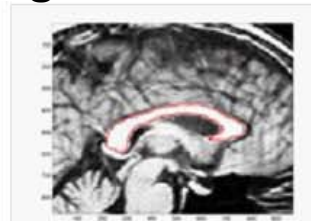
O1401U01X.tif



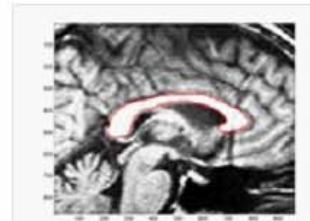
O1402U01X.tif



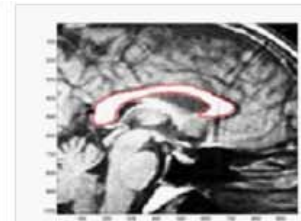
O1402U02X.tif



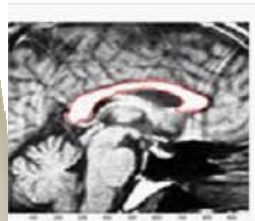
O1402U03X.tif



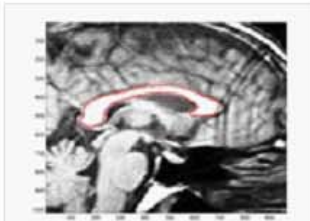
O1402U04X.tif



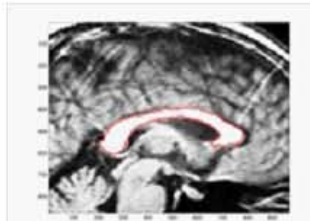
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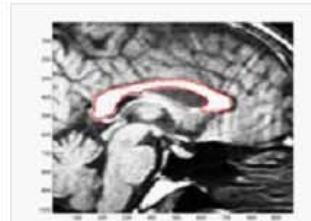
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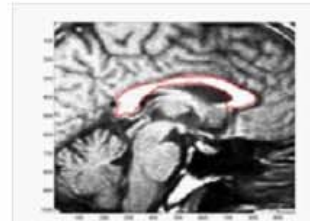
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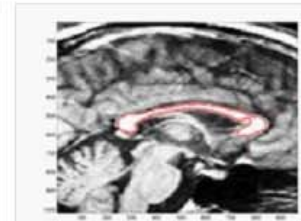
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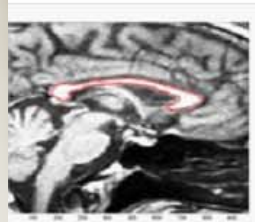
O1402U09X.tif



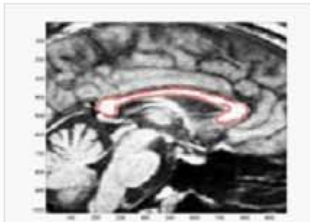
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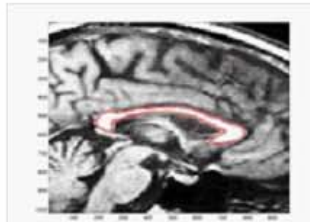
O1403U01X.tif



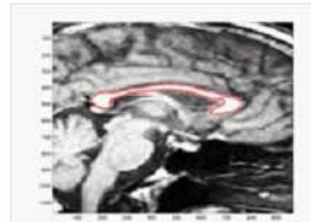
O1403U02X.tif



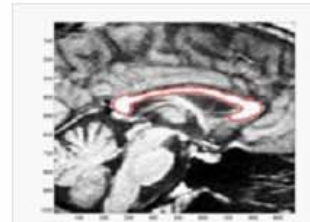
O1403U03X.tif



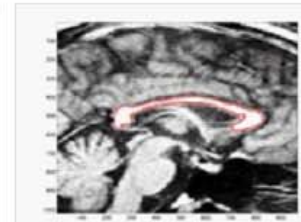
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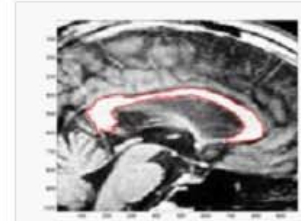
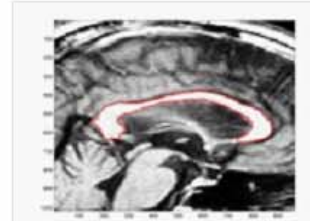
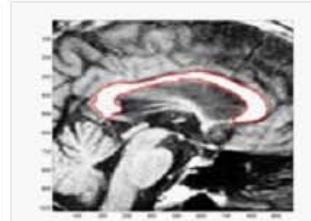
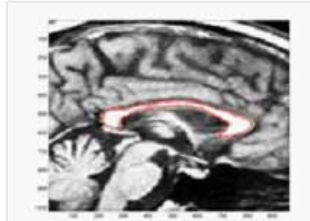
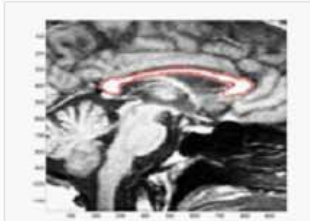
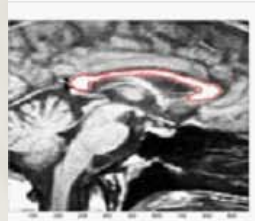
O1403U05X.tif



O1403U06X.tif

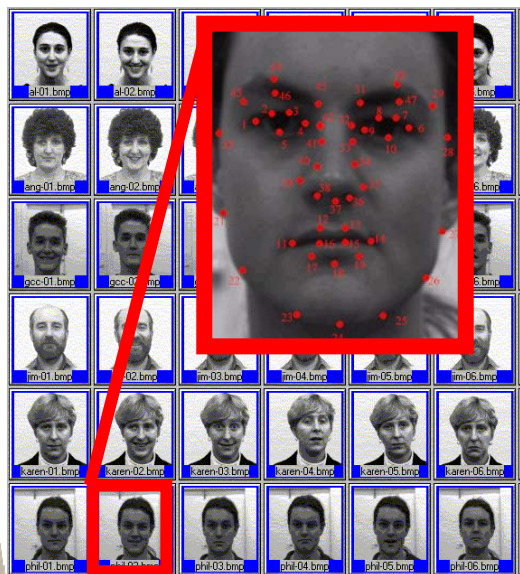


O1403U07X.tif





# Global Shape Statistics



$x_1$   
 $y_1$   
 $x_2$   
 $y_2$   
 $\vdots$   
 $x_n$   
 $y_n$

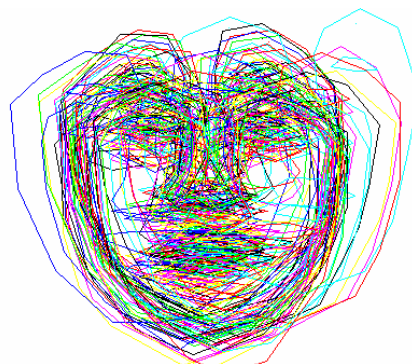
ORL database

## Training set

Labeling corresponding landmarks, **aligning** shapes

Prior shape knowledge:  
**Point Distribution Model**  
**Allowable Shape Domain**

PDM utilized in segmentation:  
**Active Shape Models**



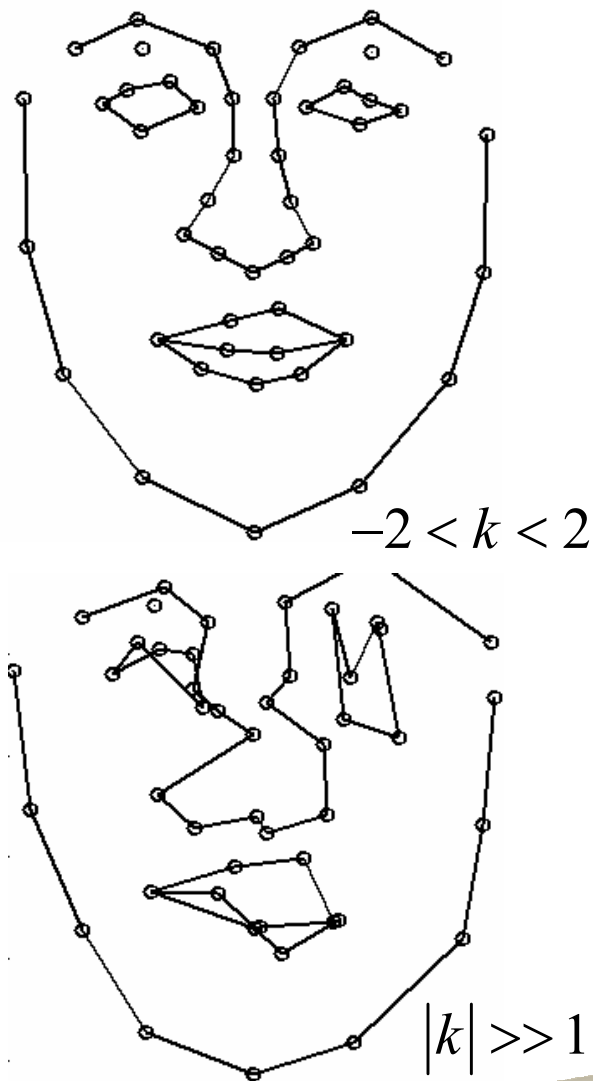
**alignment**



**PCA**

$$S = \bar{S} + \mathbf{Pb}$$

$+k\sqrt{\lambda_i}$   
 $-k\sqrt{\lambda_i}$

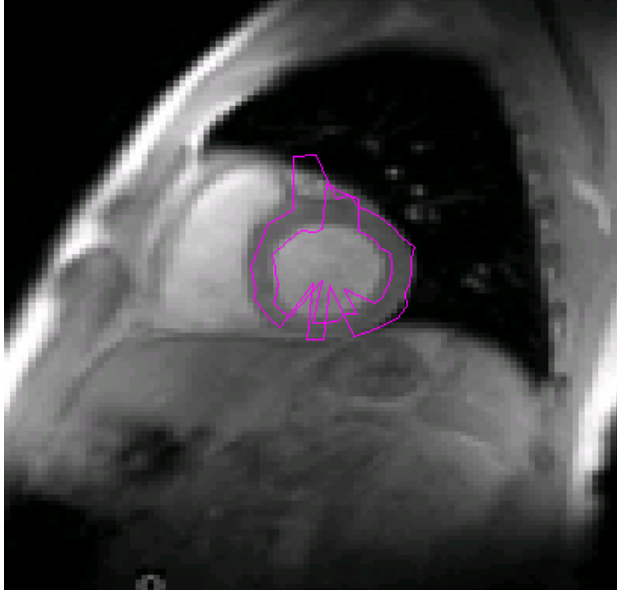




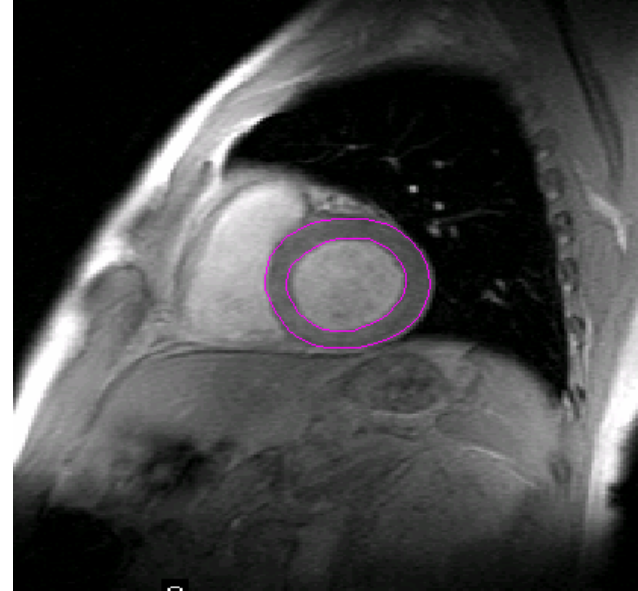
# PDM/ASM Segmentation



Un-allowable shape

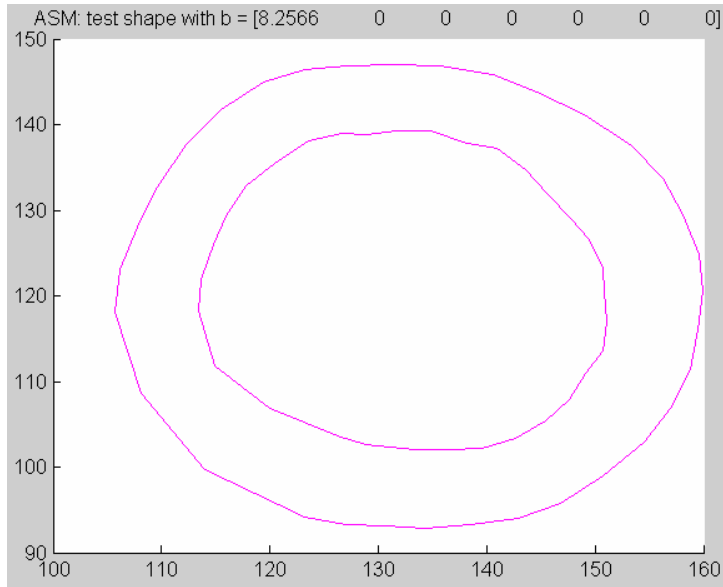


Allowable shape domain

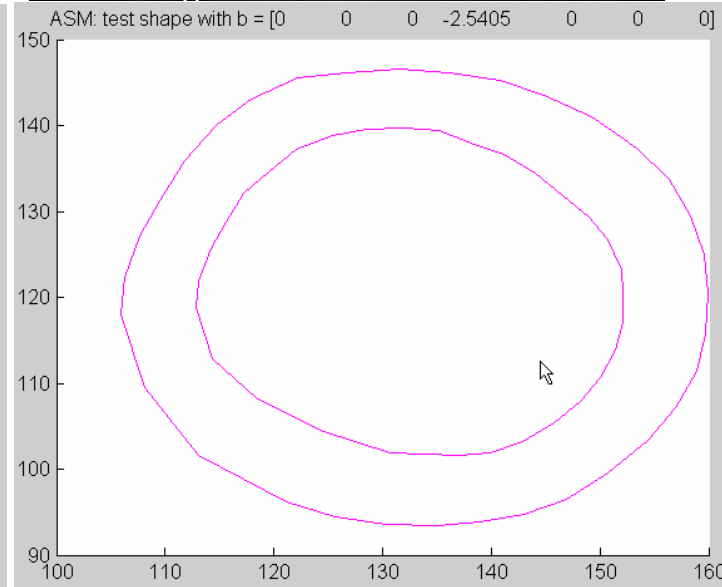


<http://www2.imm.dtu.dk/~aam/datasets/>

1st mode

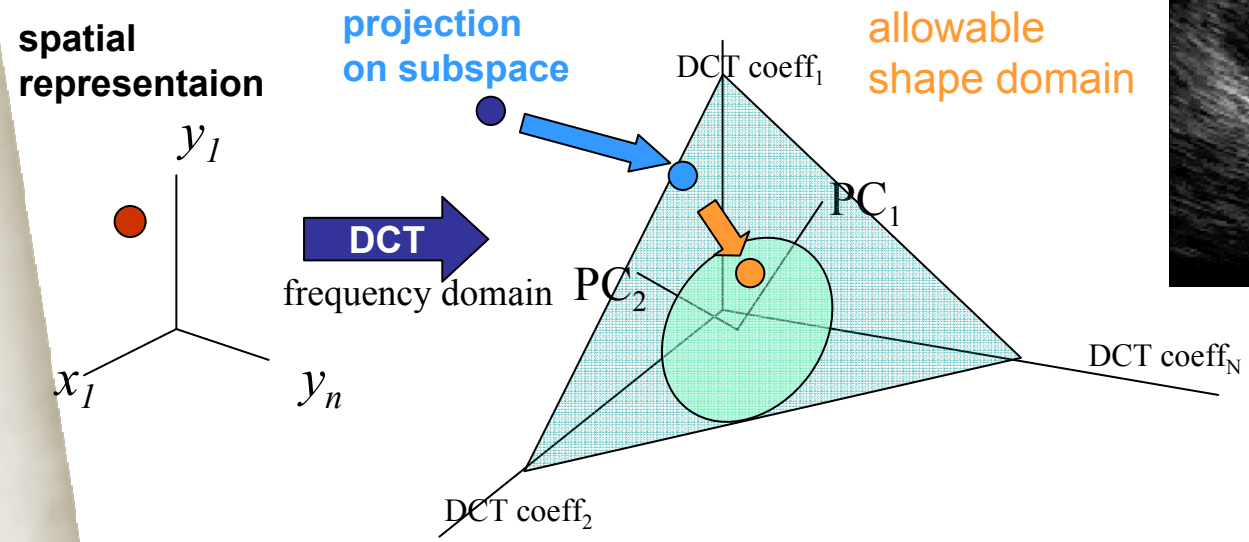
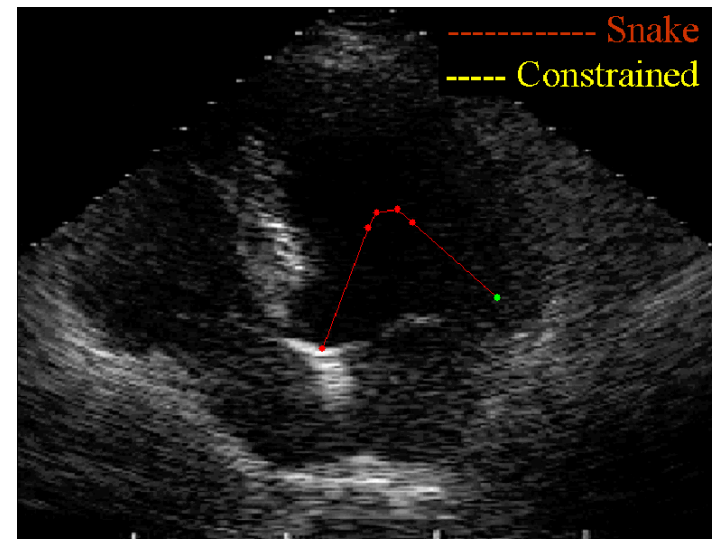
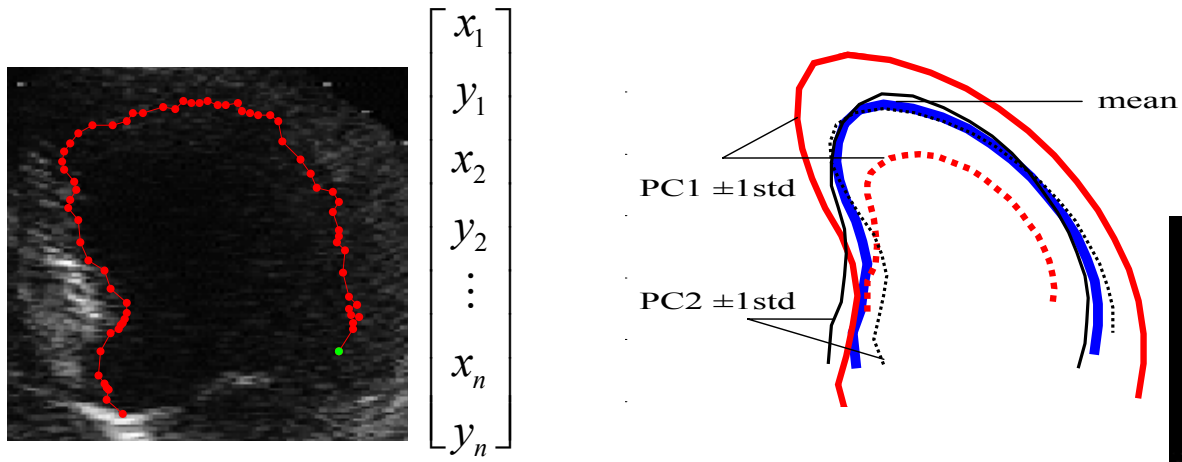


4th mode (too much)



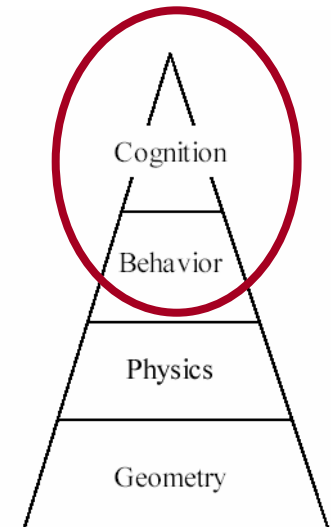
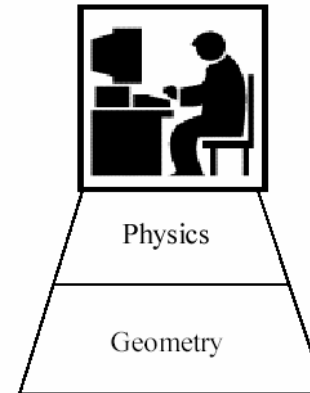


# “Fourier Snakes”



# Deformable Organisms

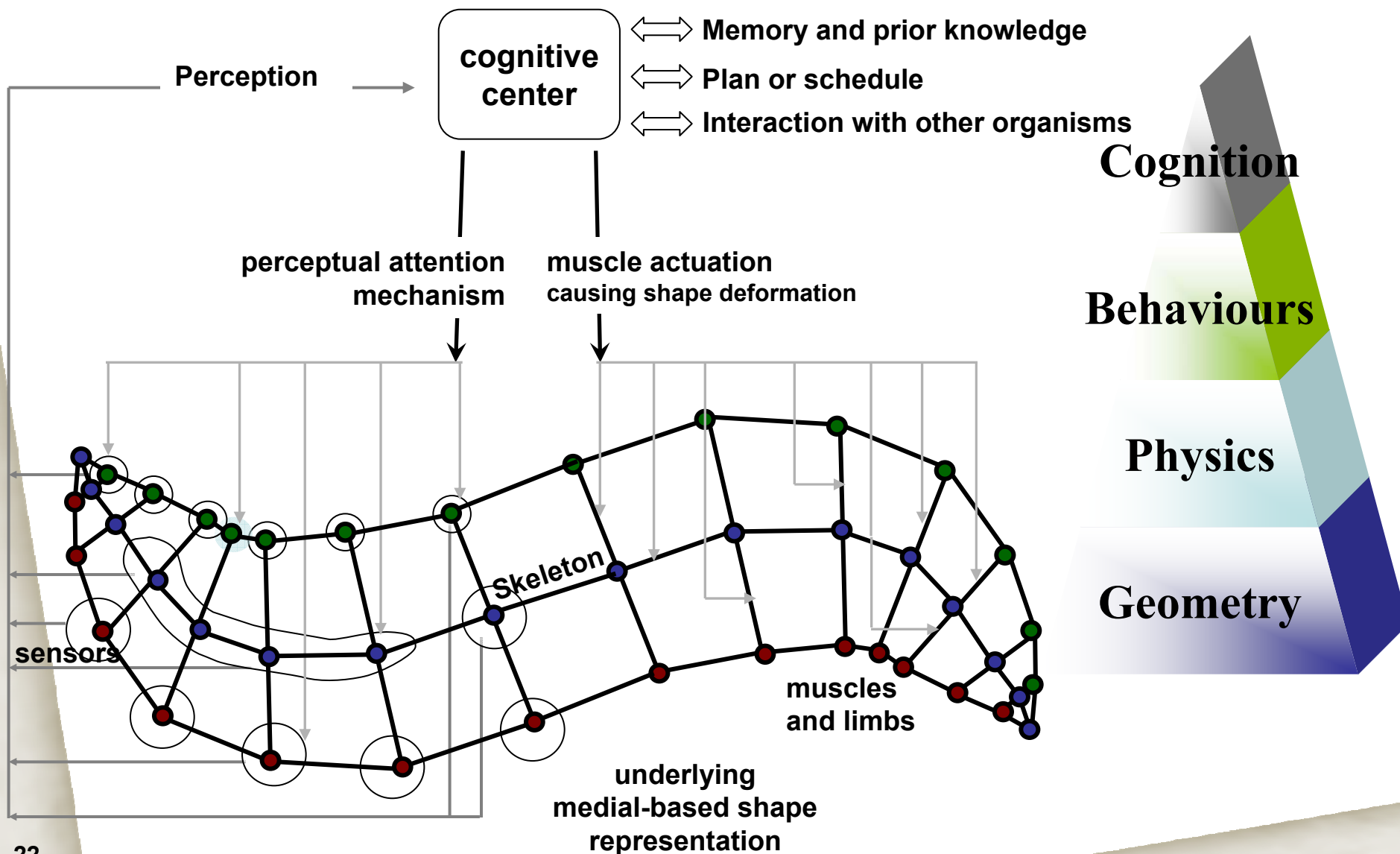
- Controlling deformation
  - User interaction
  - Global to local deformations
  - Global shape statistics
  - Setting low-level parameters
  - New cost/force terms



- Utilize high-level knowledge to guide model-fitting
- Difficult to encode knowledge in low-level terms
- Require intuitive, controlled shape deformation handles
- Artificial-Life framework that complements
  - **bottom-up data-driven** functionality of deformable models with...
  - **top-down knowledge-driven** model-fitting strategies

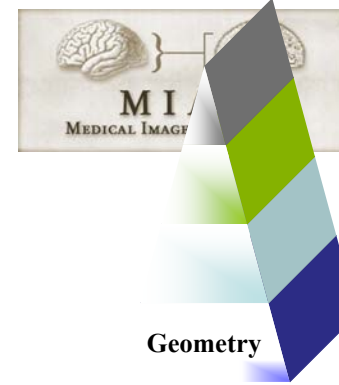


# Deformable Organisms

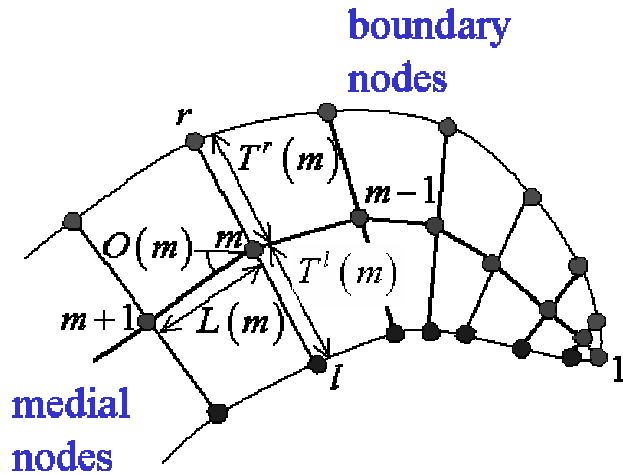




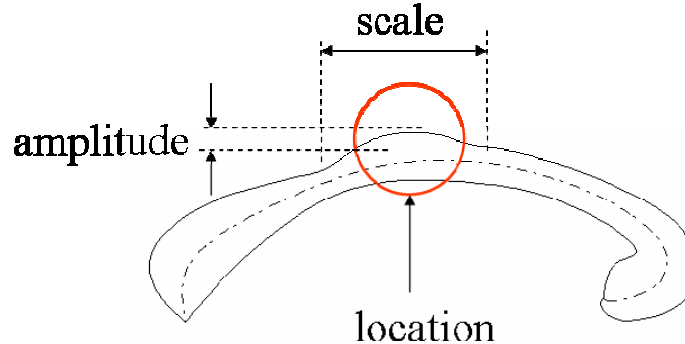
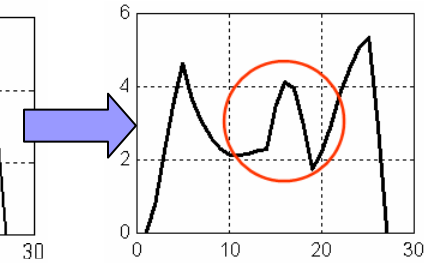
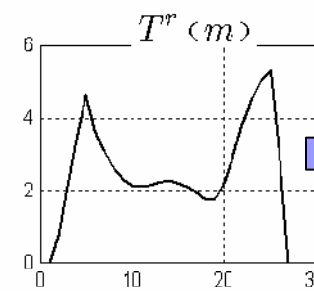
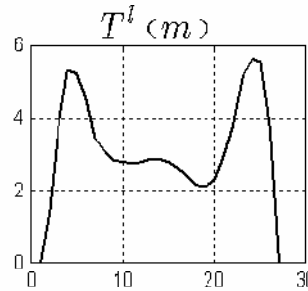
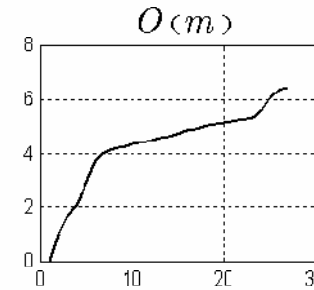
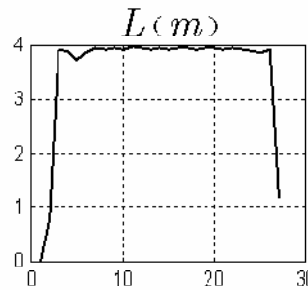
# Controlling Shape Deformation



## Medial-Based Shape Profiles

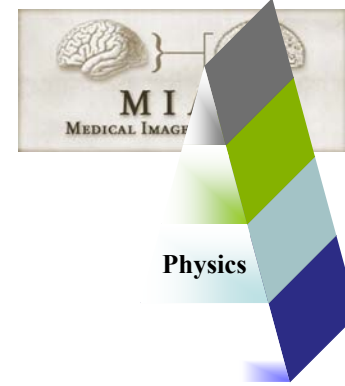


Length, Orientation,  
Left and right thickness





# Controlling Shape Deformation

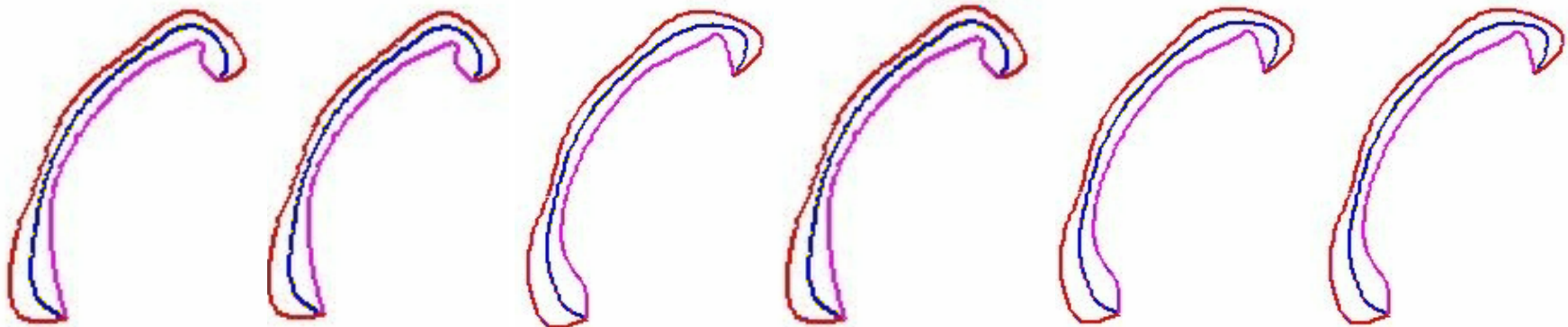


## Medial-Based Shape Profiles

Type: bending

stretching

thickening



**HR-PCA**

$$p_d = \bar{p}_d + \sum_l \sum_s \left( M_{dls} w_{dls} + \sum_t \alpha_{dlst} k_{dlst} \right)$$

location

scale

variation mode

operator type

amplitude





# Controlling Shape Deformation



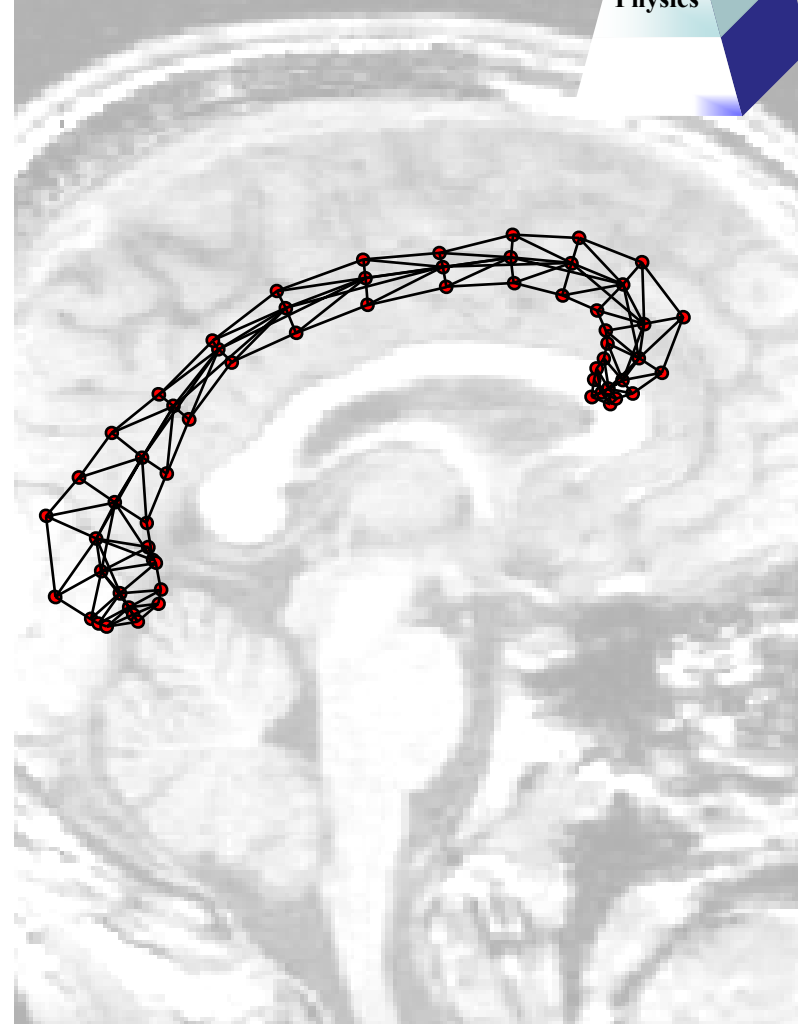
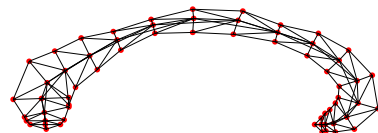
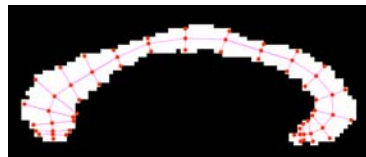
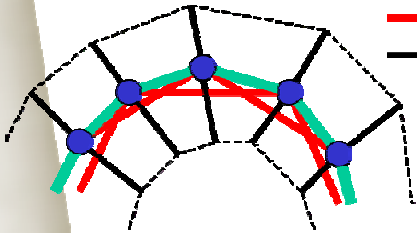
Physics

## Physics-Based Shape Deformations

- Mass-spring model
- User interaction
- Intuitive deformations
- Feasible shapes

Spring types:

- Stretch
- Hinge
- Thickness





# Controlling Shape Deformation

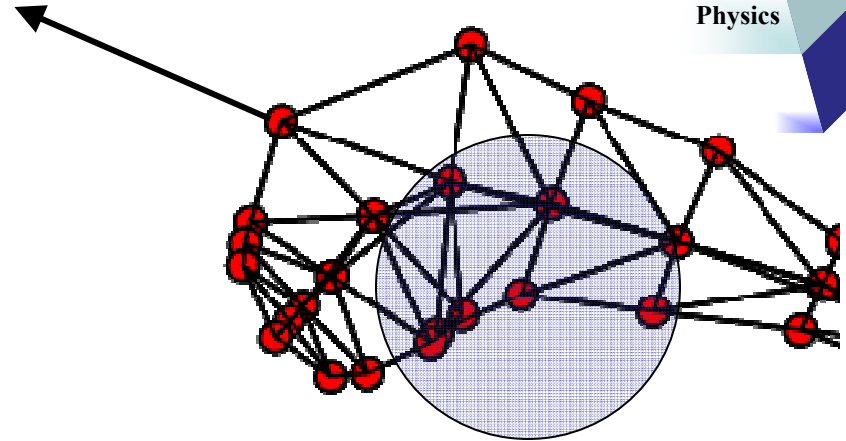
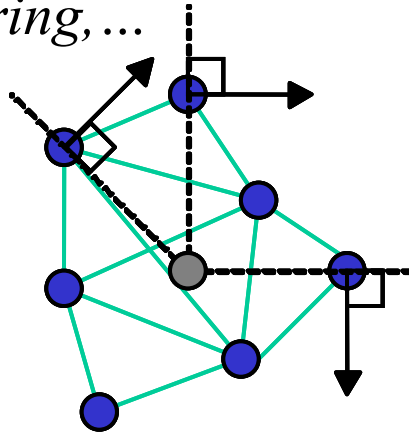


Physics

Deformations:

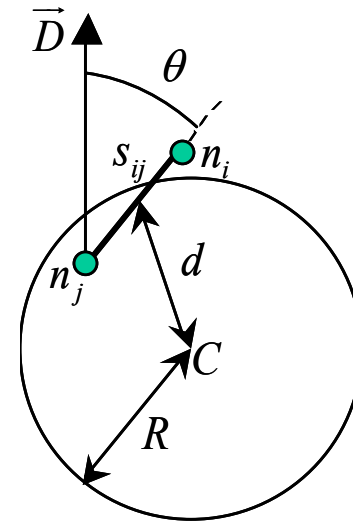
*Translation, rotation, scaling,  
Bending, bulging, tapering, ...*

External forces



Spring actuation

$$r_{ij} = \left( \left( 1 - \frac{d}{R} \right) \left( 1 - \frac{2\theta}{\pi} \right) (K - 1) + 1 \right) r_{ij}^{old}$$

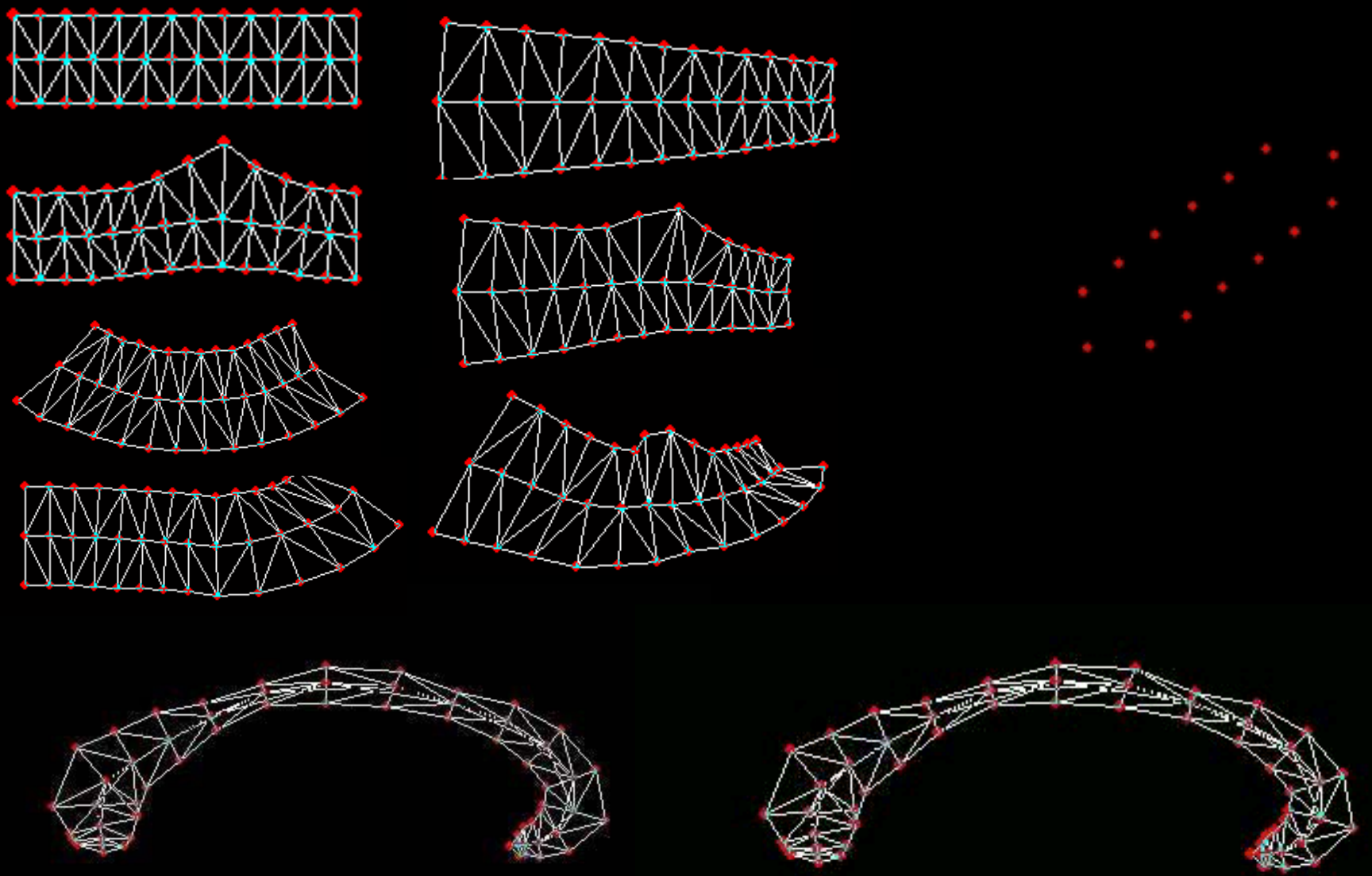


Statistics-based deformation **HR-PCA**

$$\mathbf{r}_{def,loc,scl} = \bar{\mathbf{r}}_{def,loc,scl} + M_{def,loc,scl} \mathbf{w}_{def,loc,scl}$$

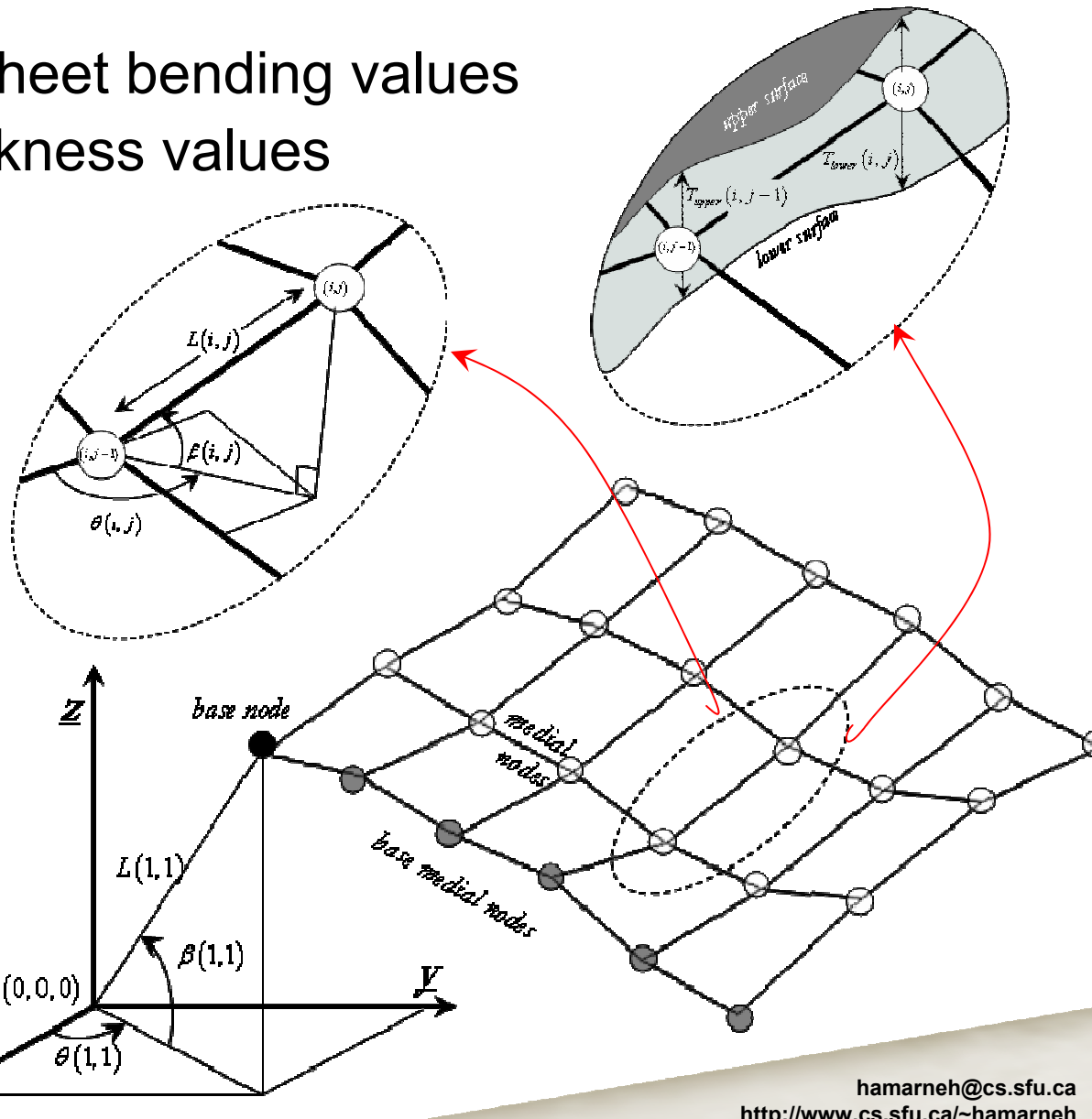
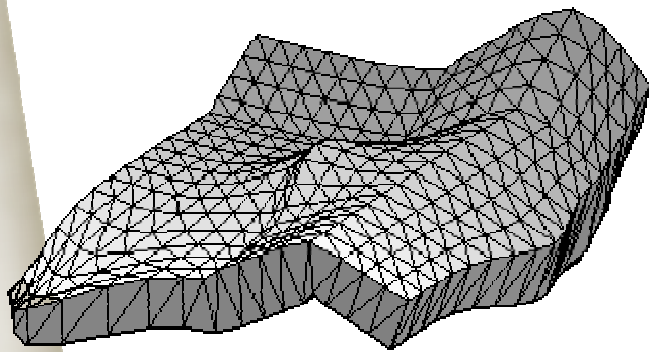


# Controlling Shape Deformation



# Controlling Shape Deformation, 3D

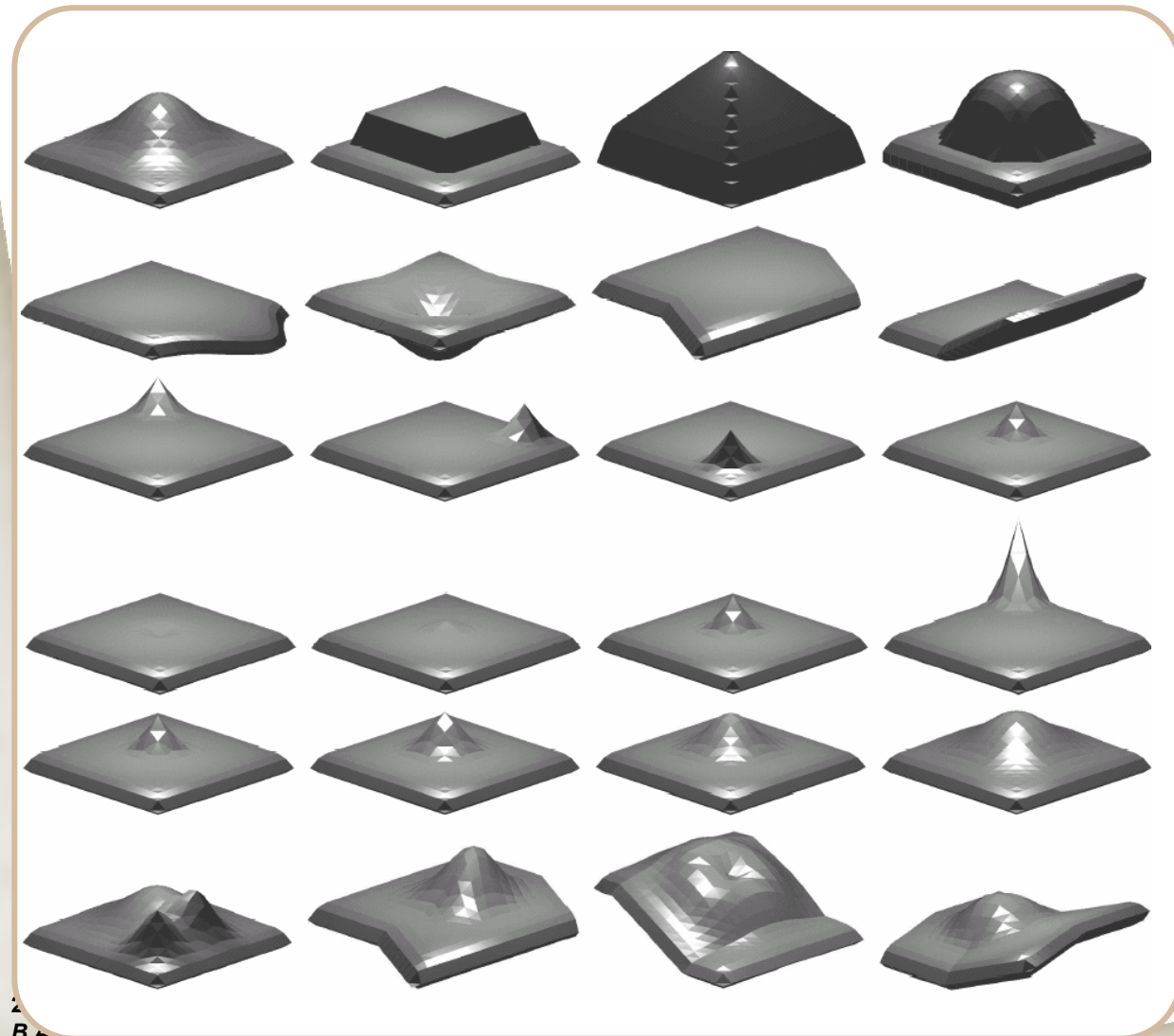
- In-sheet and out-of-sheet bending values
- Upper and lower thickness values
- Elongation values

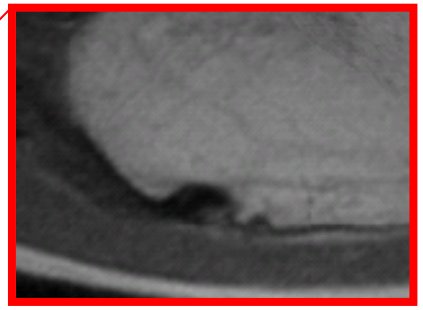
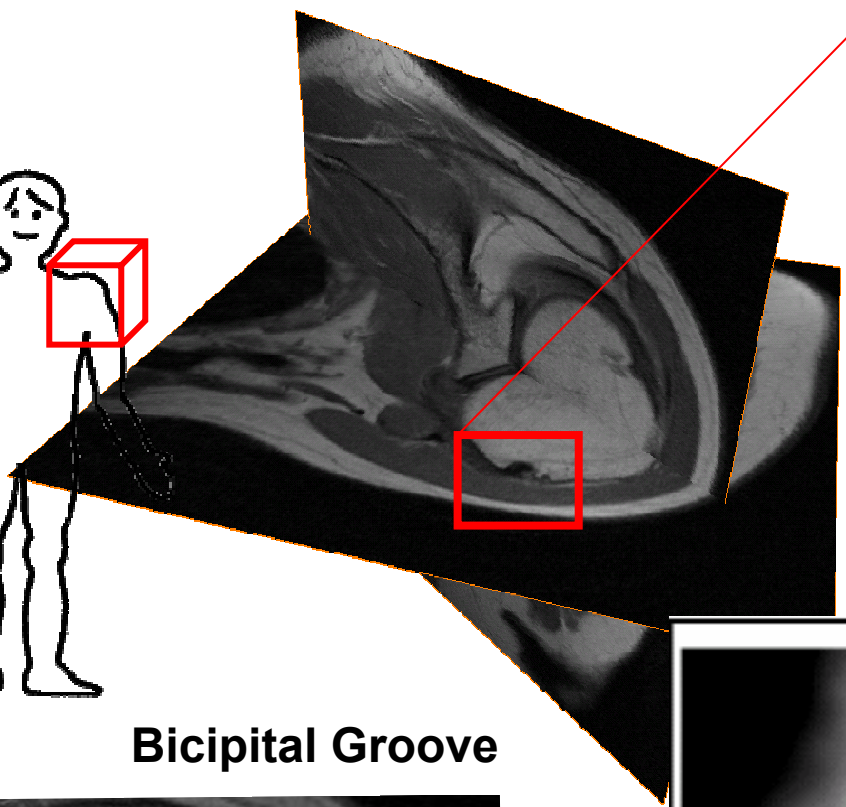
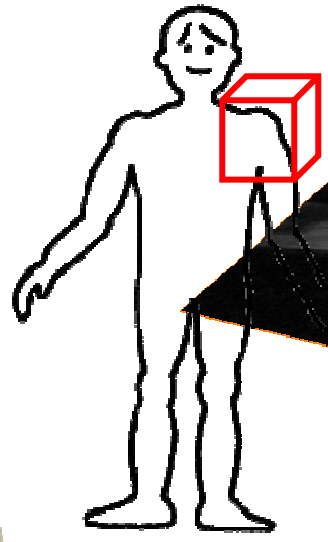




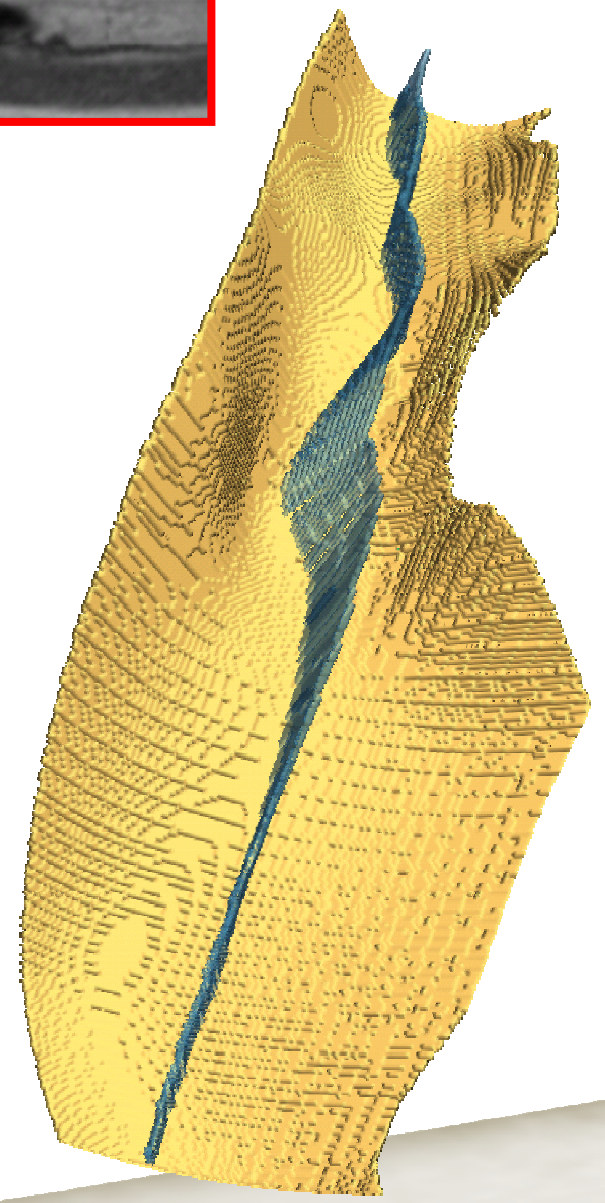
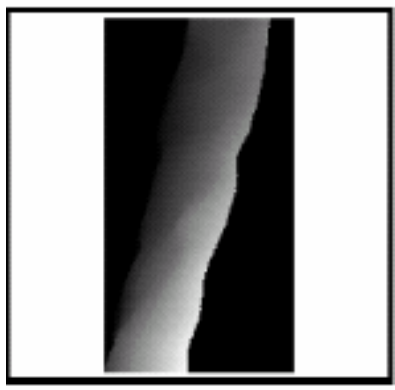
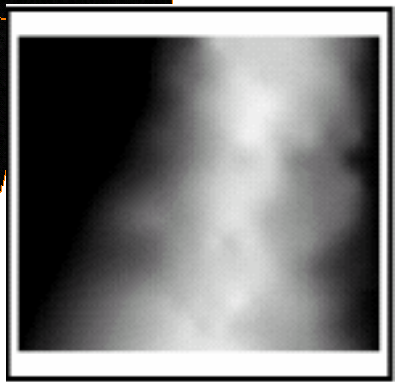
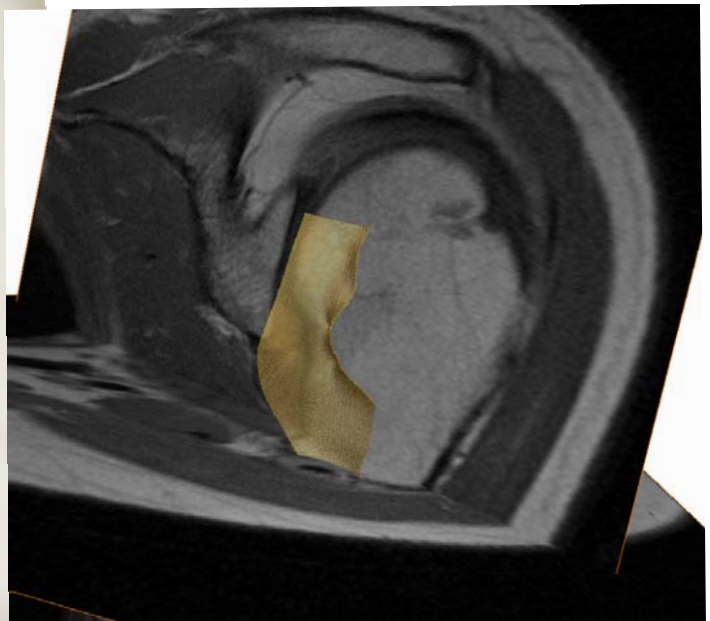
# 3D Deformations

Apply operators  $\rightarrow$  Intuitive, controlled shape deformation





**Bicipital Groove**

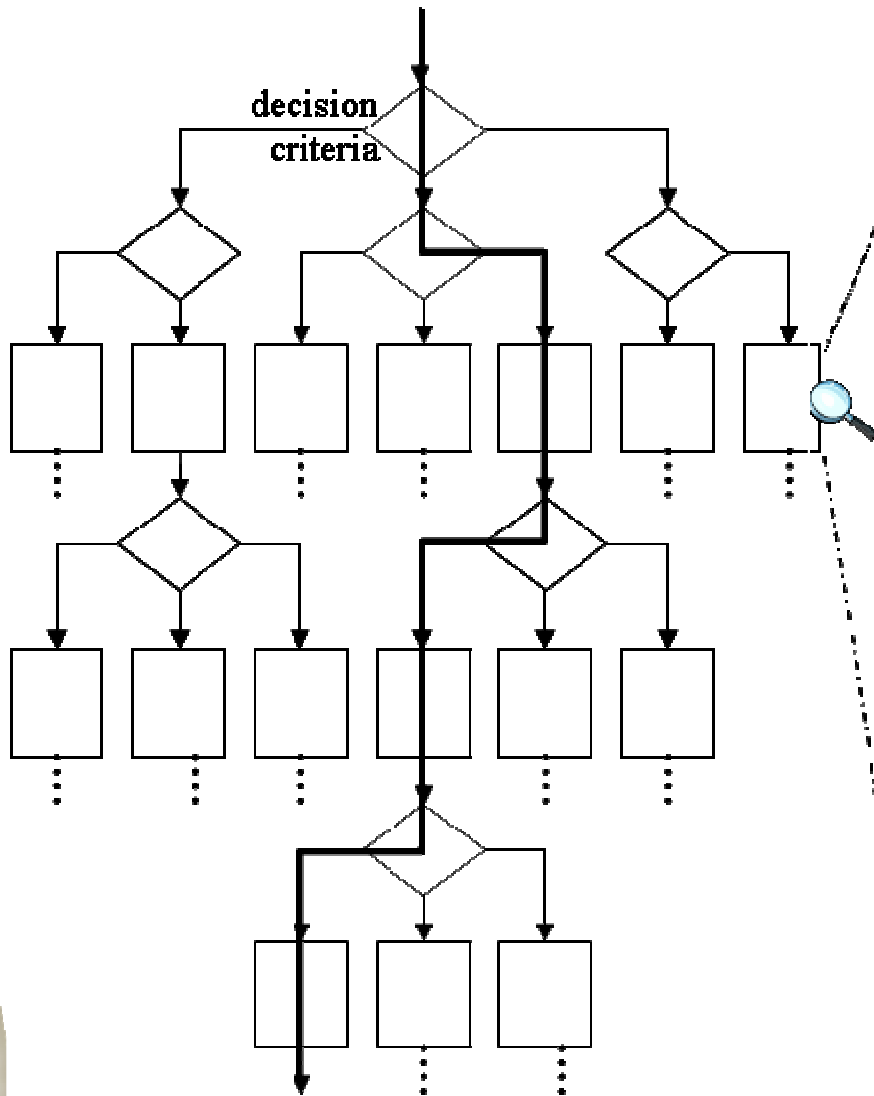




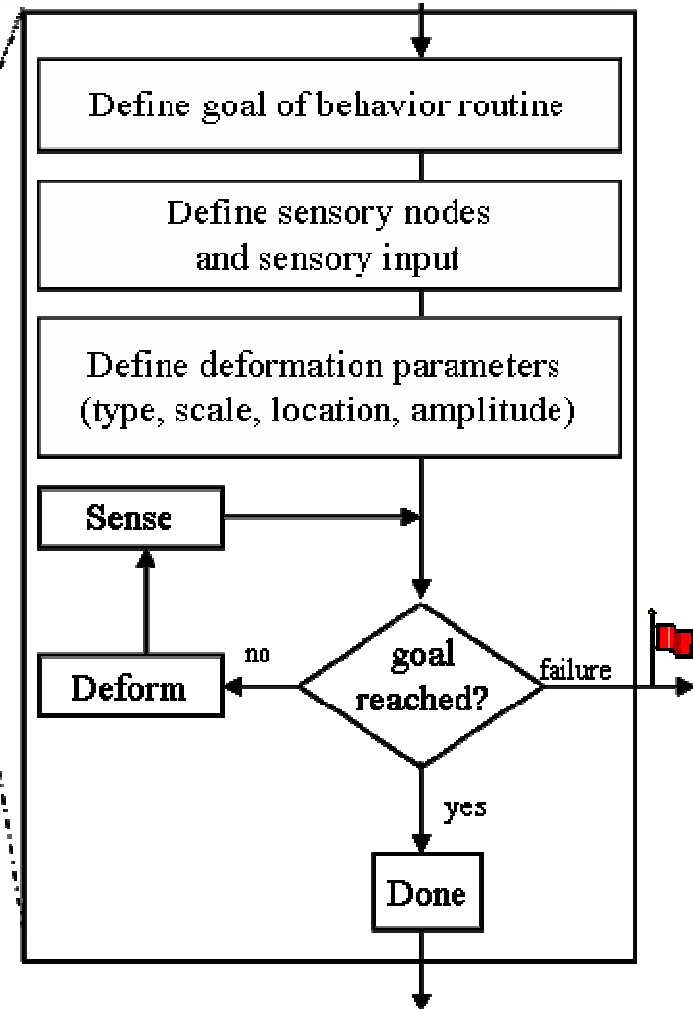
# Procedural Plan and Behavioral Routines



Behaviours



## standard behavior routine





# Cognitive Centre



*Combines:*  
sensory information,  
prior knowledge,  
instructions from a  
pre-stored segmentation plan,  
interaction with other  
organisms

*To carry out:*  
active, explicit searches  
for object features by  
activating behavior  
subroutines.

## Cognition

behaviour

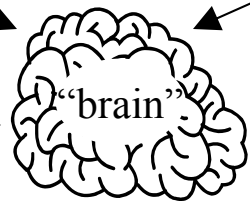
Physics

Geometry

Plan or schedule

Memory and  
prior knowledge

Perception



Interactions with  
other organisms

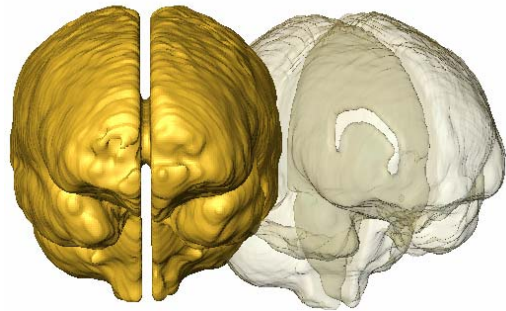
perceptual attention  
mechanism

muscle actuation  
causing shape deformation

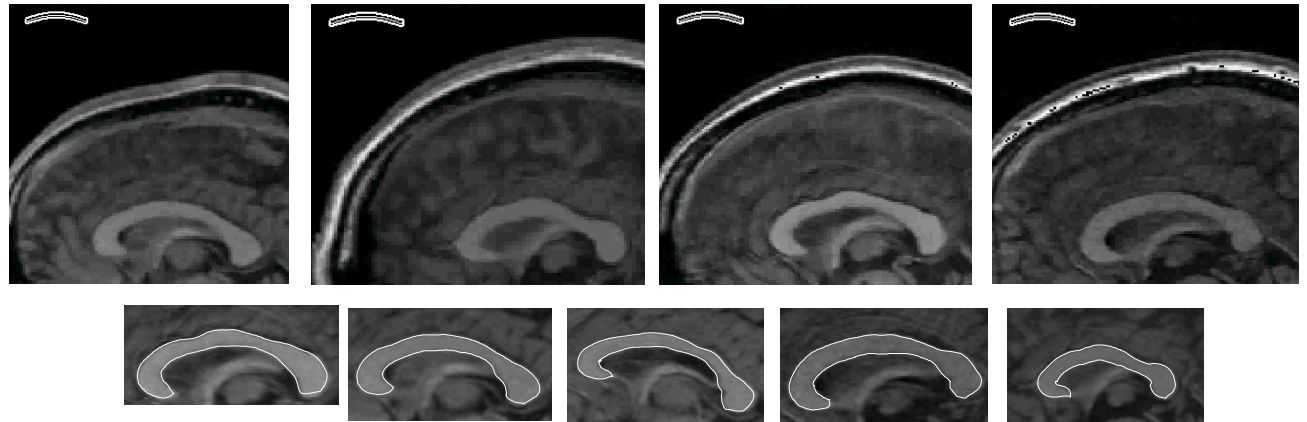




# Deformable Organism

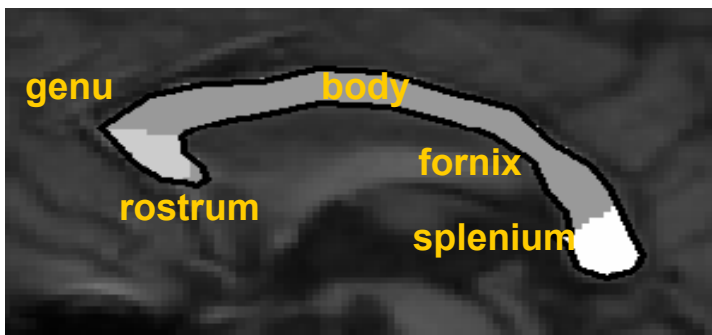
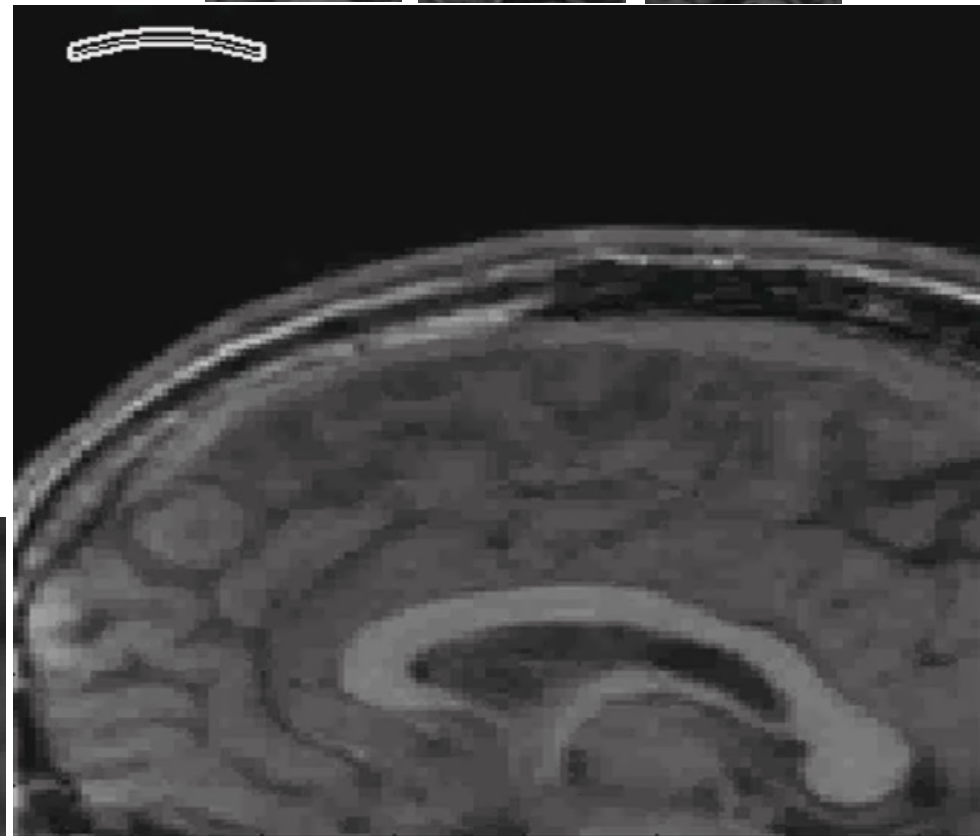
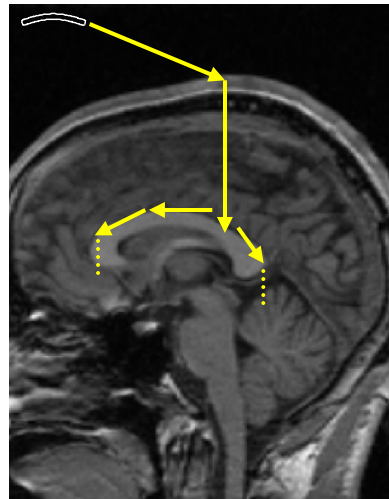


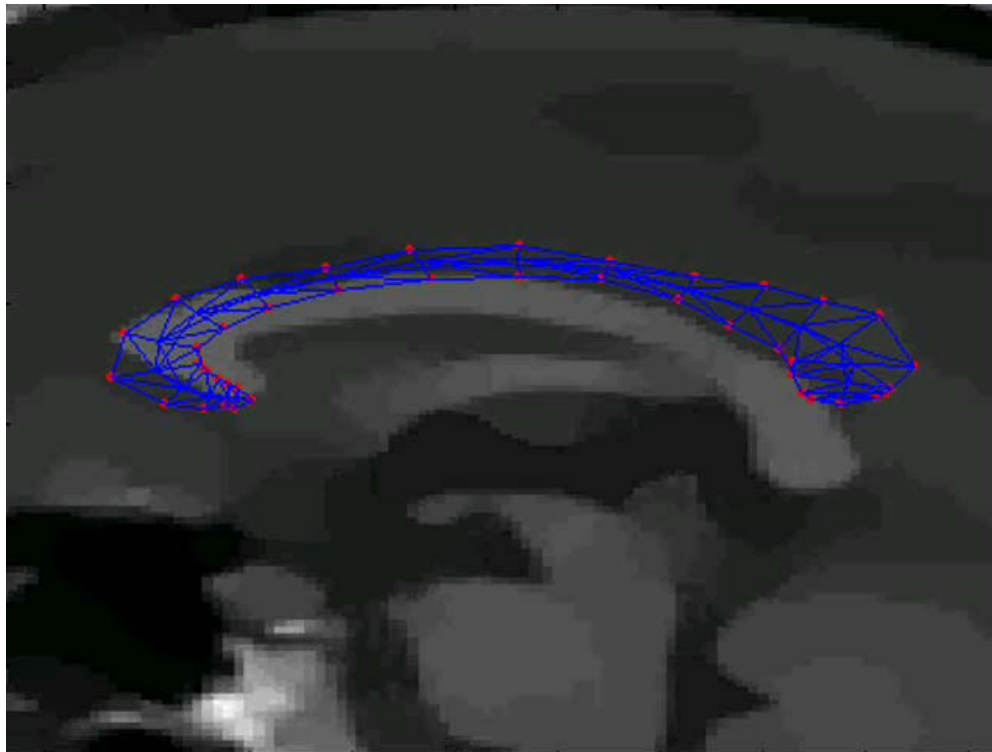
**Corpus callosum**



**Behavioral routines**

- find-top-of-head
- find-upper-boundary
- latch-to-boundary
- find-genu,
- find-rostrum,
- find-splenium

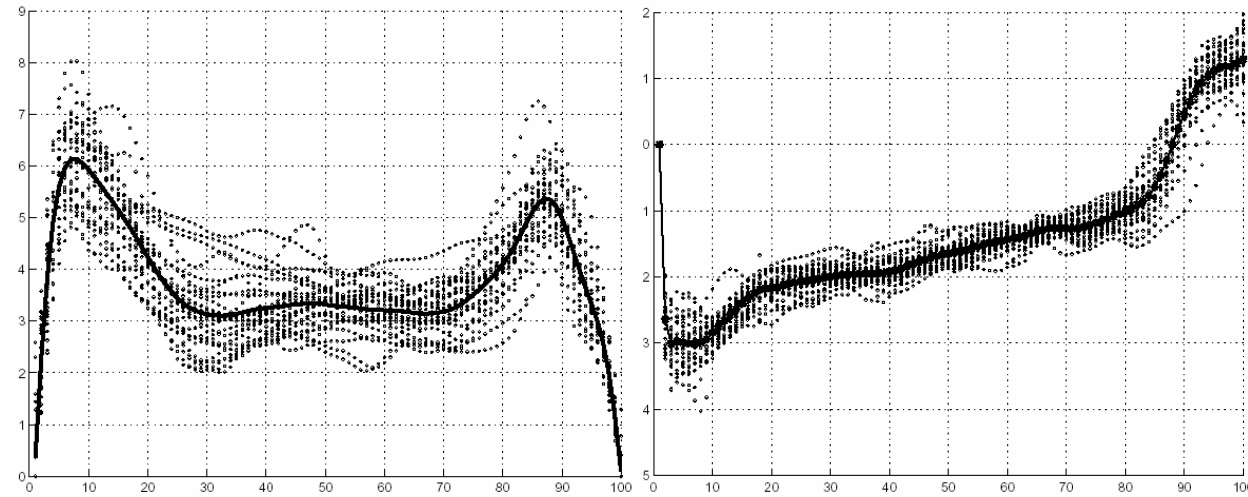




- Global model alignment:
  - Deform: Translational forces
  - Sense: norm mean & variance
  - Decide: max mean, min variance
- Model parts' alignment:
  - *For each: Splenium, Genu, Rostrum*
  - Deform: rotational & translational forces
  - Sense: norm mean & variance
  - Decide: max mean, min variance
- Model parts' contraction/expansion:
  - *For each: Splenium, Genu, Rostrum*
  - Deform: contraction/expansion
  - Sense: norm regional mean, variance, area
  - Decide: max mean, min variance, max area
- Medial-axis alignment
  - Deform: Stretch along thickness springs
  - :
- Fitting to Boundary
  - Deform: Forces at boundary nodes along thickness spring
  - Sense: edge strength (+ mean, var)
  - :
- Detect/repair fornix dip:
  - Detect based on parallelism to medial/upper-boundary, gradient, thickness
  - Repair by interpolate, ...



# Statistical Shape Analysis



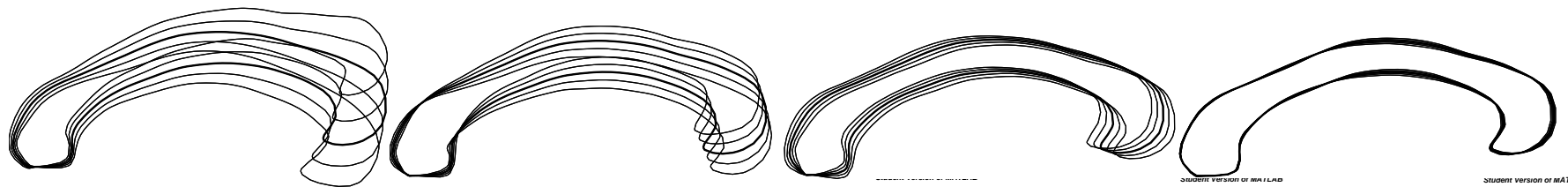
Thickness and orientation profiles



Shape histogram



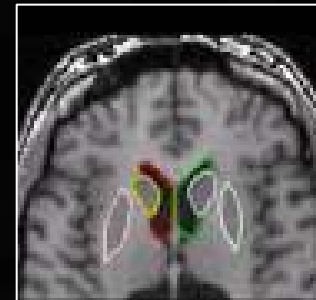
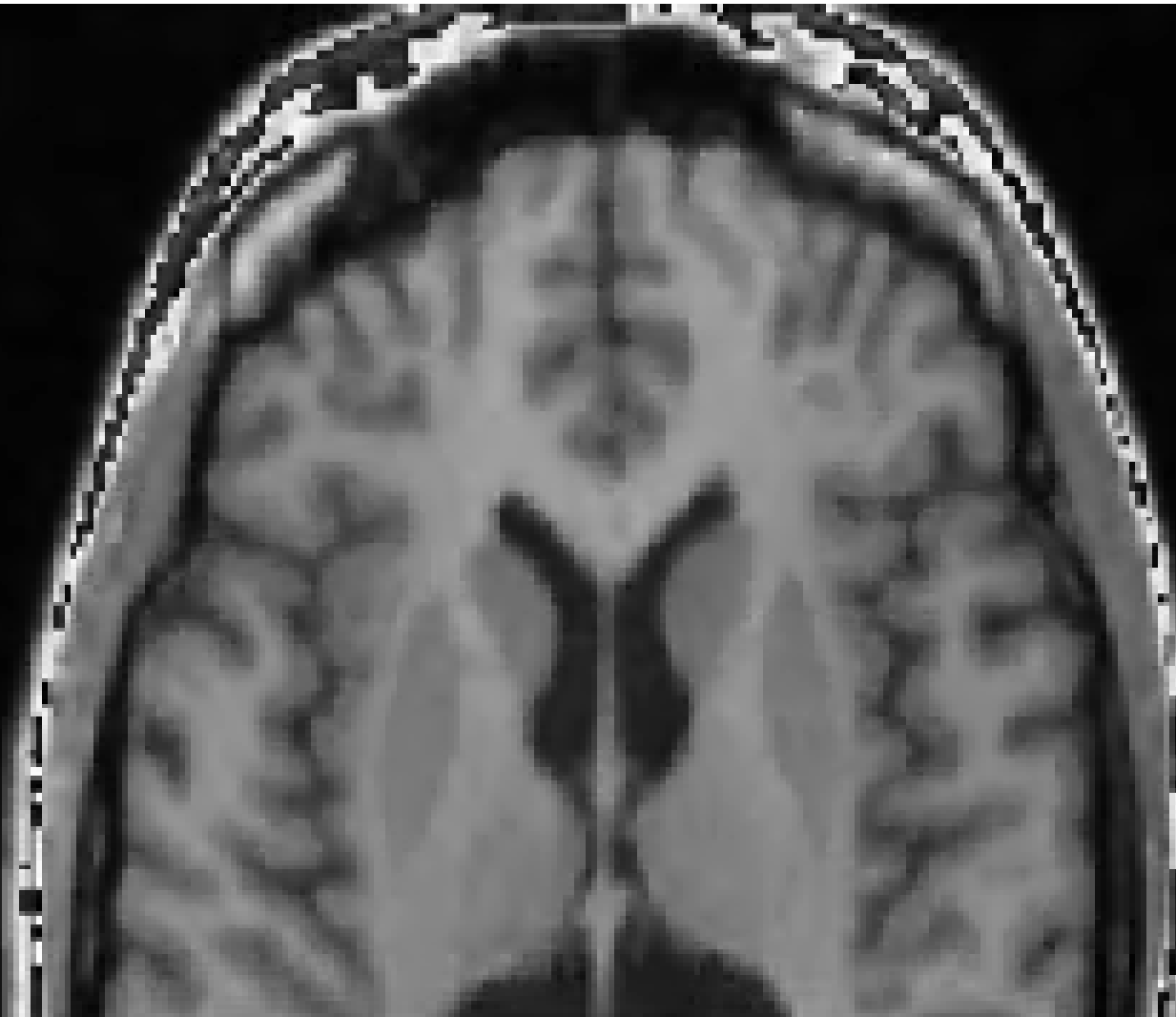
Main modes of localized and deformation-specific shape variation



1<sup>st</sup>, 2<sup>nd</sup>, 3<sup>rd</sup>, 4<sup>th</sup> main modes of global bending explaining 41.07, 14.15, 11.96, 6.68% of the total variation

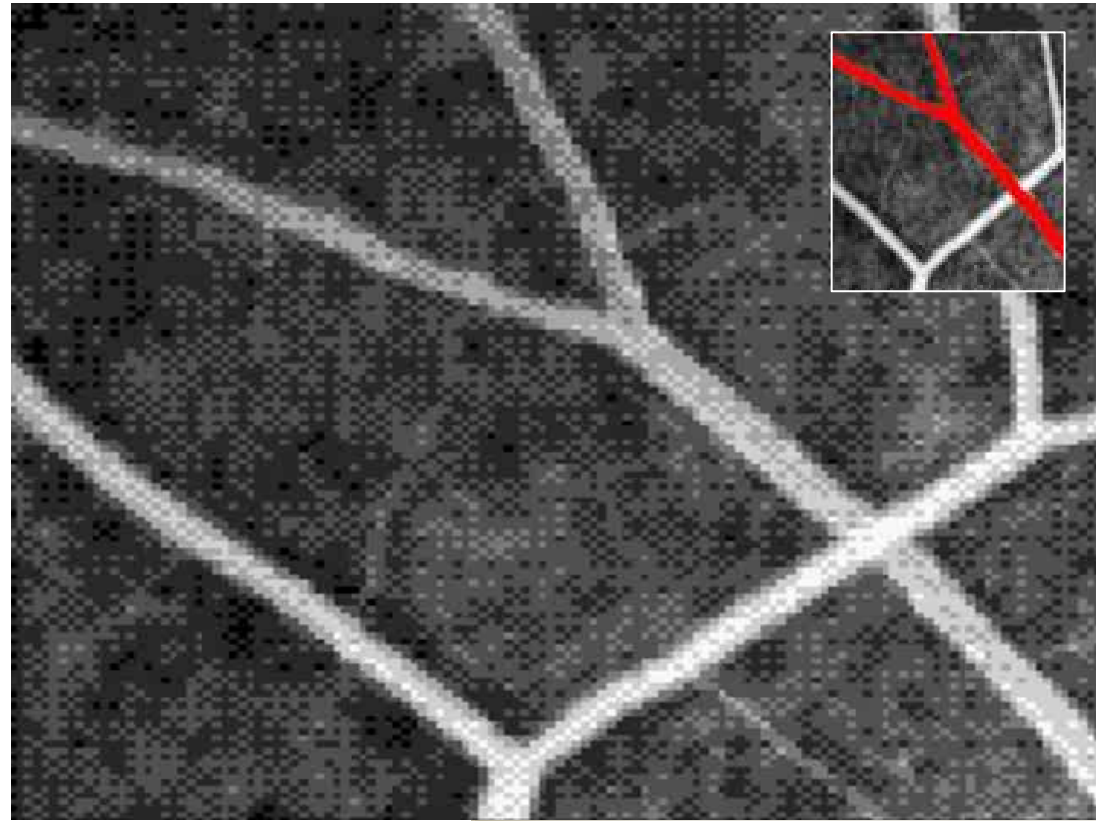
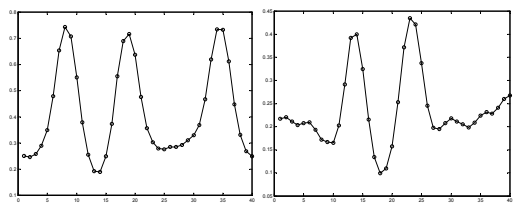
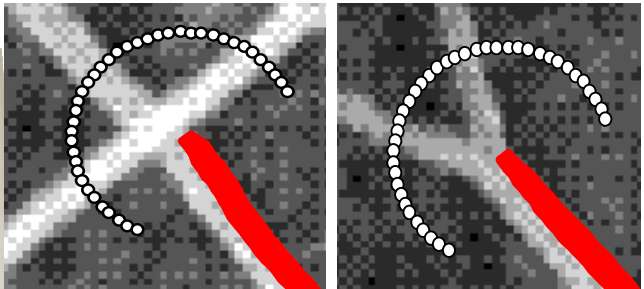
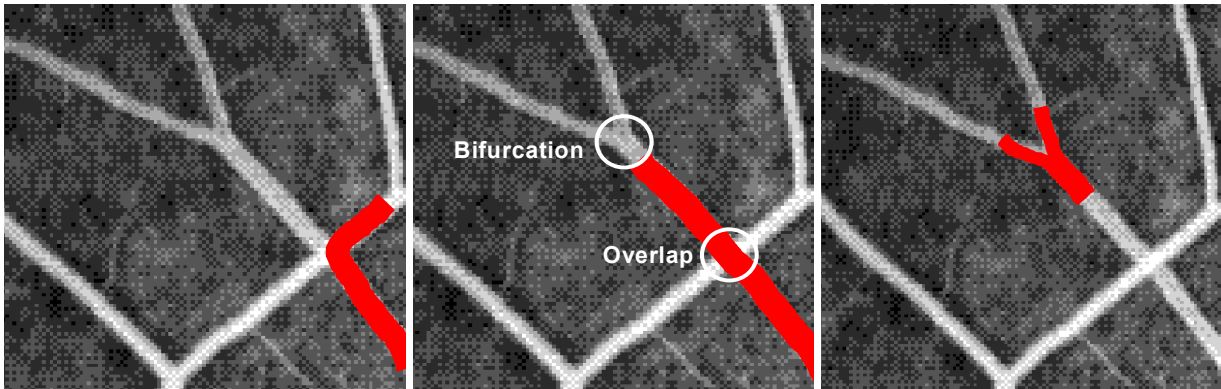


# Deformable Organisms: Lateral Ventricles, Caudate Nuclei, and Putamina



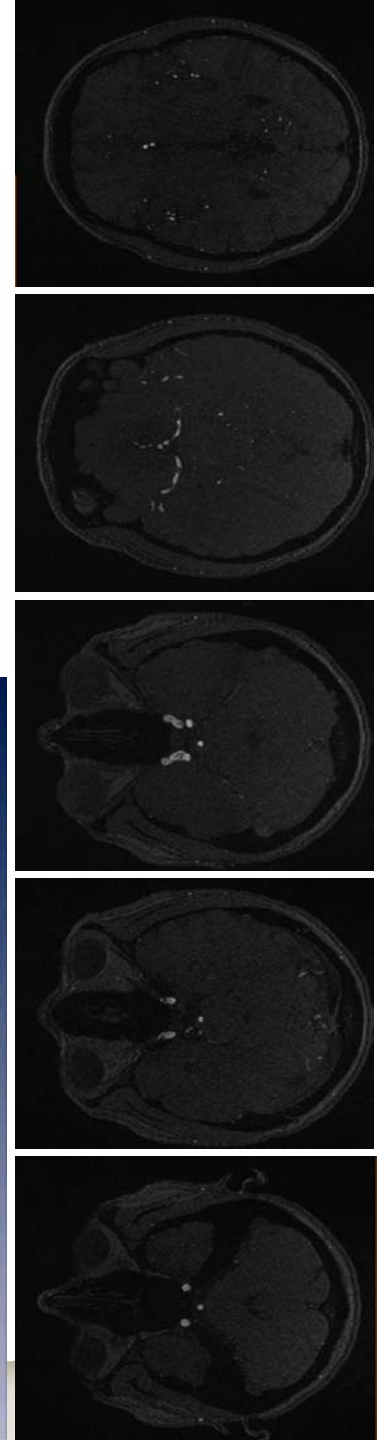
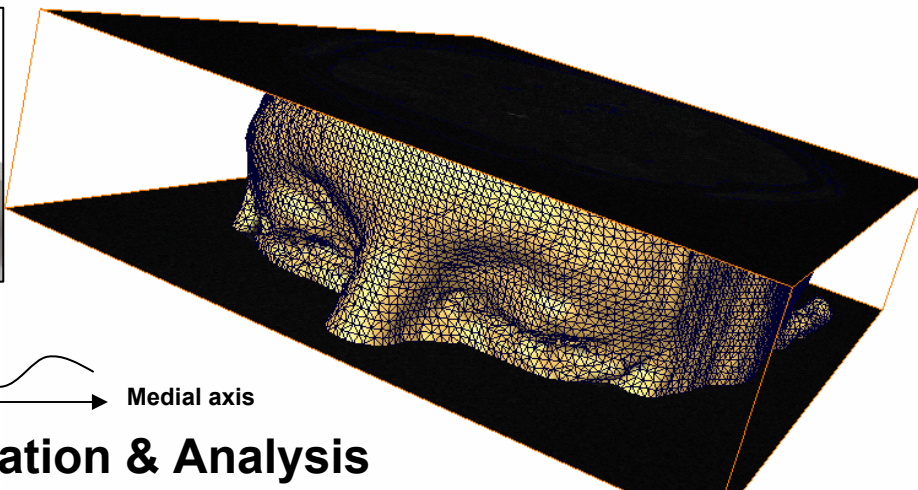
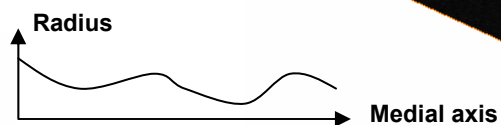
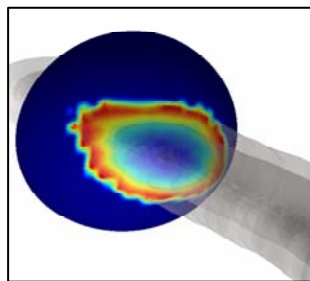
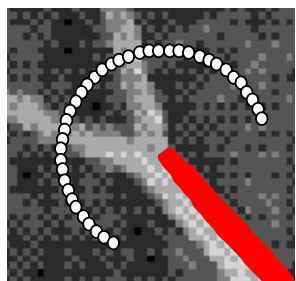


# 2D Vessel Crawler

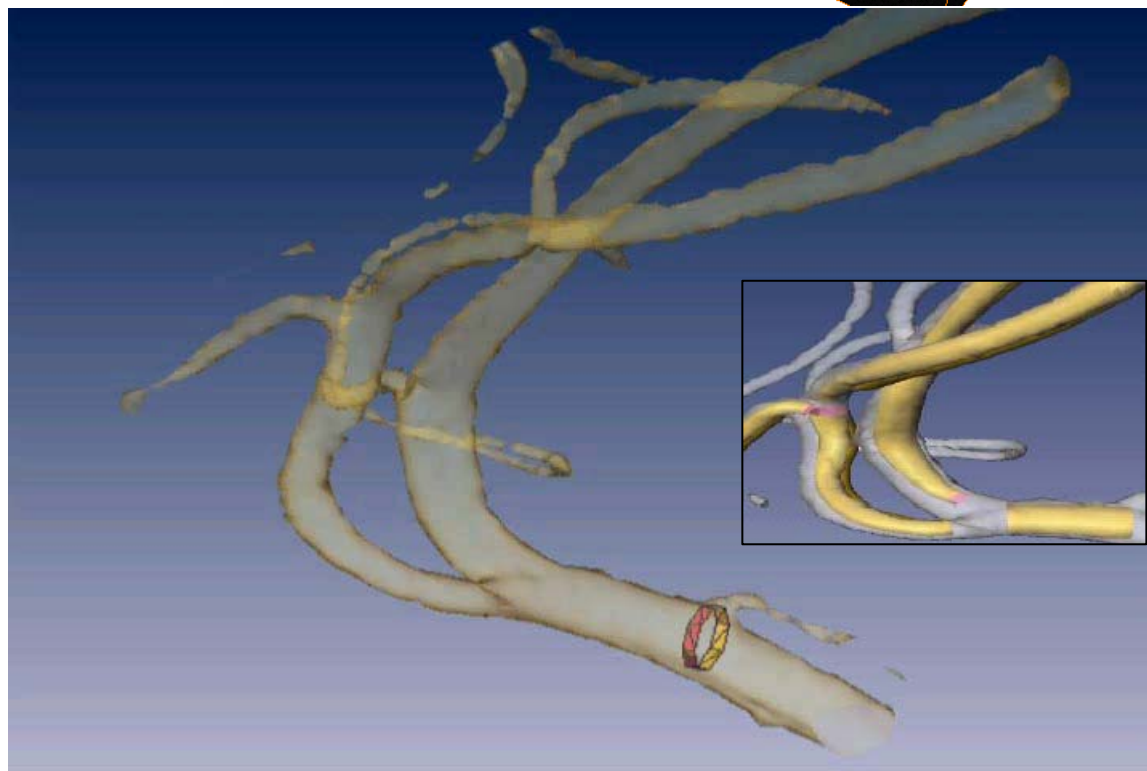
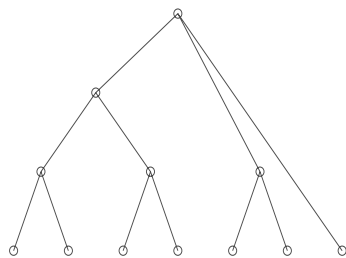
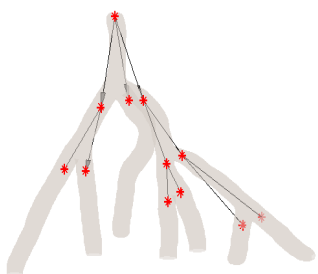
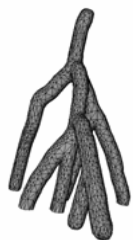




# 3D Vessel Crawler



## Segmentation & Analysis





# Summary



- Multimedia patient record
- Medical images & analysis
- Deformable models for segmentation
- Synthesizing and analyzing deformable shapes
- Deformable organisms, A-Life approach to MIA
  
- Challenges...
  - Robust, highly-automated MIA
  - Large data... store, communicate, visualize, process, analyze, access, link to patient records...
  - Small displays and mobile users



# Acknowledgements



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- Funding:
  - NSERC, CFI, SFU