SSIP2003 Romania

The Analysis of temporal series, Data reduction and Image Fusion

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Romania 2003

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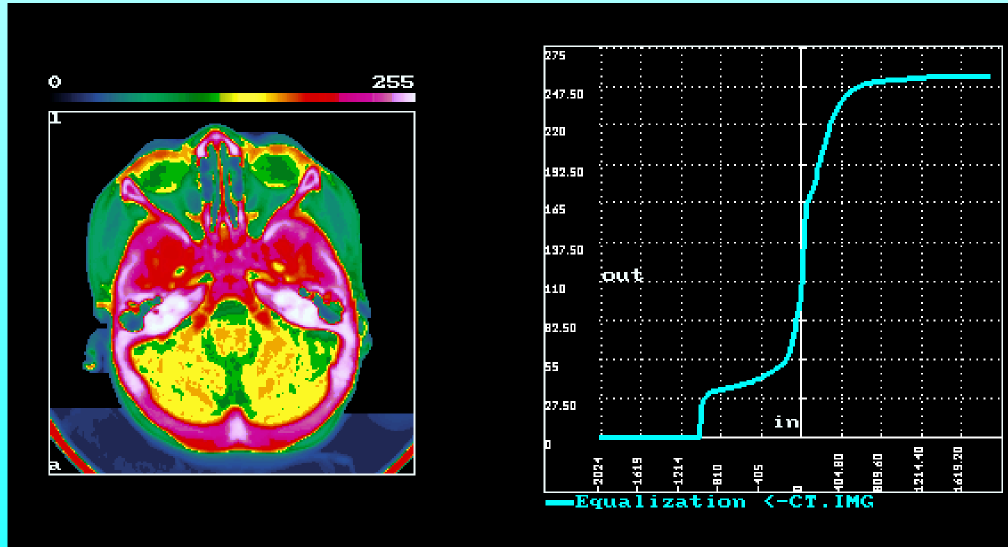
Image processing in general

- Aims of image processing
  - Detection
  - Measurement
  - **Description**
- Types of data
  - 3D in time with multiple channels

- Pre-Processing
- Manipulation
- Assessment



Histogram Equalization

Some Image Processing Tools

- Transforms | filters
  - choose basis function
  - transform
  - filter “eigenvalues”
  - inverse operation
- Solution to inverse problems
  - set up forward model
  - solve
- Hierarchical descriptions
  - combine
  - classify
  - isolate
- Model fitting
  - find model
  - **find distance measure**
  - minimise

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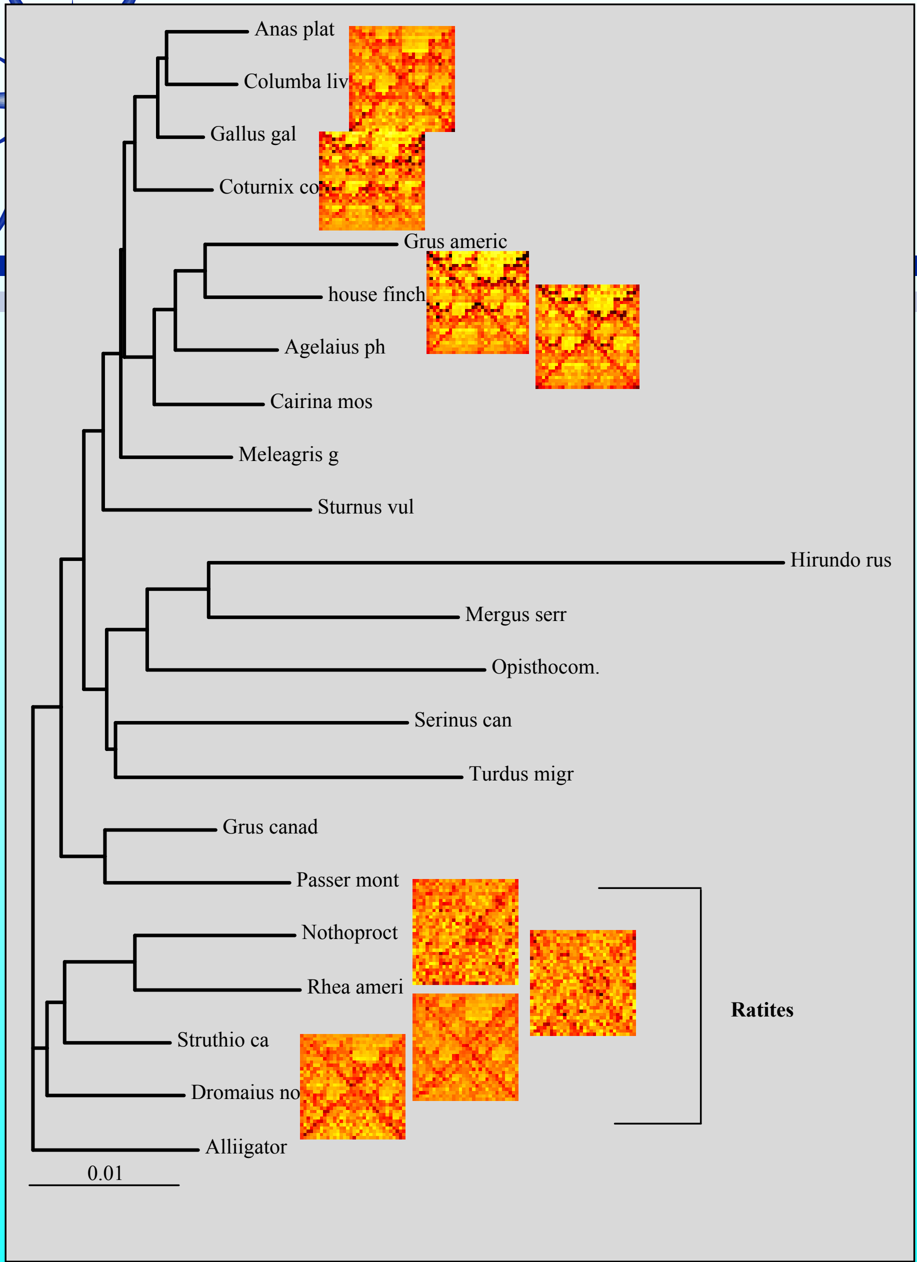
Phylogeny



Problem :

- Place of 'running' birds (ratites) with respect to other birds

Method :

- **Supertree of relationships**

Collaboration avec S Edwards (Seattle, USA) et H Philippe (Paris, France)

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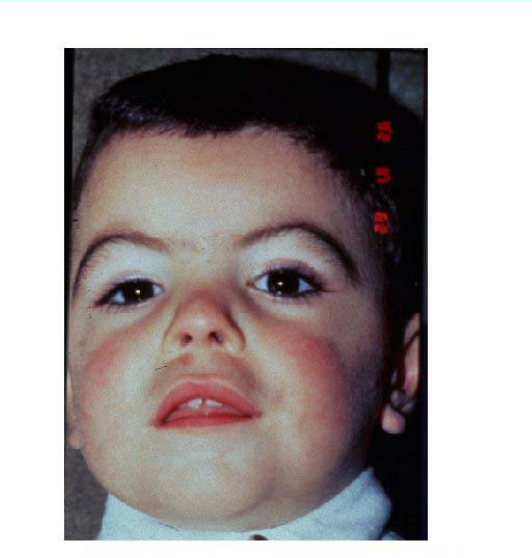
Why is image recognition so difficult for a computer?

Image Retrieval



Ack Ian Bradford

Knowledge Hierarchy

- High level
  - State of structure
  - Clinical condition
- Intermediate
  - Structures
  - Organs
- Low level
  - Lines, edges, tubes
- Pixel
  - standard image processing

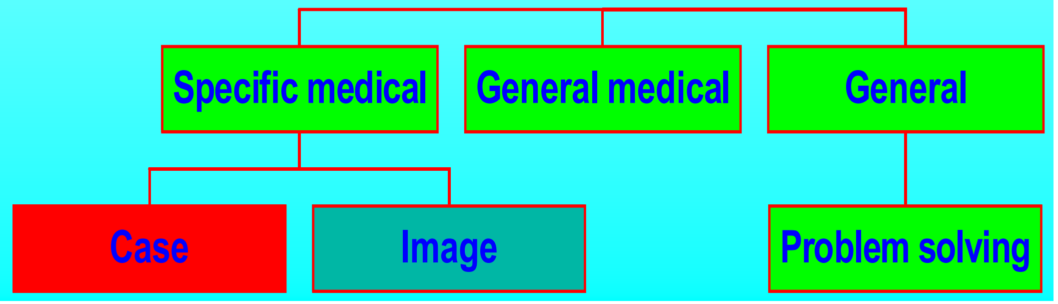
- Goal
  - forward/backwards chaining
- Objects
  - inheritance
  - attributes and methods
- Knowledge
  - local/global
- Agents
  - serial/parallel

Using A-priori knowledge

- Statistical pattern recognition
- Syntactic pattern recognition
- Model based constraints
- Knowledge based methods

- Going towards the right solution
- Avoiding bias
- Including the observer
- Solving higher level problems

Knowledge based engine



PostModernism

Any representation of the real world

is bound to be self-referential

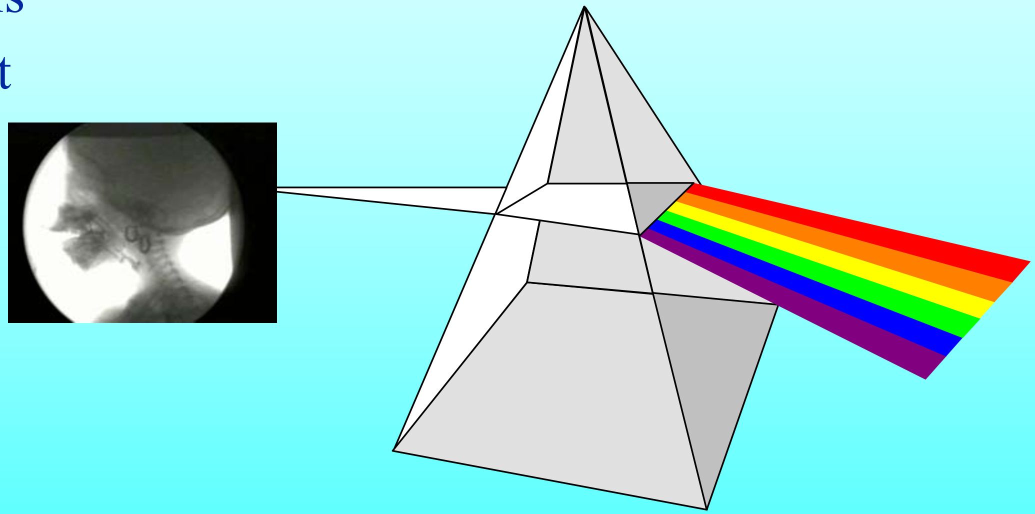
using any combination of language, mathematics and symbols

[Variation on Heisenberg uncertainty]

- "Everything I say is false"

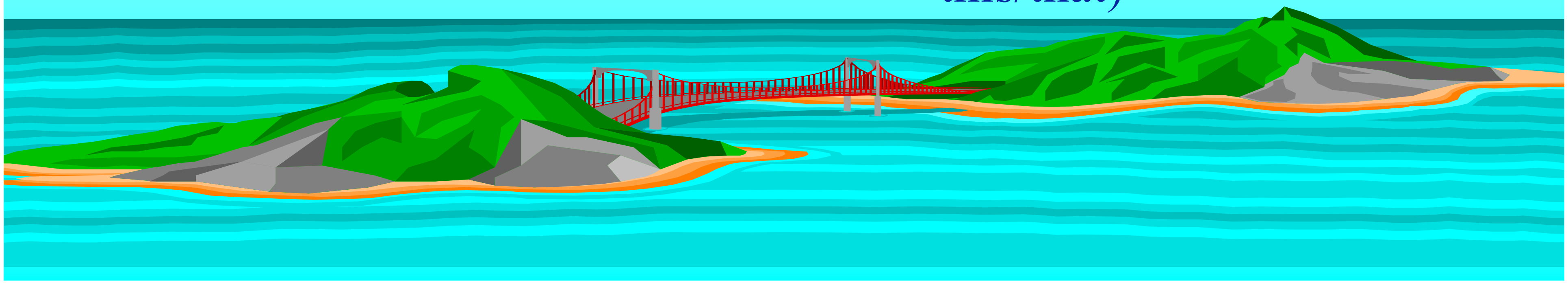
Data driven v. Hypothesis driven methods

- Hypothesis driven
  - find a (null) hypothesis
  - generate statistical test
- Data driven
  - look at data
  - suggest hypothesis
- Constraints
  - limit search space
  - investigate hypotheses
    based on a priori knowledge



Boundary conditions/ Constraints

- Physical
  - spatial extent
  - positivity
  - initial/final states
  - statistical variation
  - regional
  - deterministic
- Context
  - classification
  - model based
    - Statistical
  - measurable (volume, biochemical level, etc)
  - <u>comparable </u>(before/ after, this/that)



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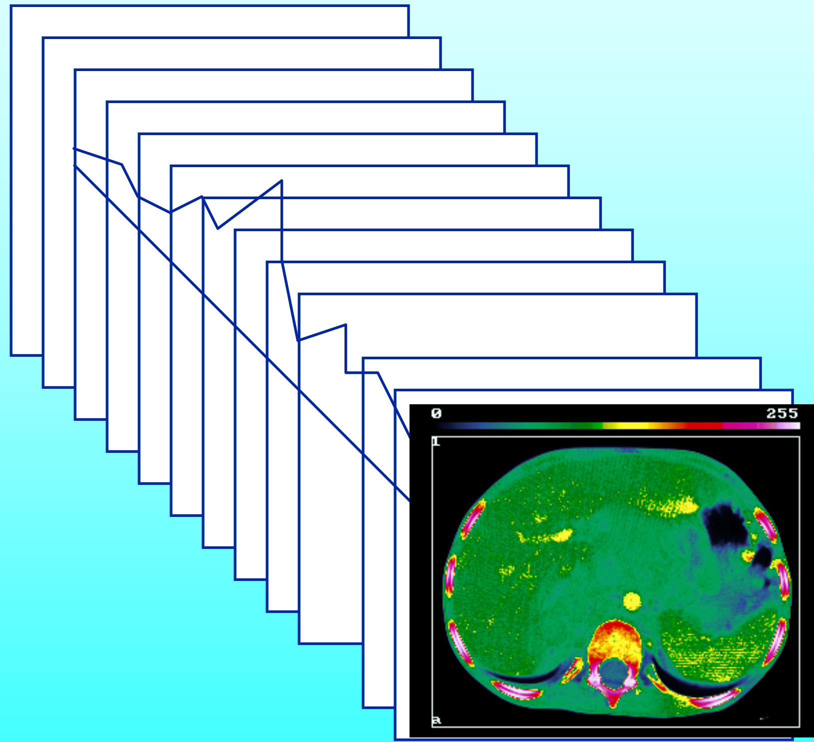
Handling of temporal data

Special class of 3-D data processing

- Looking for change
- Looking for (derived) function

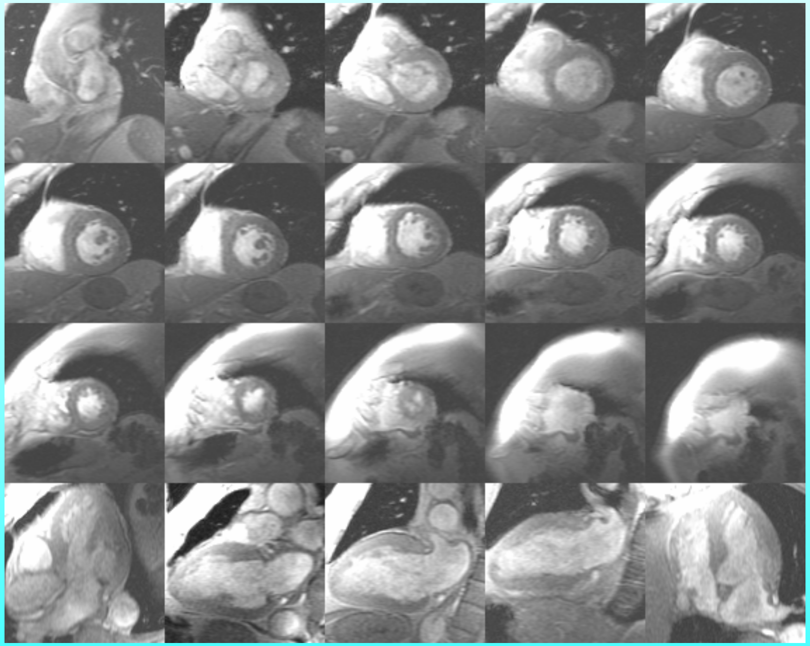


Consider set of time curves for every pixel

- Dual curve/image data set

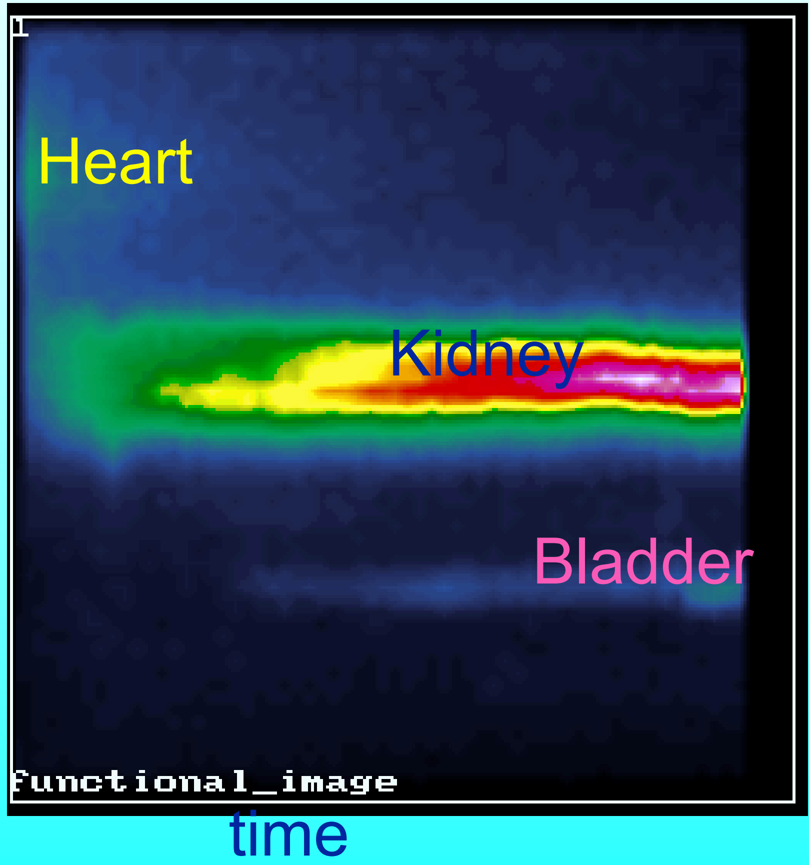
Weather Satellites

Cardiac registration



Data compression/ projection

- Removing redundancy
- Reducing dimensionality
- Projection against
  - time (summation)
  - y (vertical axis)
  - oblique
- Constraints are required (a priori information)



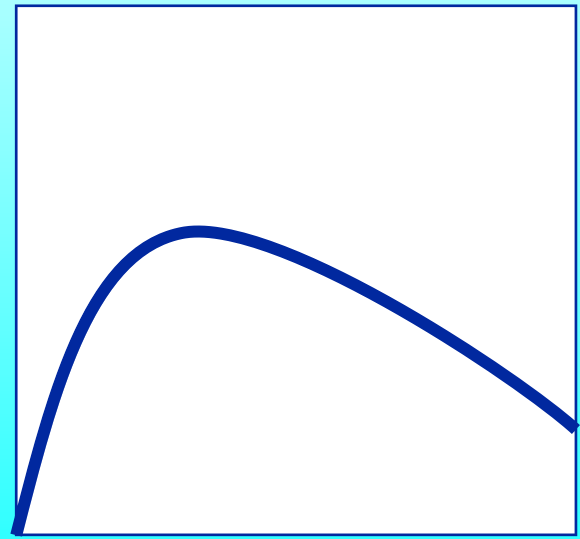
Function fitting

- For cyclical function
  - A[i,j] = Σ_k C[i,j,k] cos(ω k)
  - B[i,j] = Σ_k C[i,j,k] sin(ω k)

  - AMP[i,j] = sqrt ($A[i,j]^2$ + $B[i,j]^2$)
  - PHASE[i,j] = $\tan_{-1}$ (B[i,j] /A[i,j])
- First Fourier component

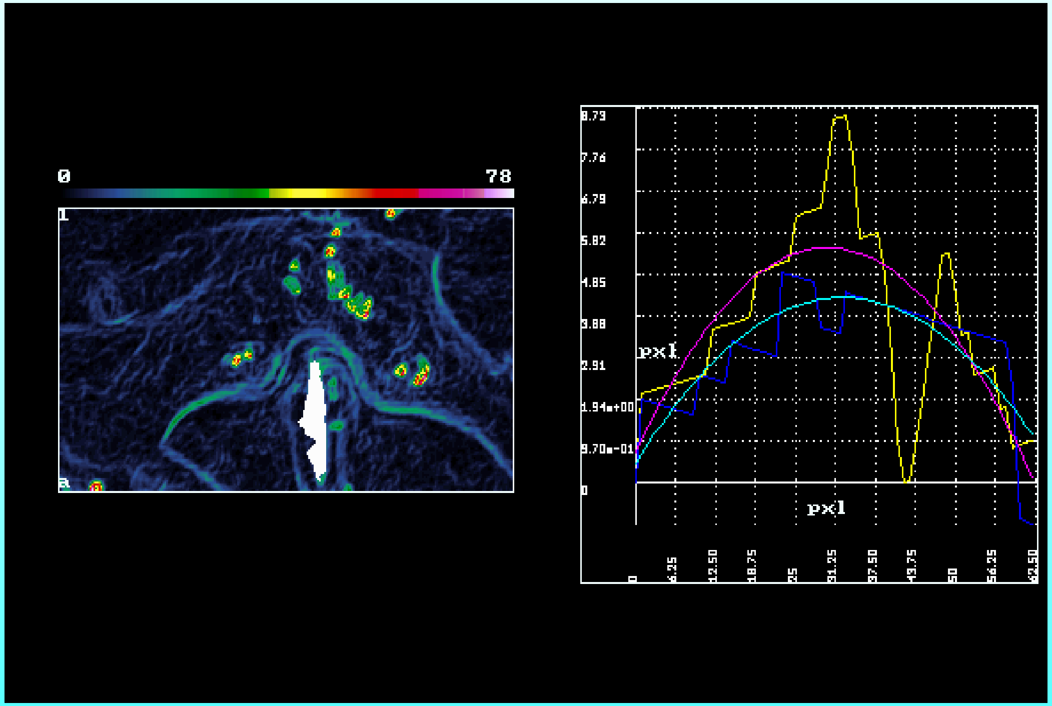
Functional Images

- Image of a derived function
  - Rate of increase/ decrease
  - Time to max
  - Variance image
- Example Kalman filtering
  - Estimating current values
  - And statistical model

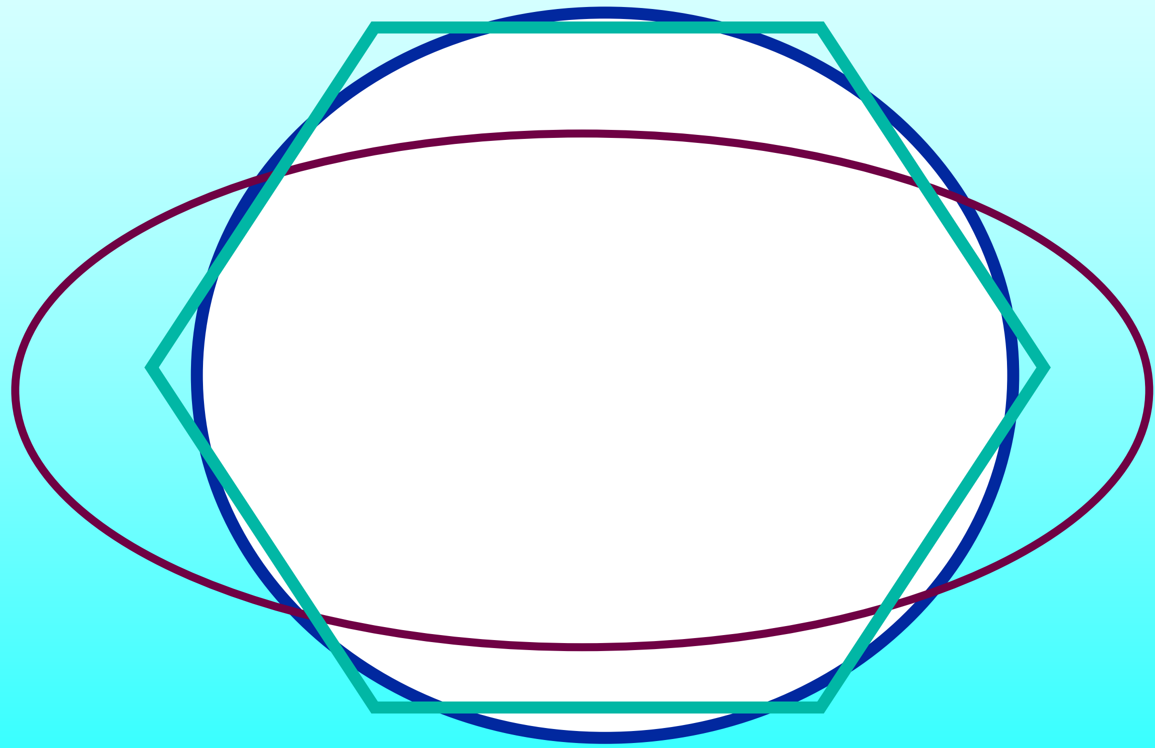


Shape Descriptors

- Skeletonization
- Circumferences
  - chain code
  - Fourier etc
- Snakes
- Active shape models
- Cores
  - (3-D) multiscale medial axes
- Composite



Fourier Contours



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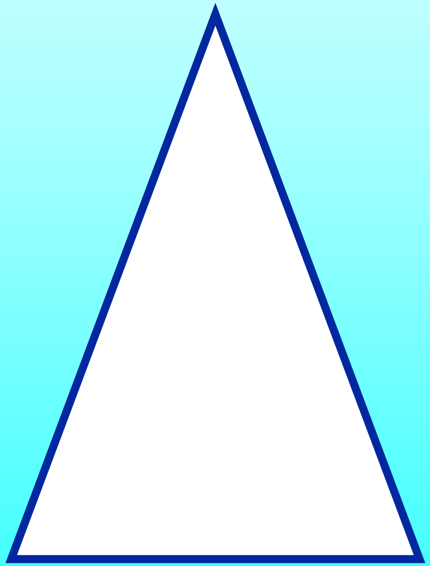
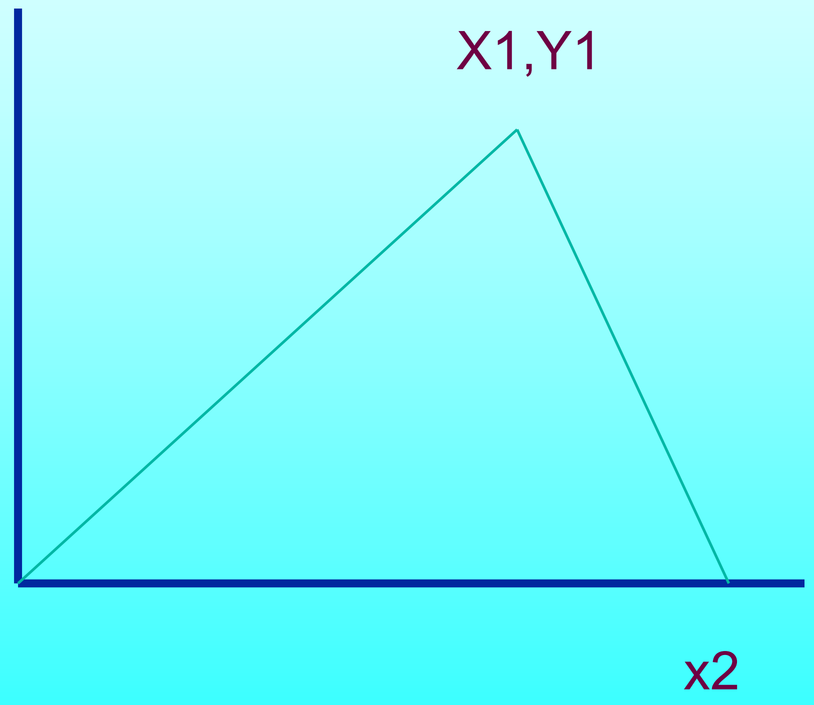
Active Shape Model
A simple example

- A set of triangles
- Characterised by 6 parameters
  - {x1,y1,x2,y2,x3,y3}
- Simpler description possible



Triangle space

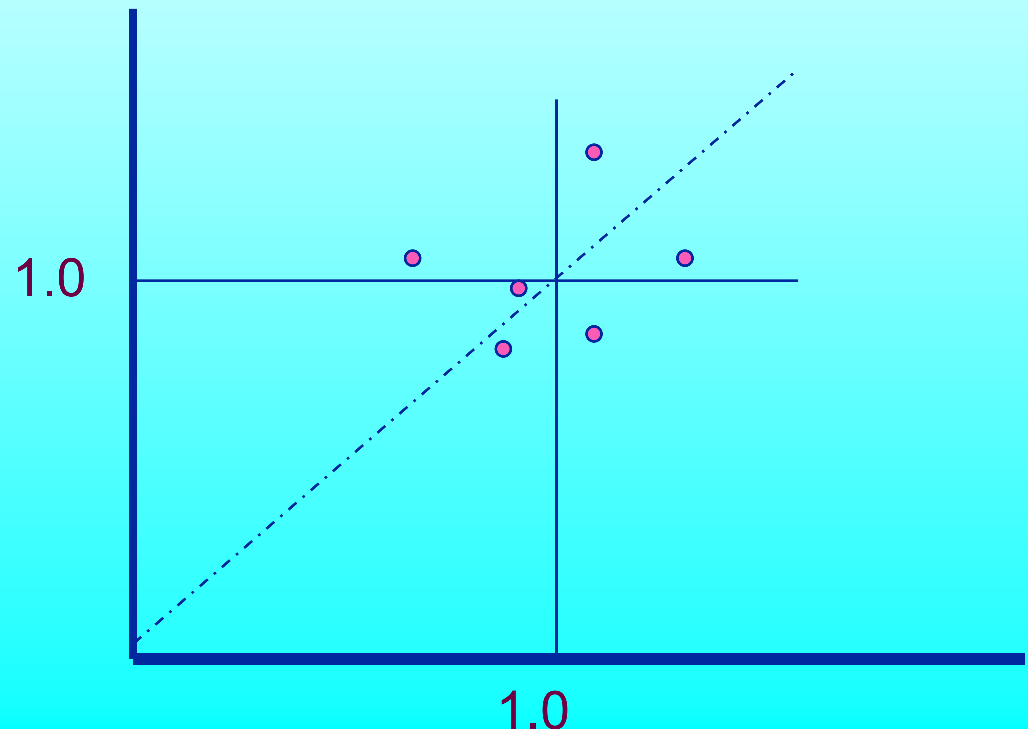
- Fix the origin
- Fix the x axis

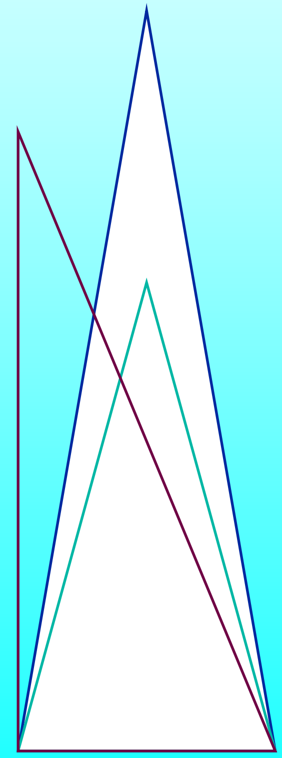


- 3 parameters
- Also lengths of 3 sides

Normalise scale

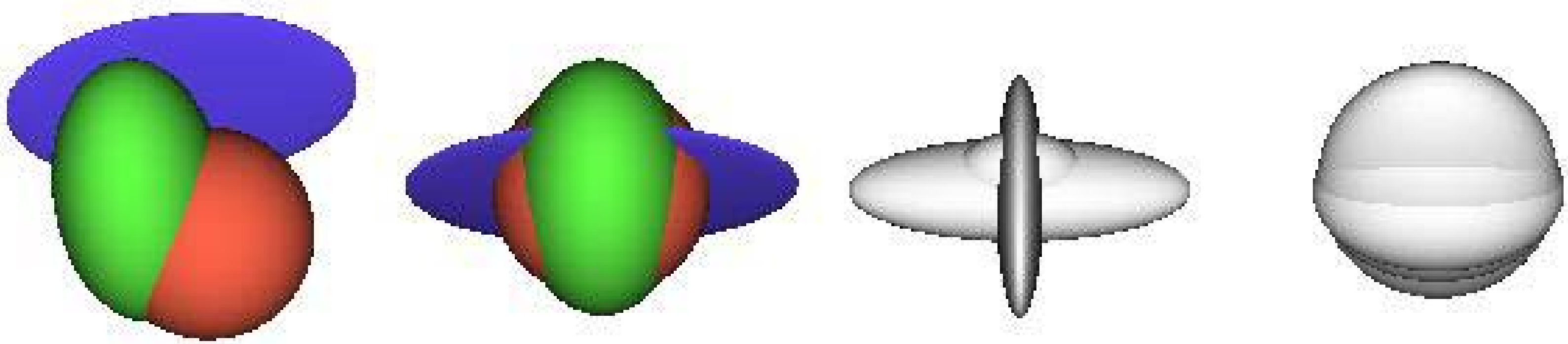
- Take ratios of lengths of 1 side v. other two
- Two dimensional space



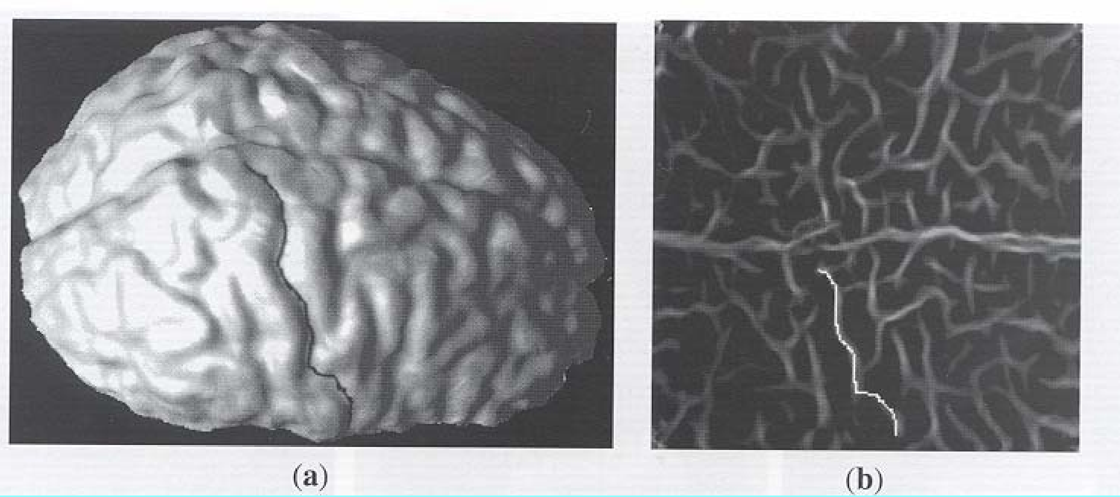


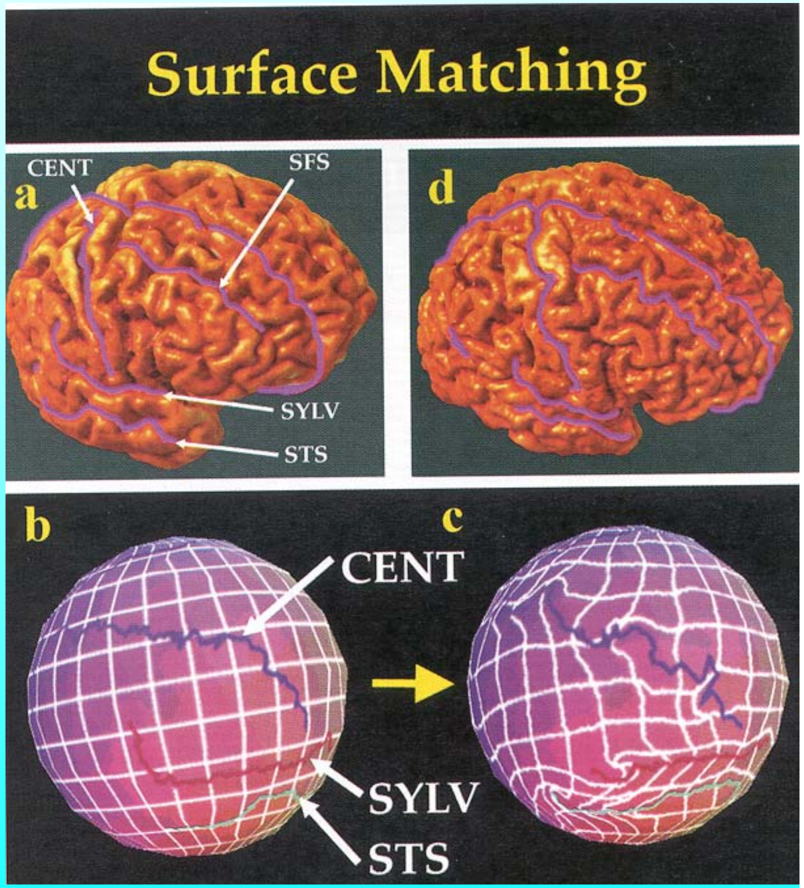
Where to place the nodes

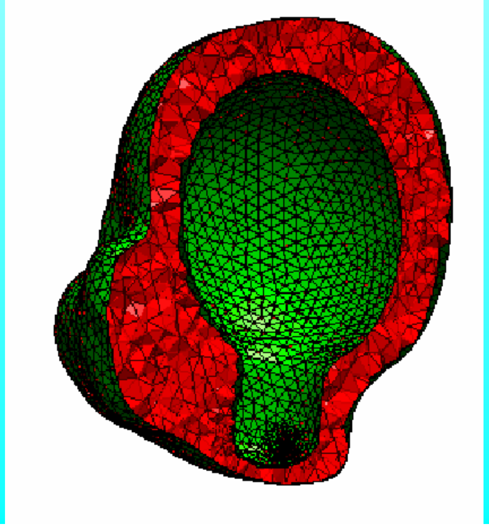
- Regular
- Maximum radius of curvature
- Minimal description length



3D deformations



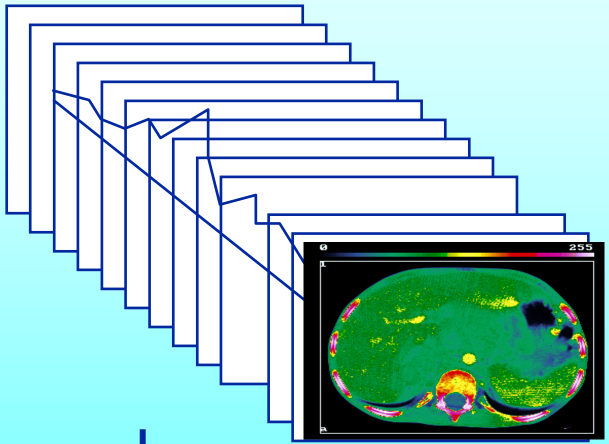


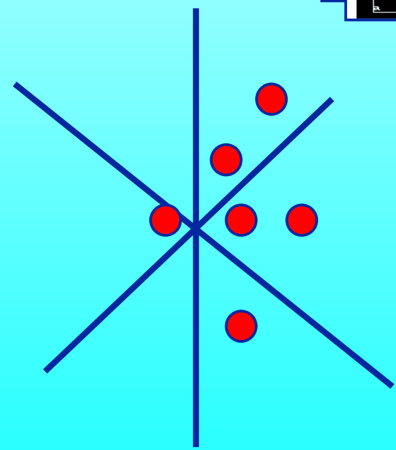


Ack. Thompson

Model based approach

- $Y = X + \epsilon$
  - Y is data matrix (m,n)
  - X is model
  - ϵ is error
- Decompose
  - $X = F\ G'$
    - F (m,k)
    - G (k,n)

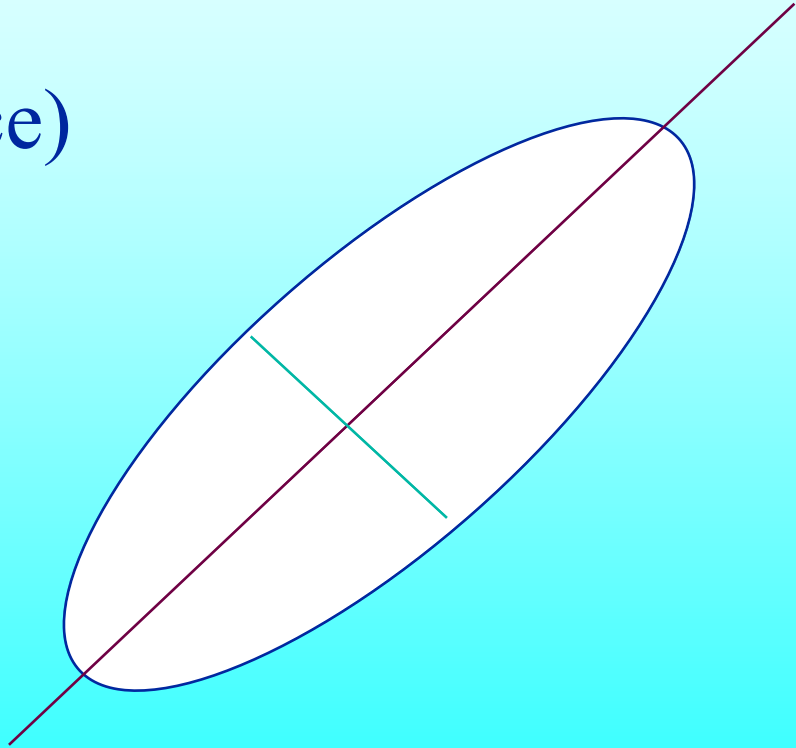




Principal Component Analysis

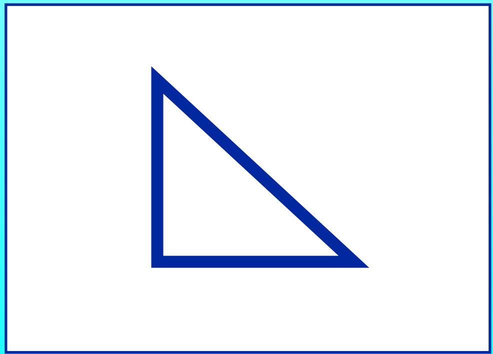
- F are Principal Axes
- G are Weights (variance)

- C (covariance matrix)
  - $C = (Y - y_m)' (Y - y_m)$



Oblique rotation

- PCA solution is orthogonal
- Make linear combinations
  - Oblique rotation
  - To satisfy constraint (positivity)
  - For example is higher dimensional space



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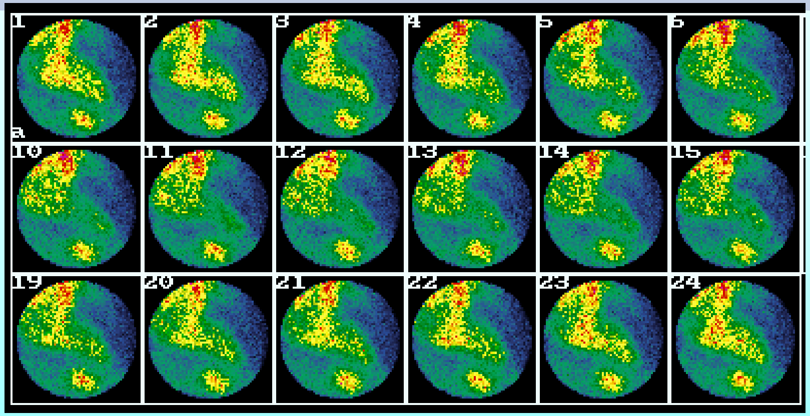
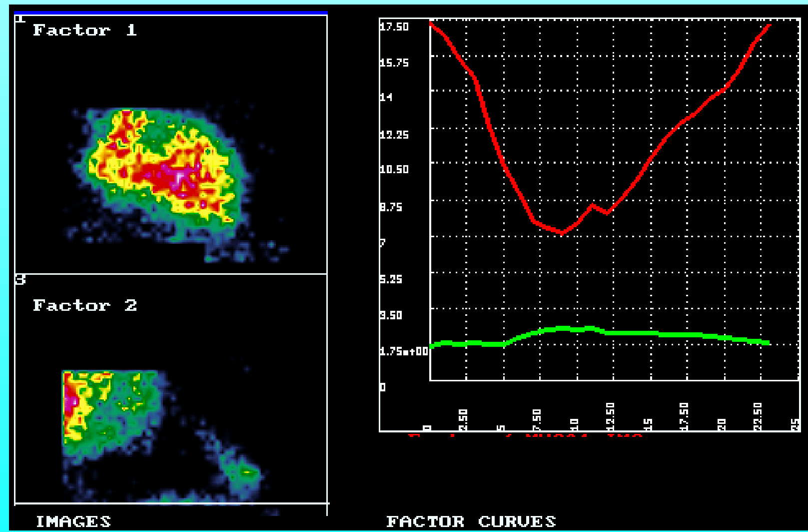
Factor analysis: an example

- Decomposition into principal component
- Oblique rotation (based on constraints)
- Display of images (eigenfuctions) and curves (eigenvalues)
- Segmentation, model fitting and quantitation



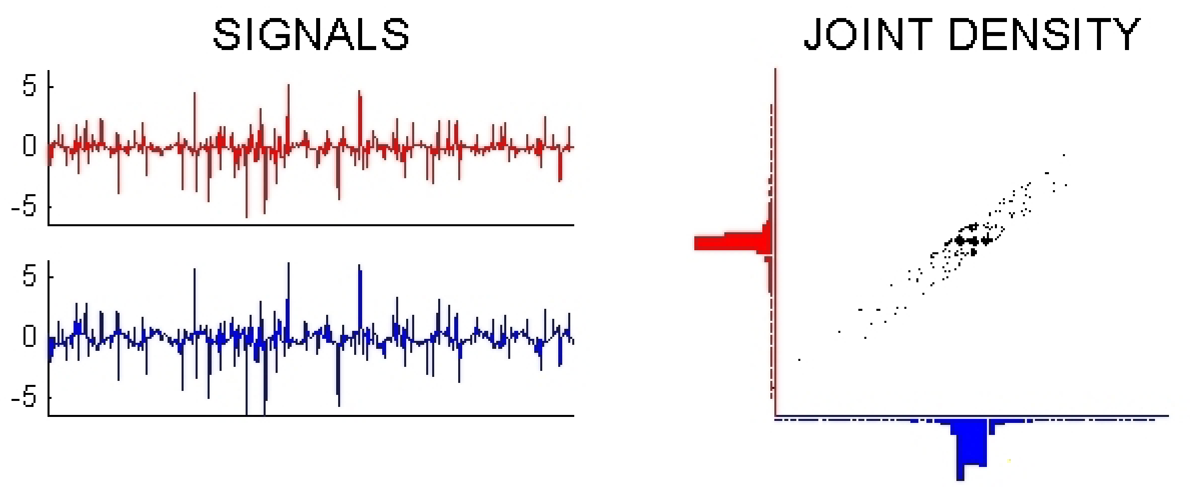


Independent Component Analysis

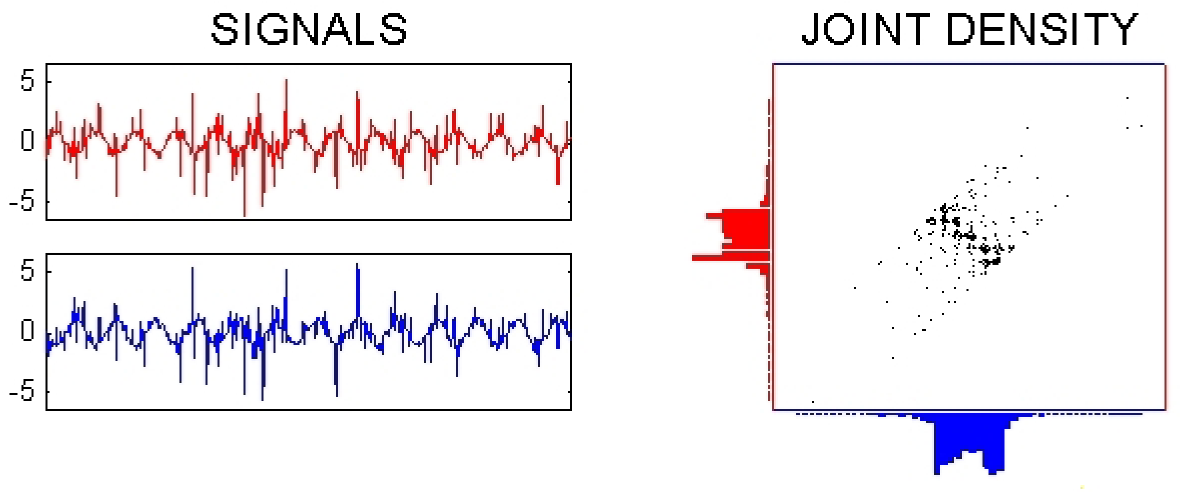
- Cocktail party problem
- Assume signals strictly independent
- Prewhitening

- Components not ordered.

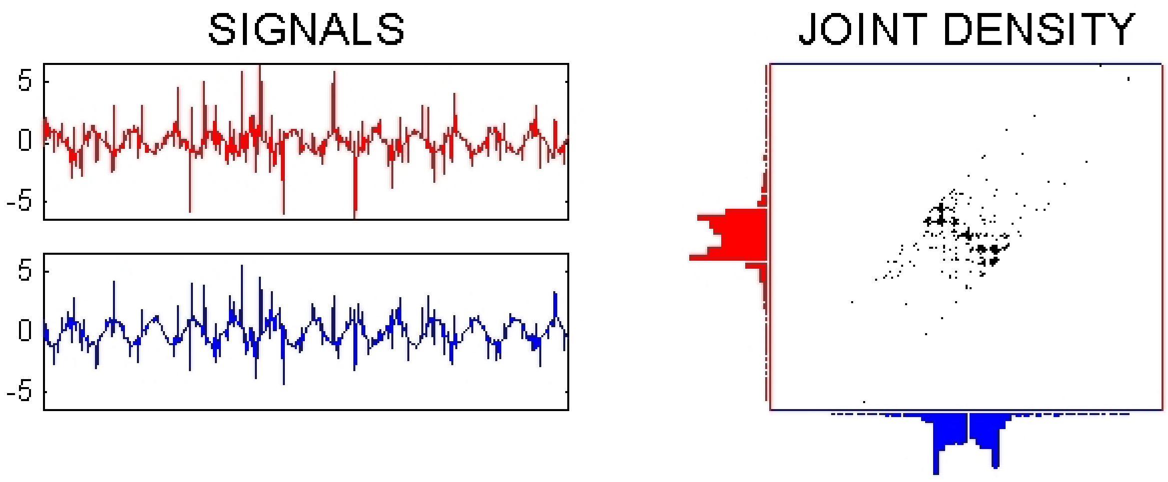
Example



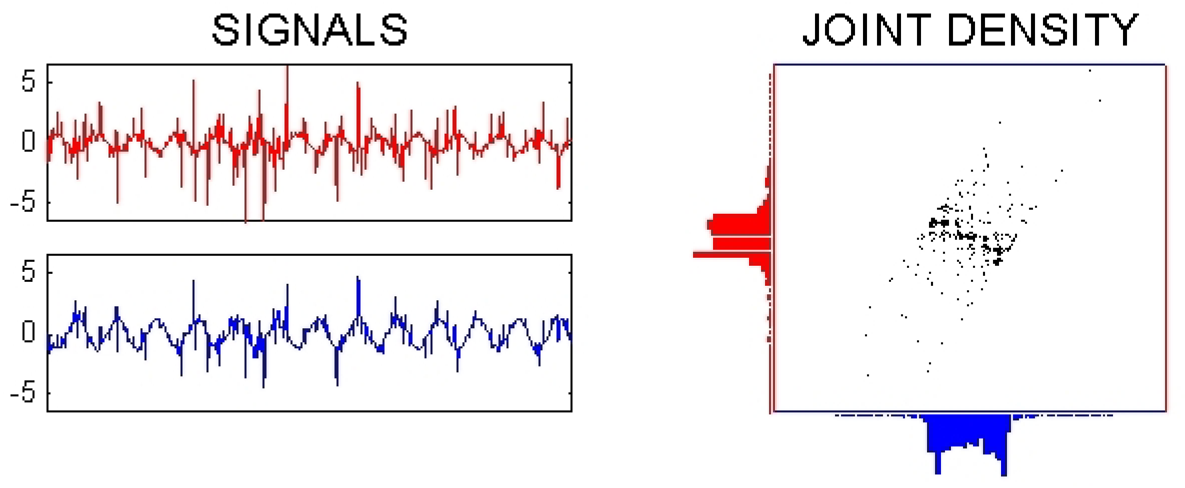
Input signals and density



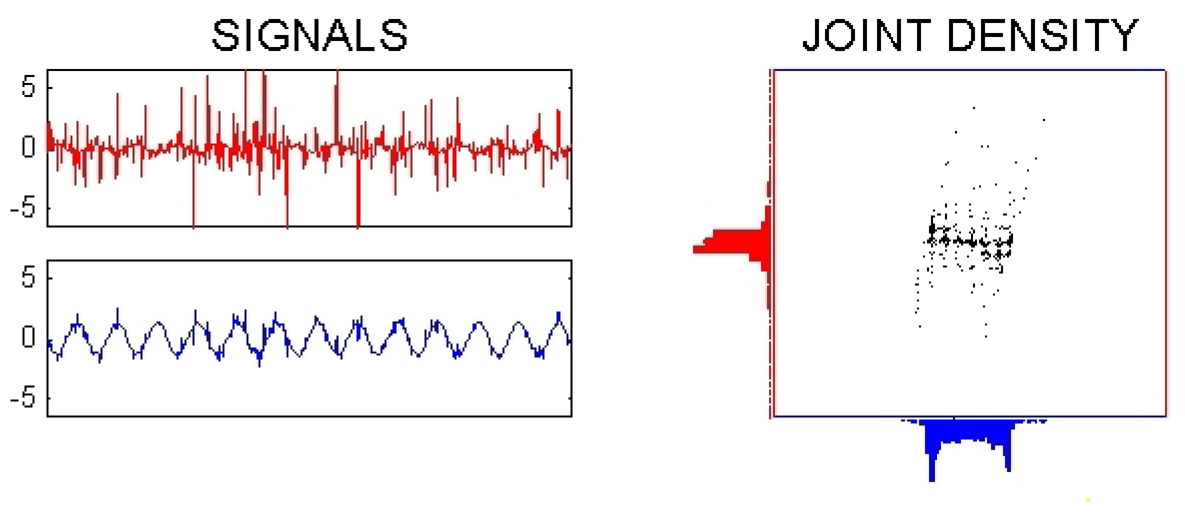
Whitened signals and density



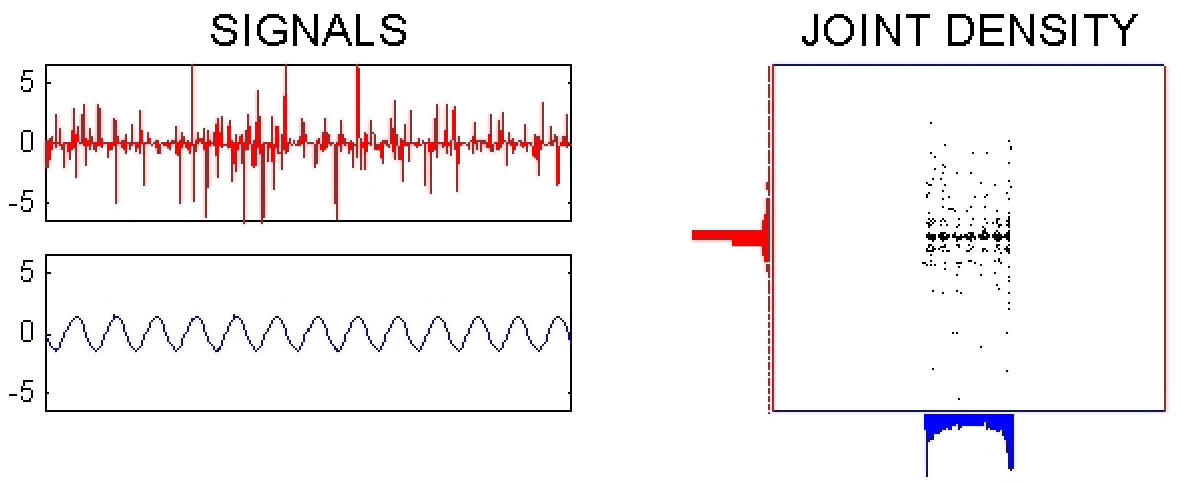
Separated signals after 1 step of FastICA



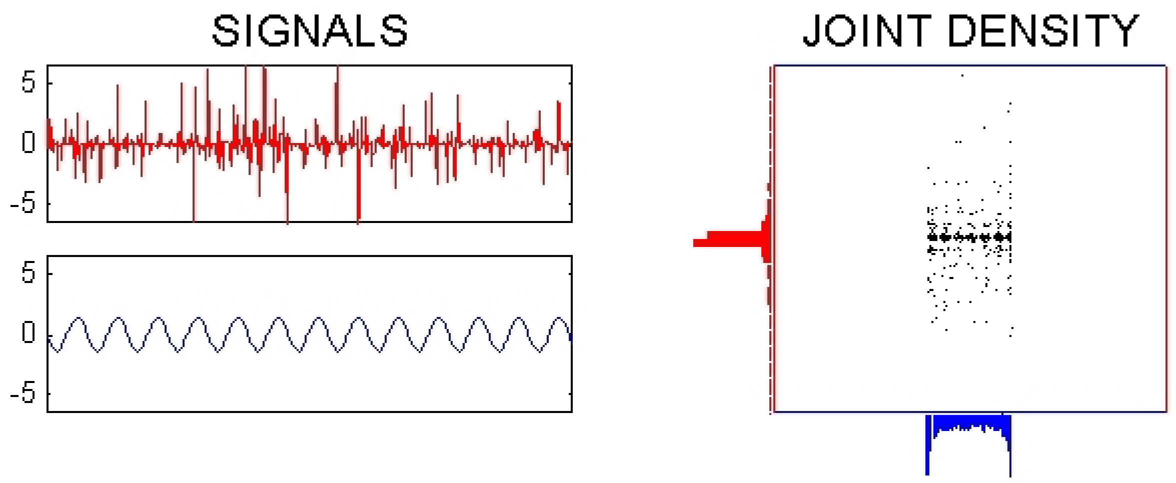
Separated signals after 2 steps of FastICA



Separated signals after 3 steps of FastICA



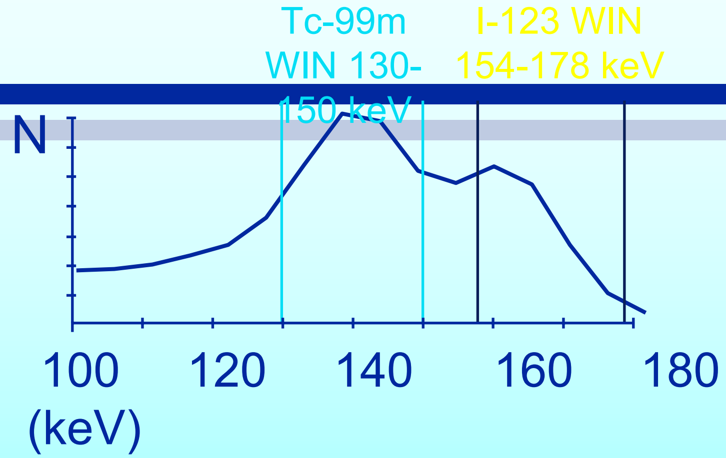
Separated signals after 4 steps of FastICA



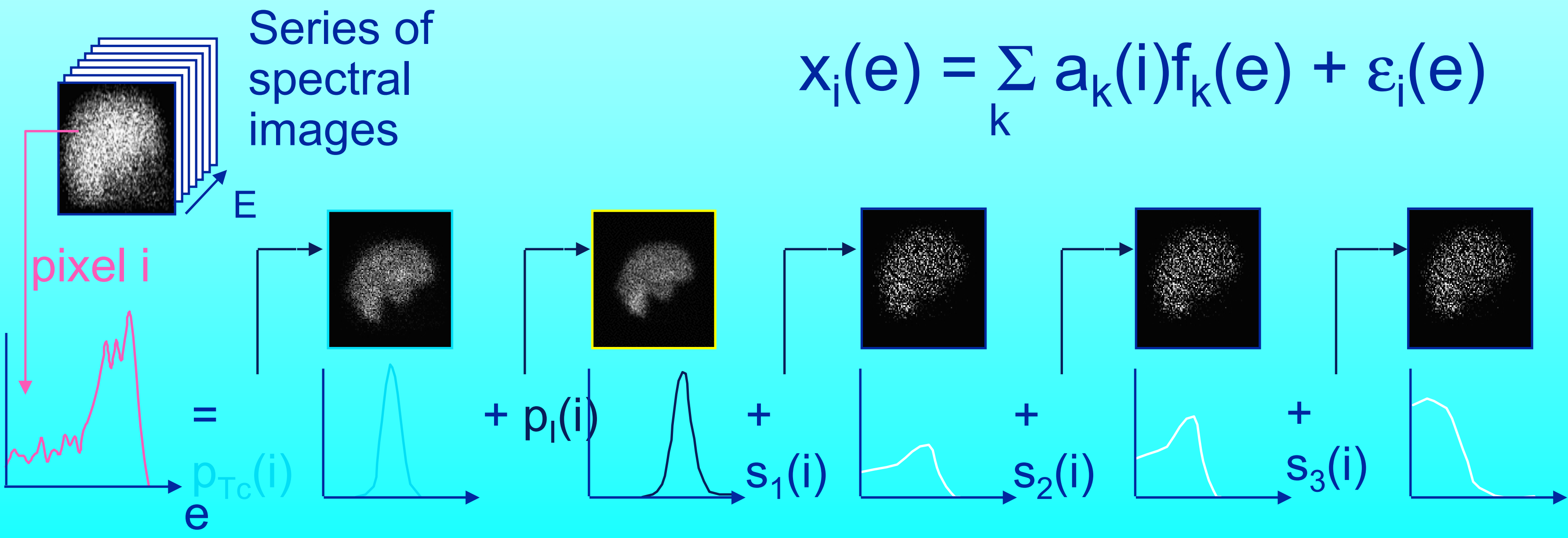
Separated signals after 5 steps of FastICA

Spectral Analysis

Ack I. Buvat



$$x_i(e) = \sum_k a_k(i) f_k(e) + \varepsilon_i(e)$$



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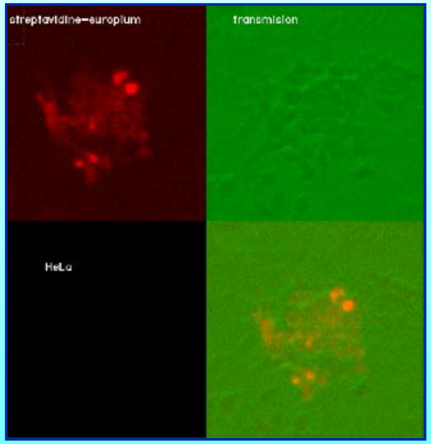
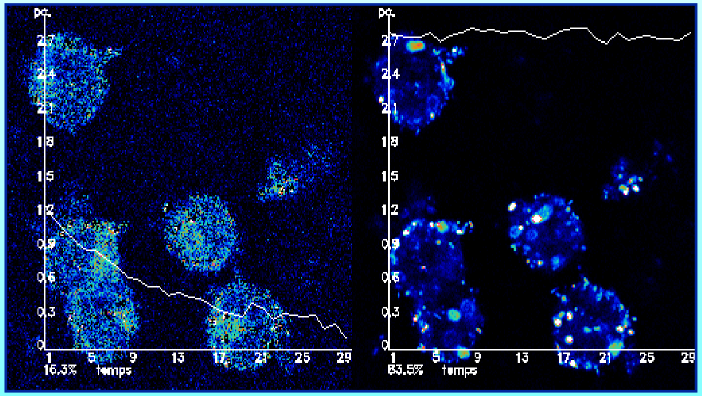
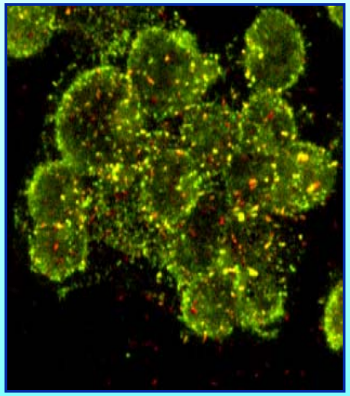
Confocal microscopy

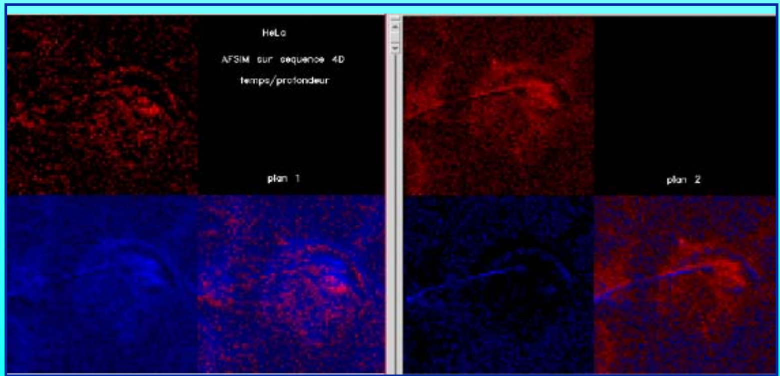
- Factor analysis of confocal image sequences of human papillomavirus DNA revealed with Fast Red in cervical tissue sections stained with TOTO-iodide. ANALYT QUANT CYTOL HISTOL. 2000, 22(2): 168-174, O.; 01-05, KAHN E et al : Confocal image characterization of human papillomavirus DNA sequences revealed with Europium in HeLa cell nuclei stained with Hoechst 33342. ANALYT QUANT CYTOL HISTOL, 2001, 23(2):101-108 O.







Temporal sequnce
(double marking thiazole orange - Fast Red



4D sequence
(double marking Hoescht - Europium)

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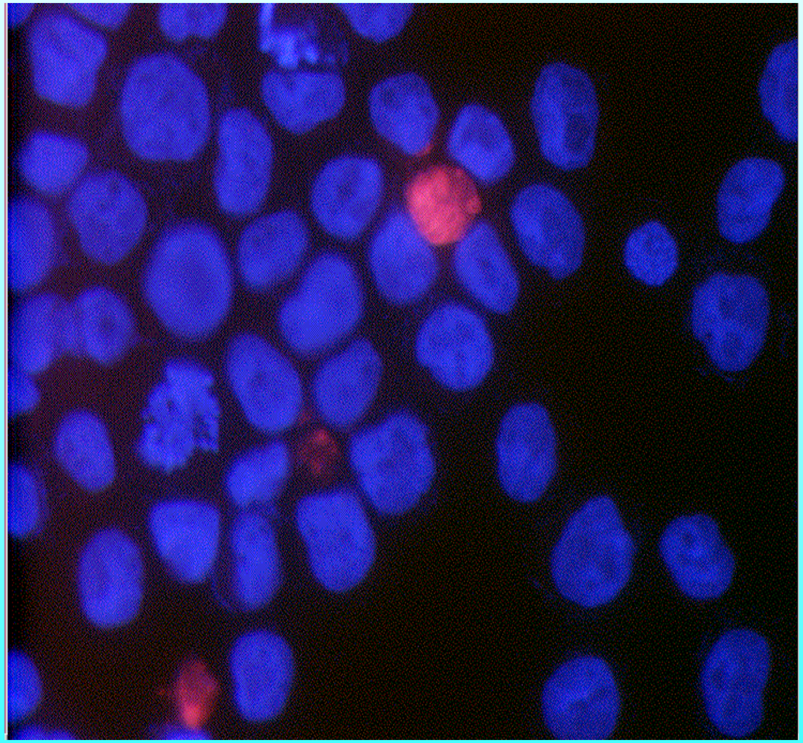
Labelled leucemic cells



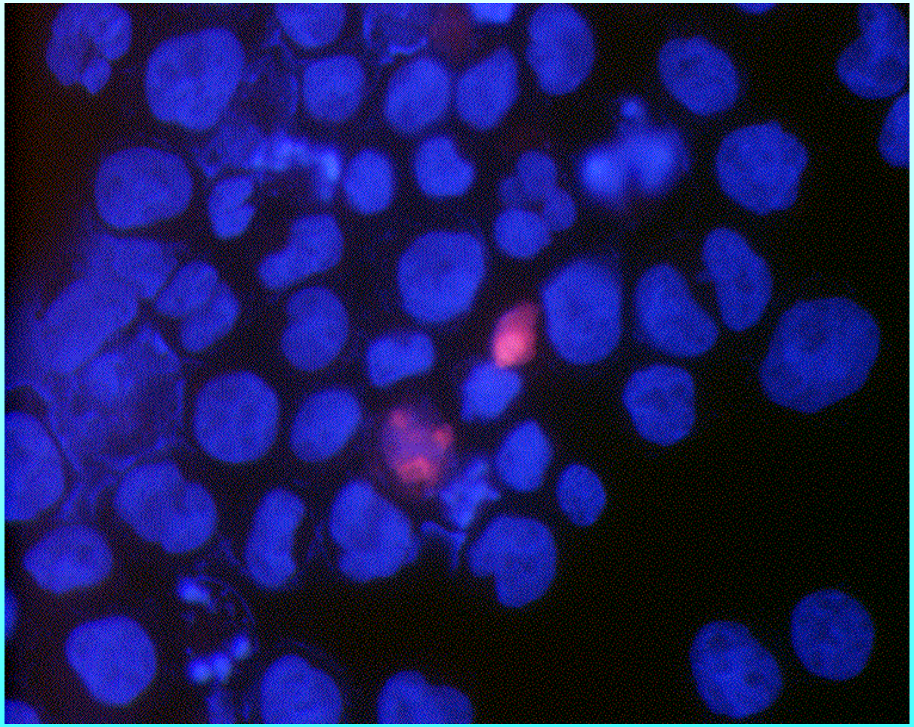


Image Registration and Fusion

- Registration

  To find relationship between two (or more) data sets so as to be able to co-register all parts of the data

- Fusion

  To compare data from different sources, or at different times/ procedures so as to extract common information (including display)

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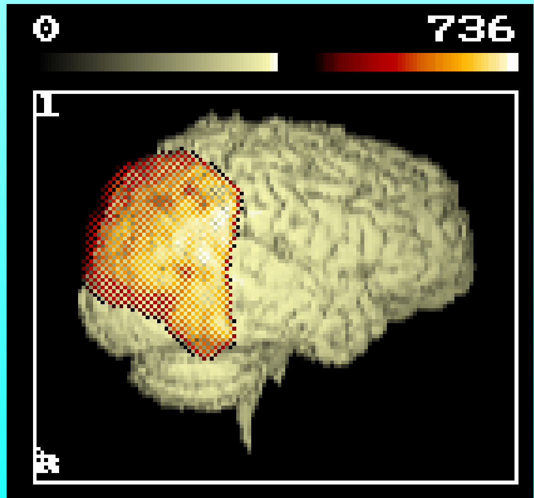
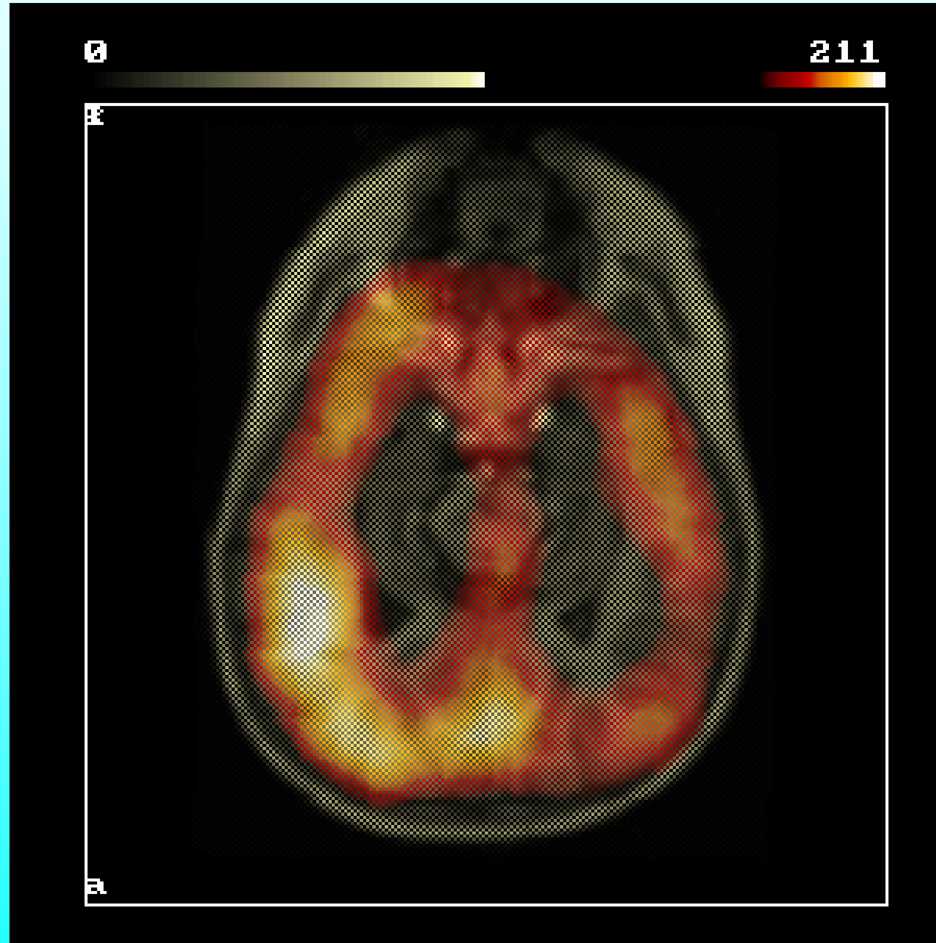
Fusion- display and extraction of common information

- **Checkerboard display**
- **3-D display with colour overlay on surface**
- **Common markers and see through**
- **Joint measurement**

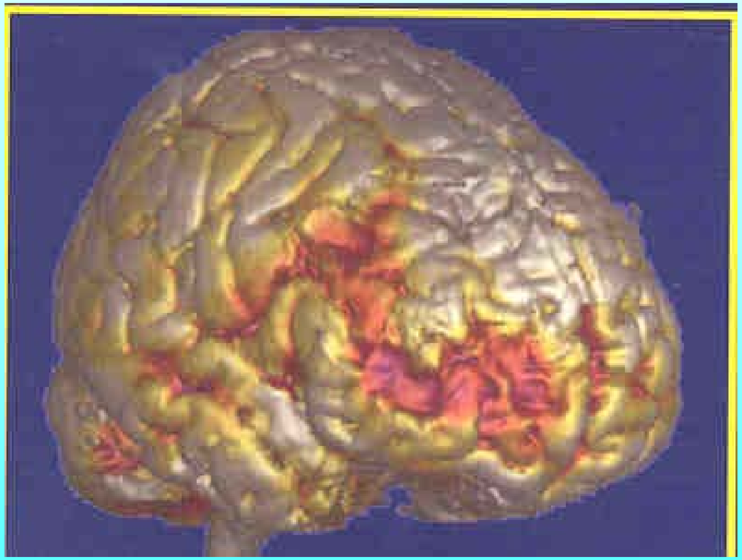
Surface colour on 3d display

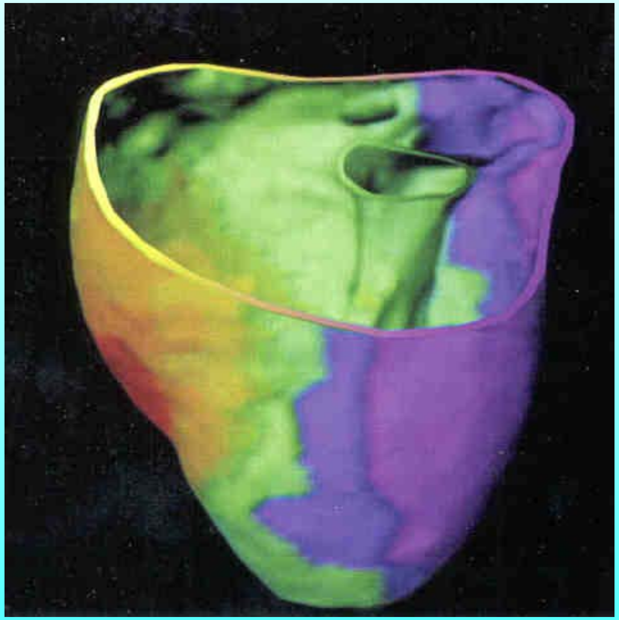




MR and NM of brain slice

Fused display





Ack. Zuiderfeld

Ack. Robb

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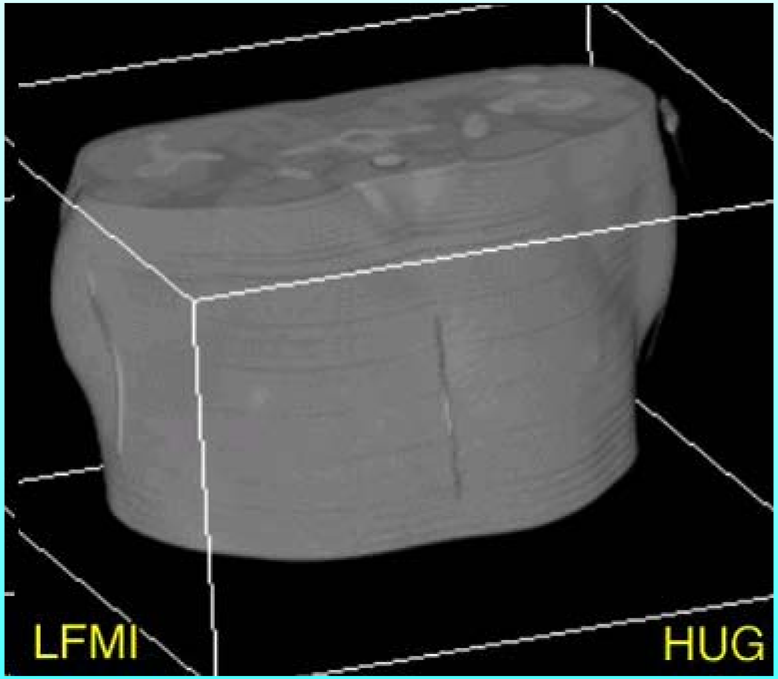
Exploring the volume



Ack L Bidaut

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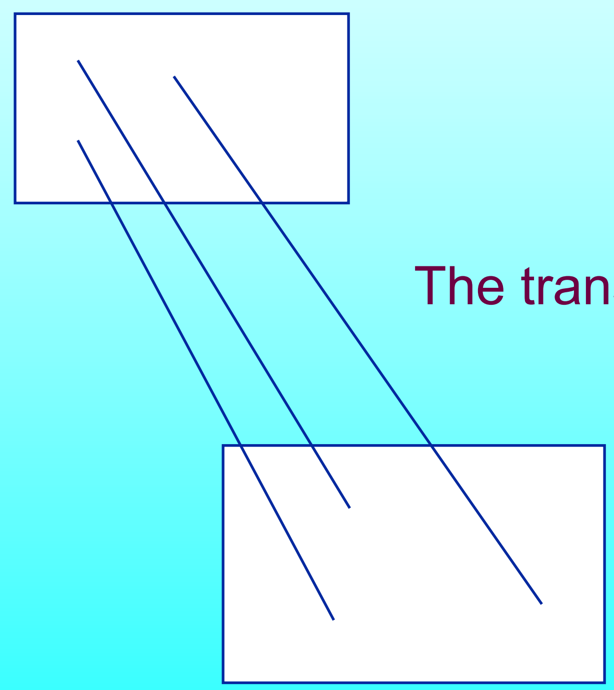
Different methods

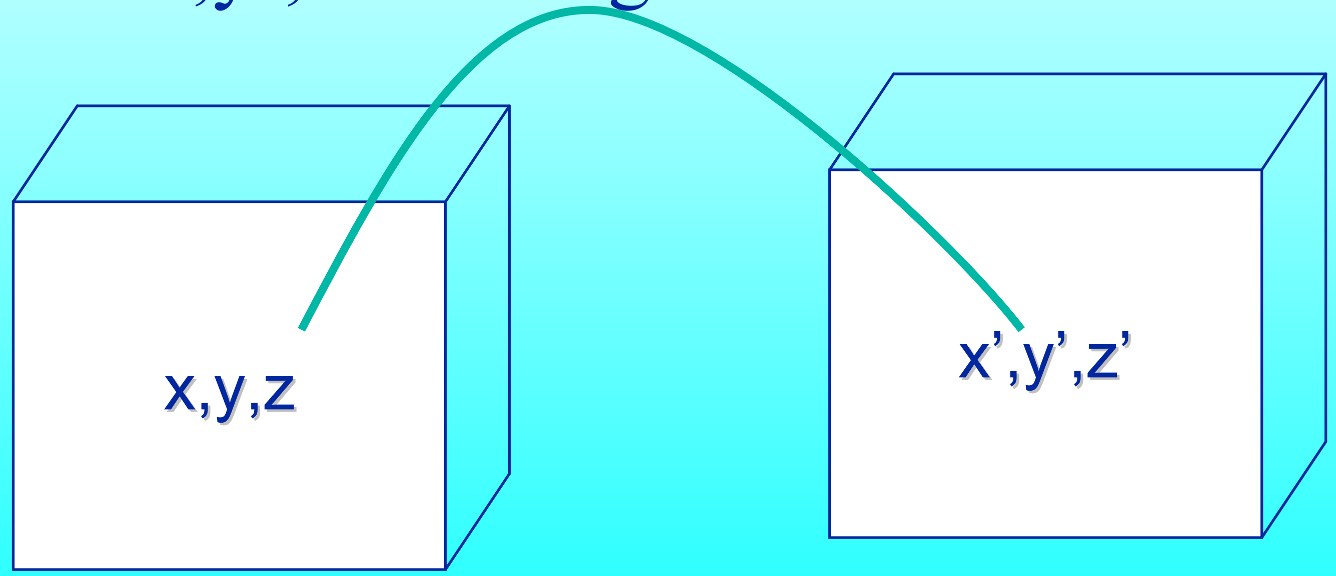
- Point based
  - internal
  - external
- Principal axes
- Head hat, surface based
- Volume based
  - Variance
  - Mutual information

....



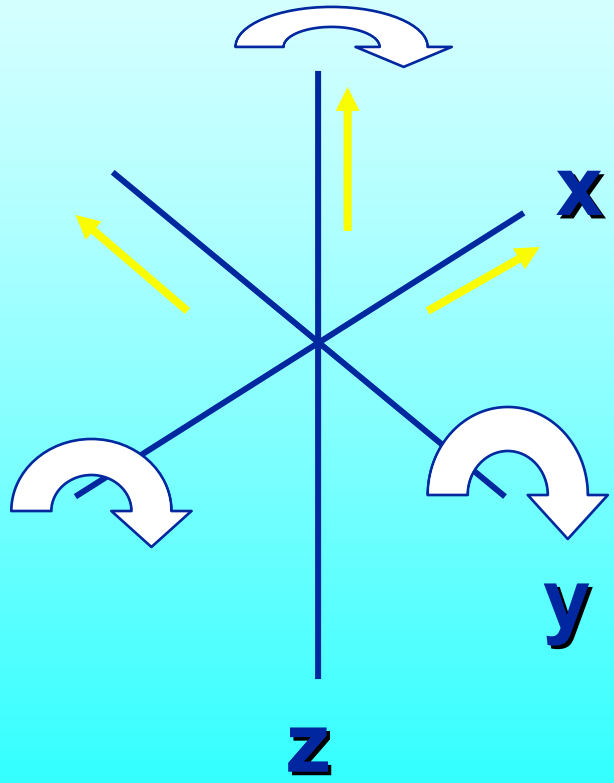
Aim of registration algorithm

- Finding a transform so that every point x,y,z in image datatset 1 can be mapped onto x',y',z' in image dataset 2



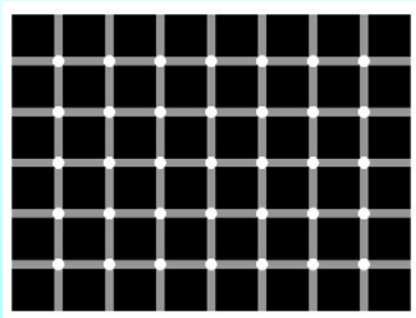
Rigid and Non-rigid registration

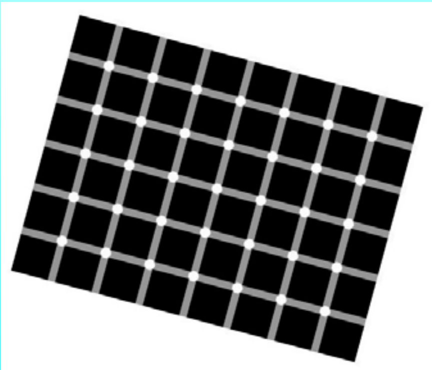
- Rigid registration: only rotations and shifts
- Intermediate: rotations shifts and variable scale change (such as affine)
- Non-rigid: including warp, different transform for every point (or region)



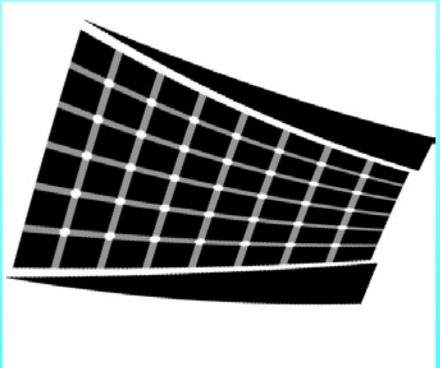
Warping

Original





Rotate and Shift
-Rigid

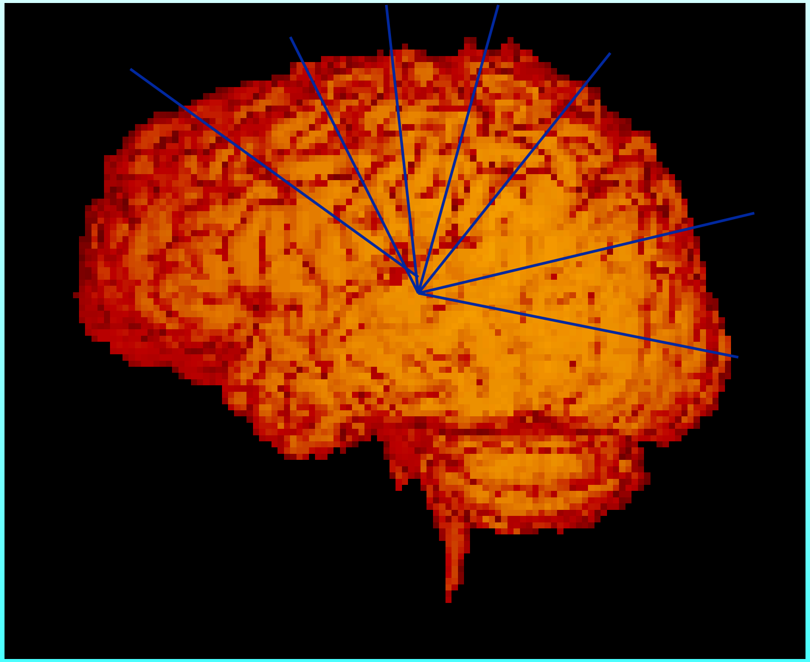


Affine

Warp
-Non Rigid

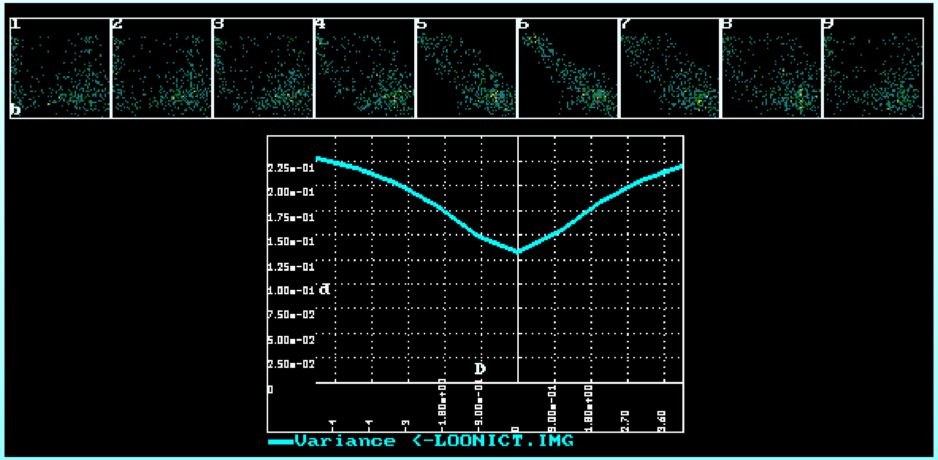
Surface based registration

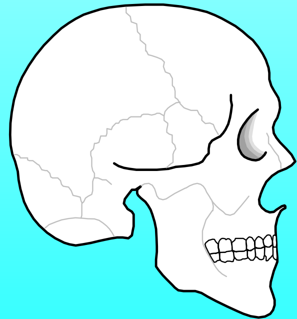
- Find centres of gravity
- Cast rays in both image datasets
- Measure difference is lengths of rays (L2 norm)
- Minimize distance to find match transform



Voxel based registration

- Find distance measure
  - for every voxel in image(1)
  - estimate voxel in image(2)
  - compute co-occurrence matrix
  - estimate ‘variance’
- Minimise distance measure
- To give transform to match image(1) to image(2)





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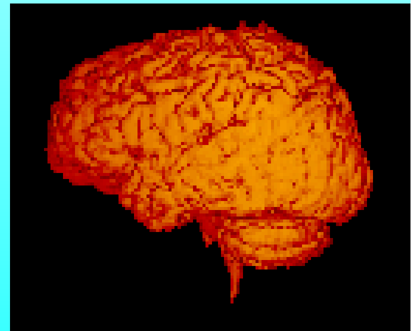

(1)

(2)

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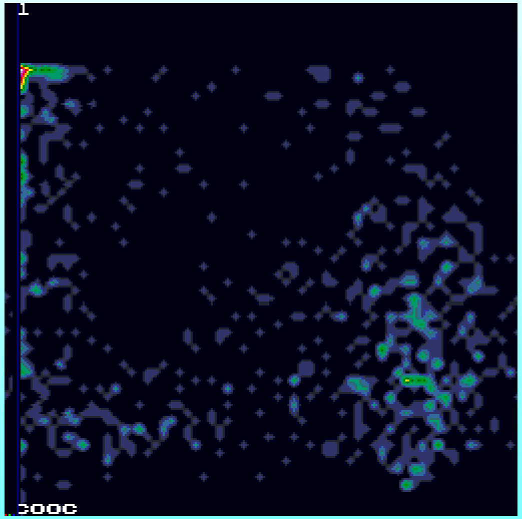
Co-occurance matrix



A loop, passing though registration with various lateral shifts.

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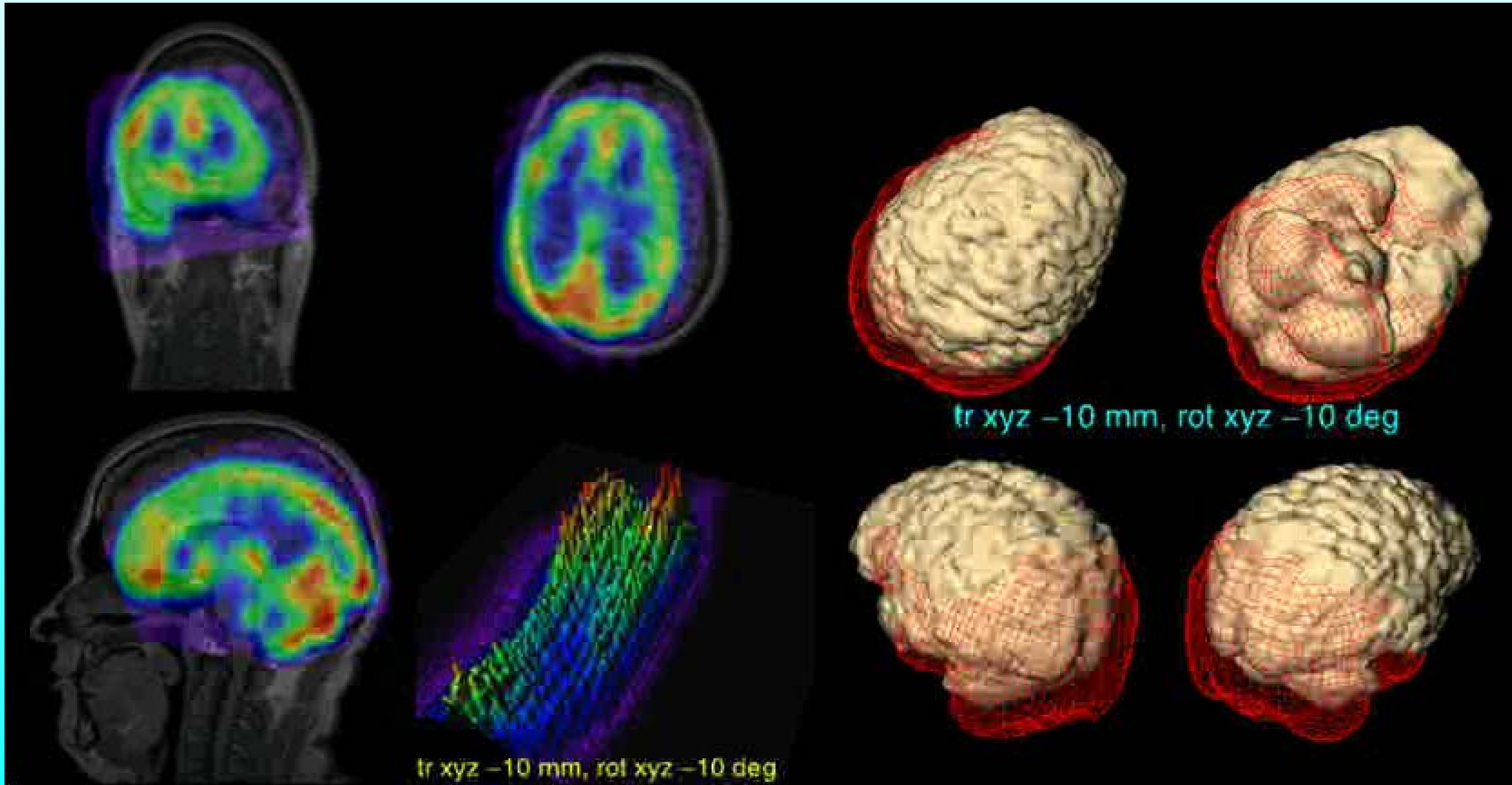
An example



Ack L Bidaut

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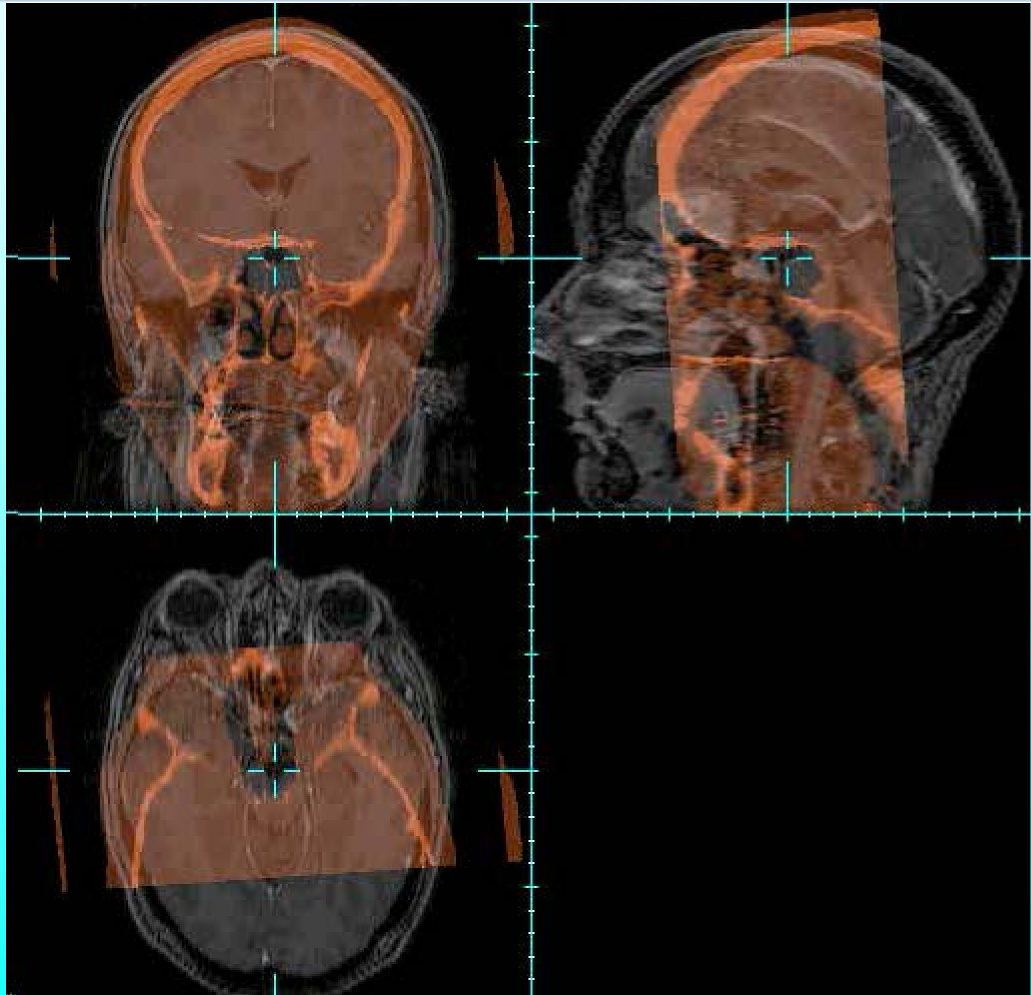
Limited volume



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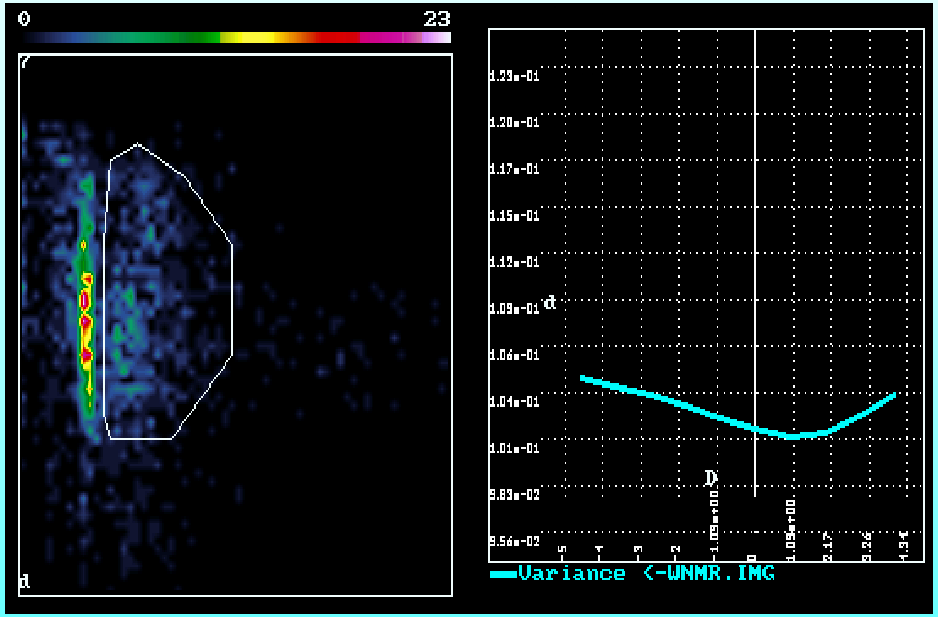
Clustered voxel registration

- For similar data, for example CT to MR
- Some voxel map from dataset to dataset
- Some voxels do not
- Select cluster(s) of voxels that minimize



Co-occurance Matrix

Distance measure with Displacement

How to add knowledge

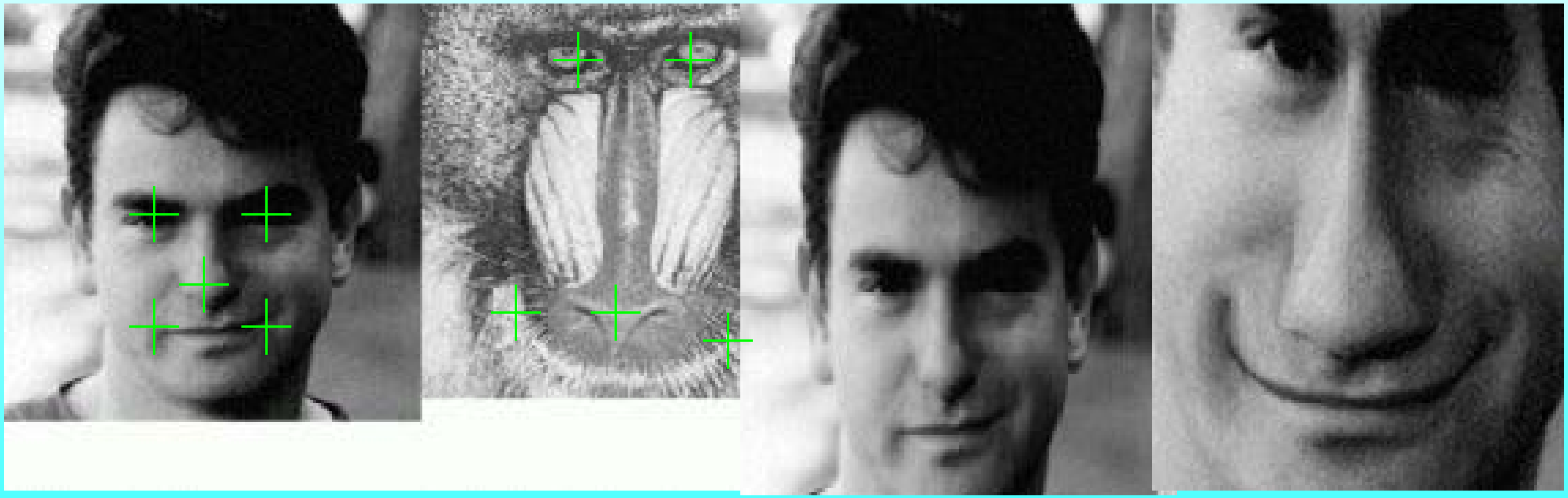
Non-rigid registration

- Need for an interpolation model
  - Optic flow
  - Thin plate spline
- Need for a spatial constraint
- Need for optimisation
- Much more compute intensive than rigid registration

How to validate

Thin Plate Spline Image Warping

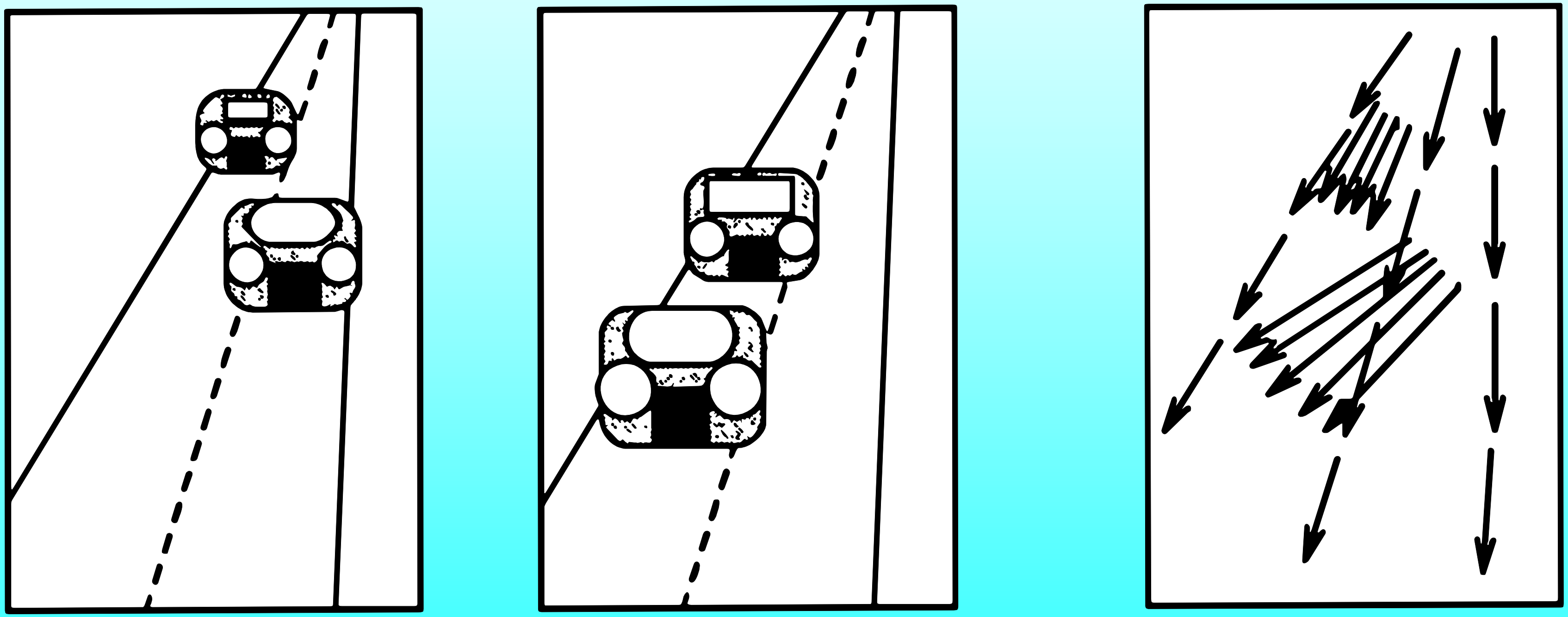
$$\int\int_{\mathbf{R}^2} \left(\frac{\partial^2 f}{\partial x^2}\right)^2 + 2\left(\frac{\partial^2 f}{\partial x \partial y}\right)^2 + \left(\frac{\partial^2 f}{\partial y^2}\right)^2 dx\,dy$$



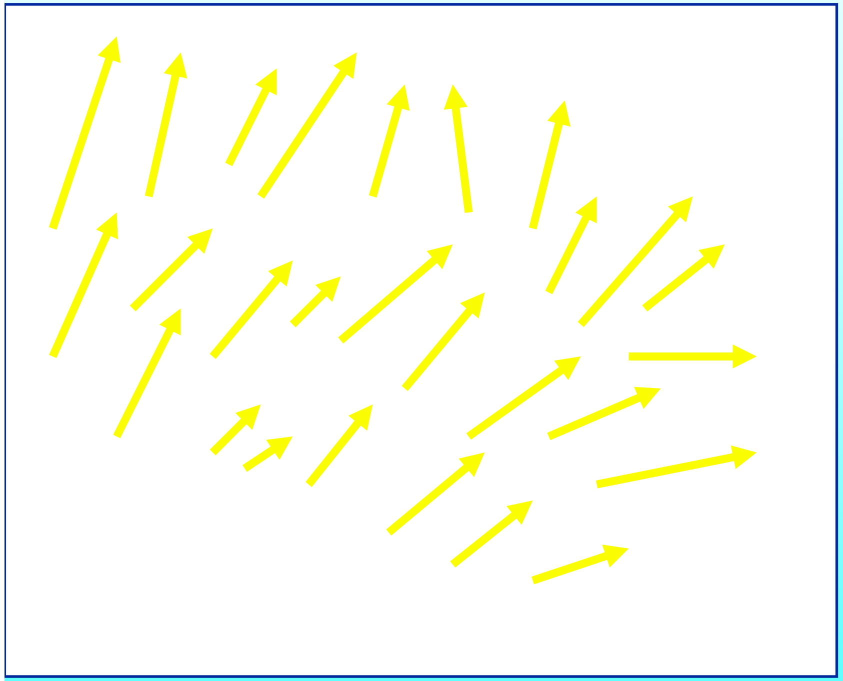
source target linear TPS warped

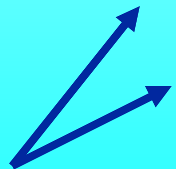
Inspired by www-ipg.umds.ac.uk/p.edwards/warpin

Optic flow- tracking

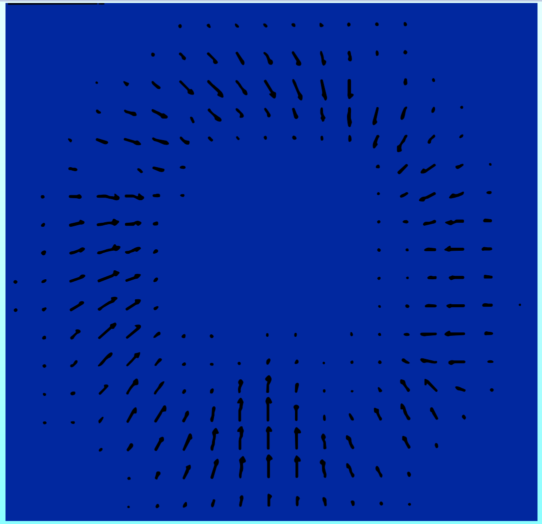


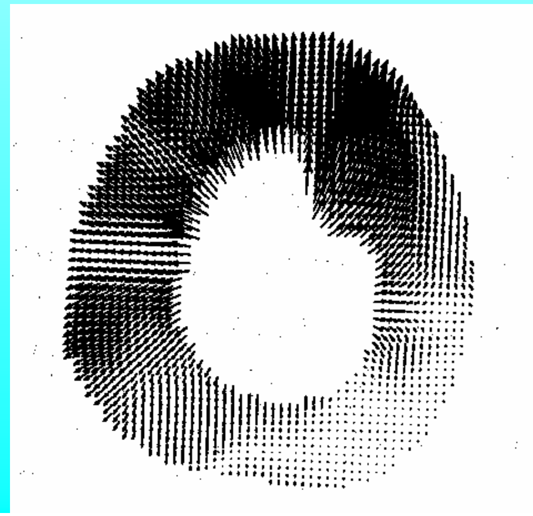
A vector field of displacements





angle





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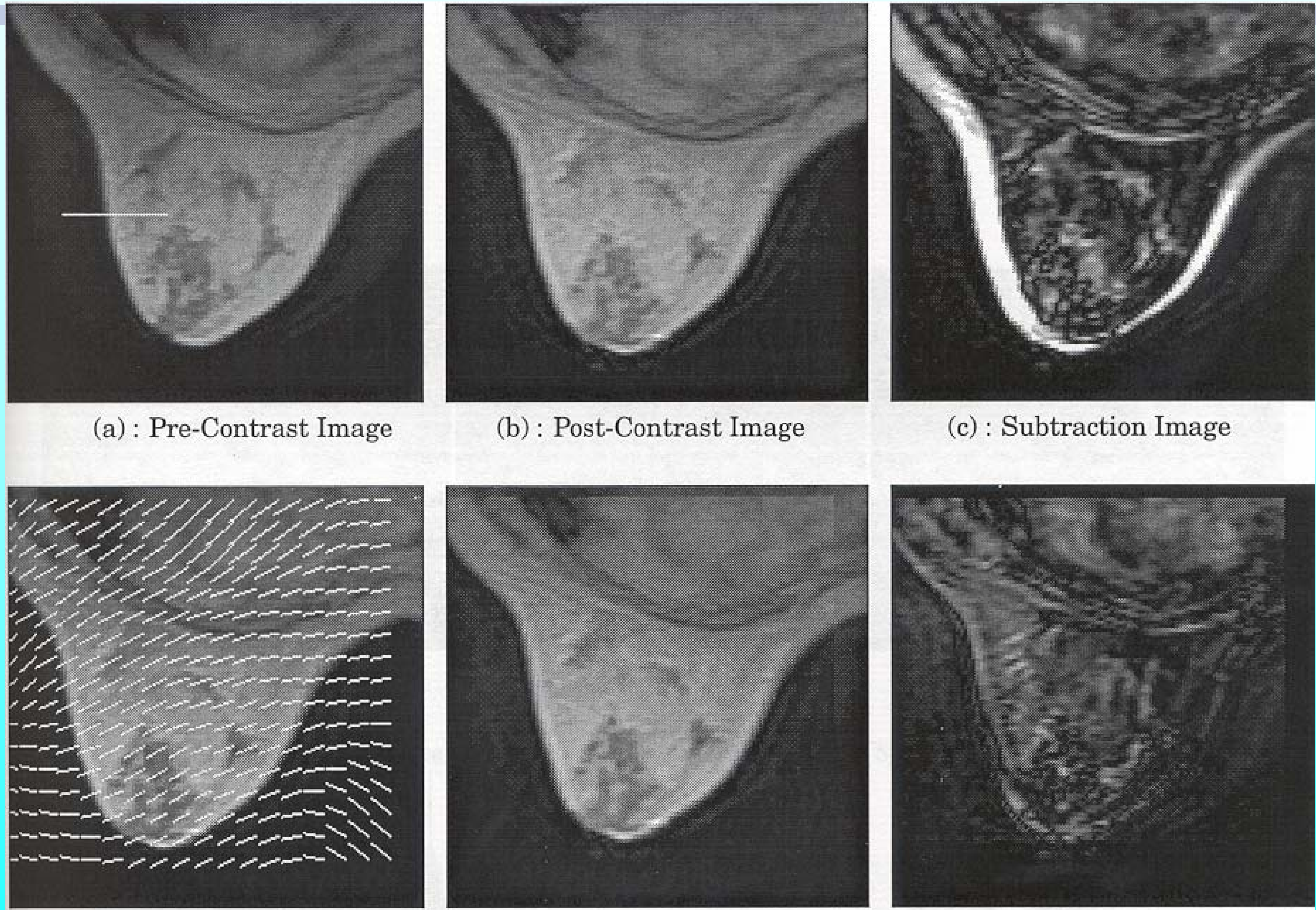
An example- MRI breasts Meta-data



(a) : Pre-Contrast Image (b) : Post-Contrast Image (c) : Subtraction Image

(d) : Motion Field (e) : Corrected Post-Contrast Img (f) : Corrected Subtraction Img

Ack. Hayton

Computational Parameters

- Number of voxels
- Minimisation algorithm
- Number of iterations
- Distance parameter (entropy, MI, etc)
- Number of regions of interest
- Type of interpolation
- Local constraint
- Multi-resolution speed-up

How to make it fast enough

Structure

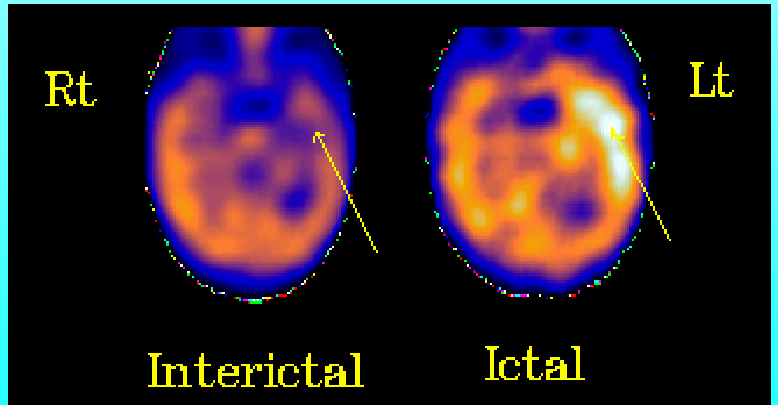
- Segmentation
- Image registration
- Active Shape Models

- Are all different aspects of the same problem

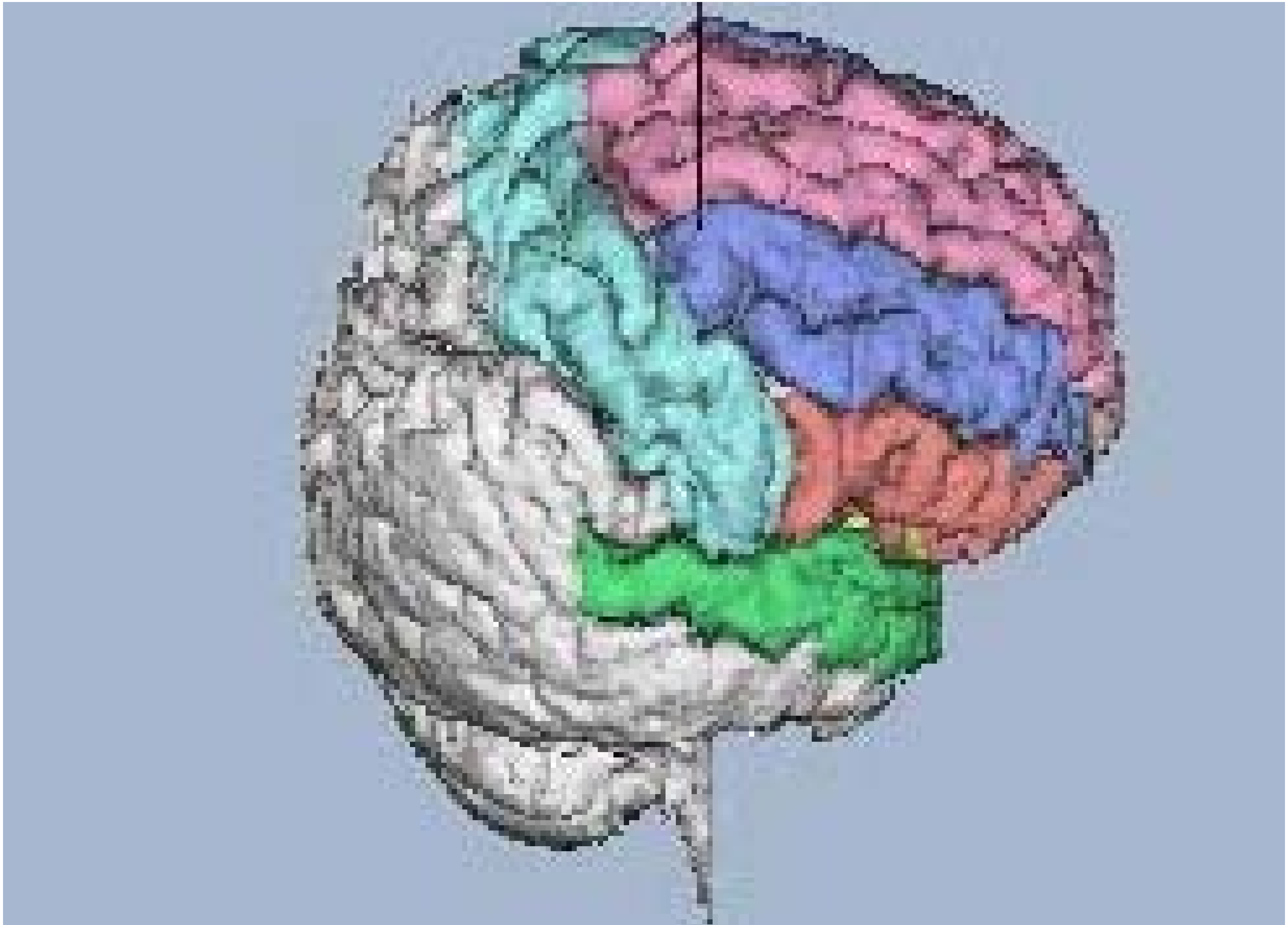
Atlas and statistical analysis

- How to interpret the significance of an observation (target / global)
- Comparison against an atlas
- Internal reference, symmetry, time
- Need for data containing voxel values, significance range, variation in position, etc
- Building atlas requires registration, warping, normal and abnormal data

How to establish the databases

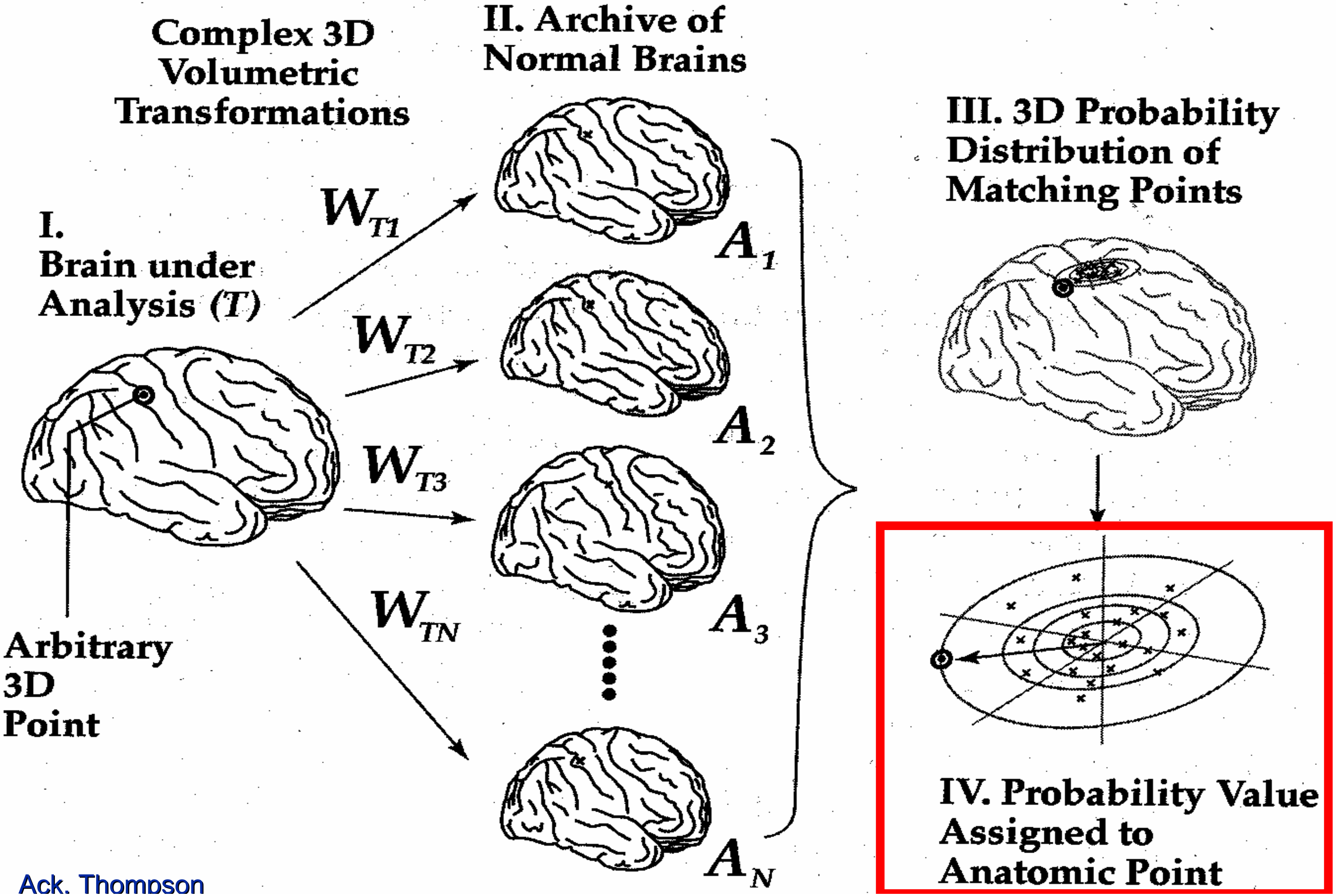


Why do we need an atlas



Ack Harvard

DEFORMABLE PROBABILISTIC ATLAS



Ack. Thompson

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The need for models: Analysis of functional MRI images

- Use of a model (such as factor analysis or ICA) to assess significance of change in fMRI images
- Registration of fMRI and anatomical MRI
- Registration of MRI and EEG/MEG data
- Handling of multi-modality functional image results
- In general- a branch of the development of spatio-temporal models (physically and statistically well founded)

How to develop robust models

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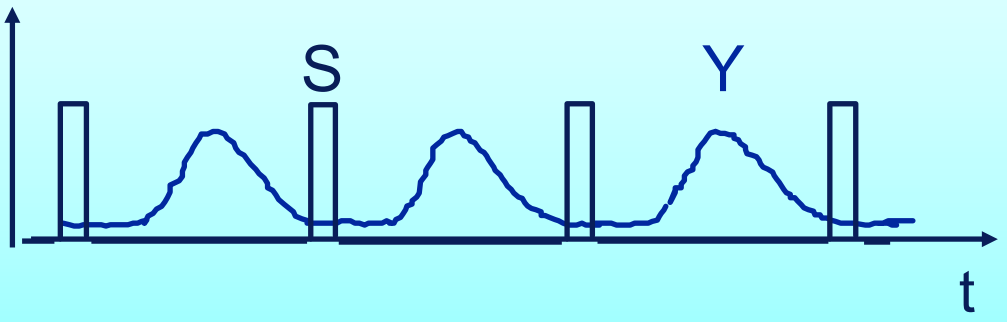
Spatial localisation of distributed group of neurons

Stimulation : single event, block and mixed



Models of detection of fMRI activation

Models of source localisation in EEG/MEG

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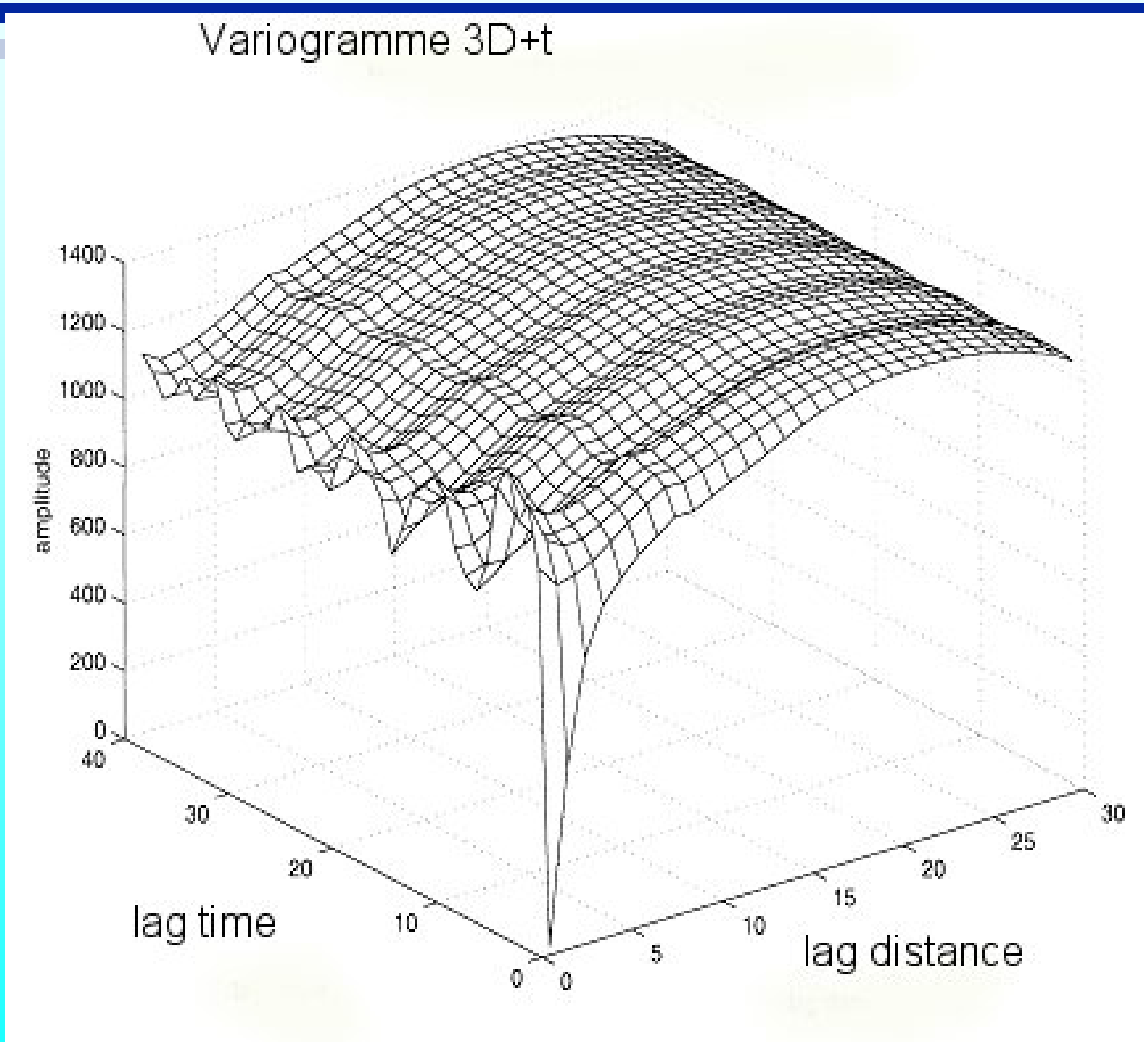
Spatial localisation of distributed group of neurons

Spatio-temporal model
In functional MRI

Variogramme



Ack H Benali

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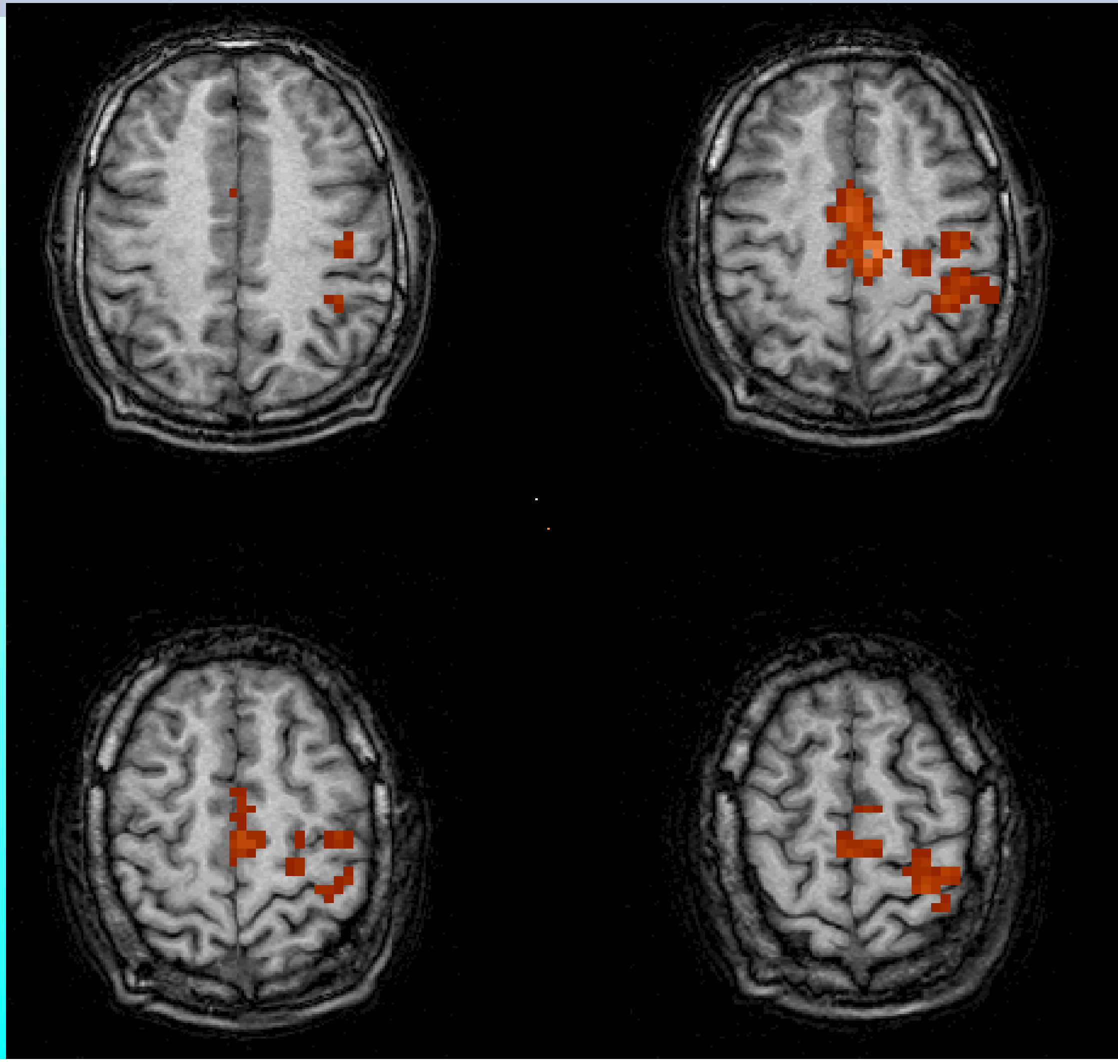
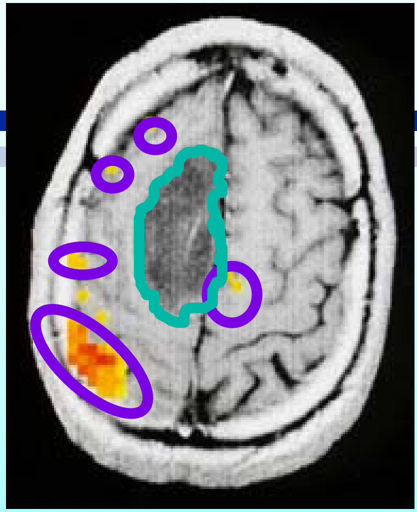
An example, a set of sites with 'significant' activation

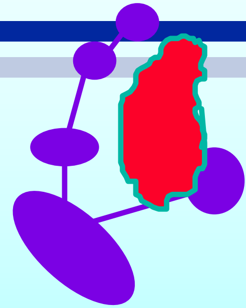


Ack H Benali

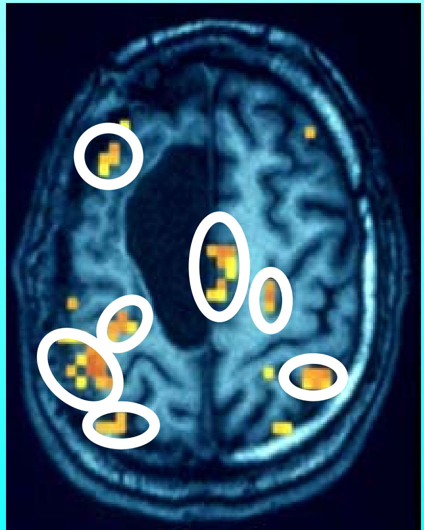
© Cerebral plasticity (connectivity in the brain)

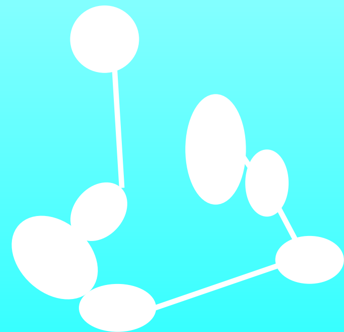
before resection





Activation maps → Association graphs





after resection

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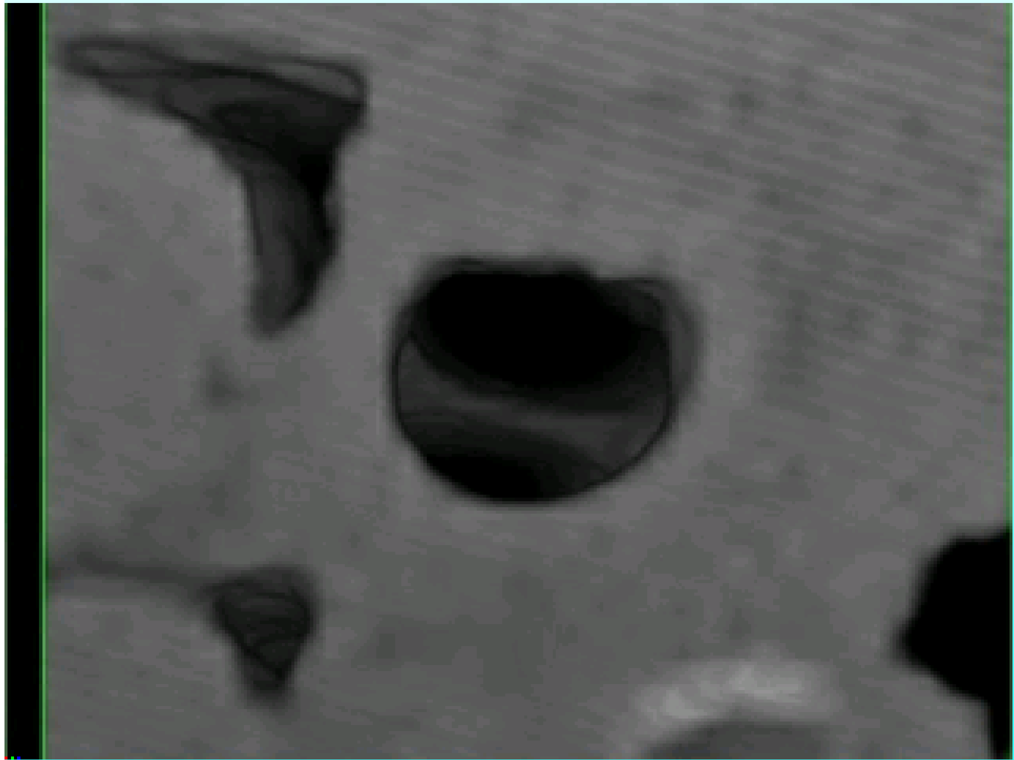
Towards Computer Assisted surgery: The Virtual Environment

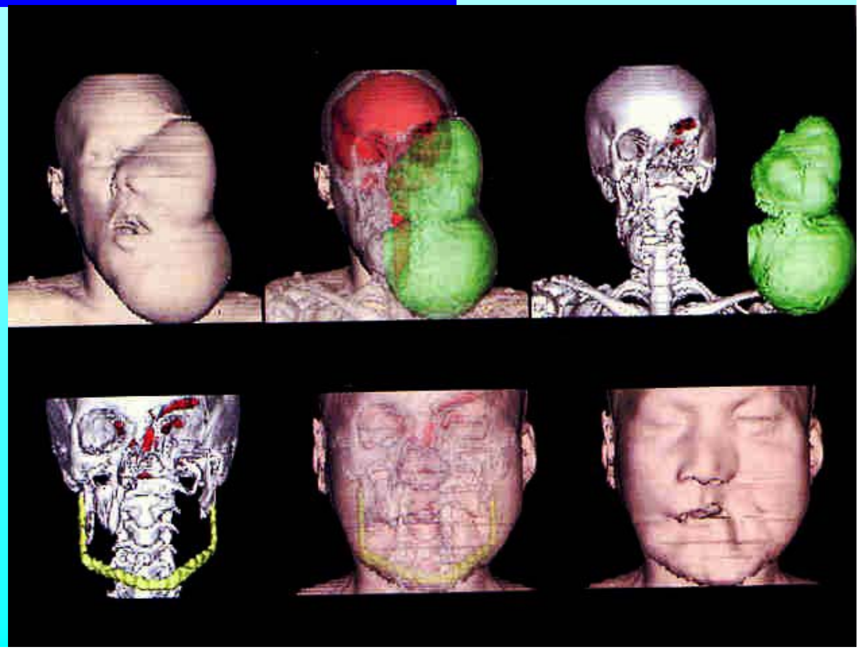


Ack A Linney

Ack. Harvard

Applications in Cranio-facial surgery

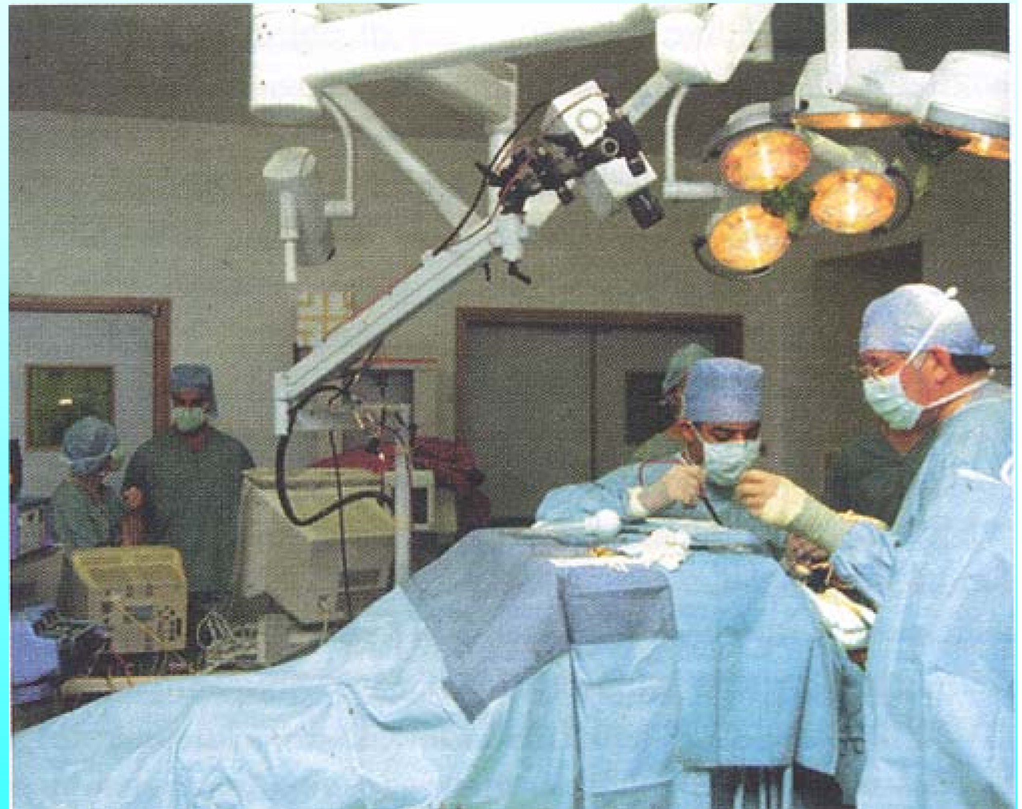
A challenge-
FEM modelling of soft tissue.



Ack. Robb

Applications in neurosurgery

- Pre-operative imaging
- Image fusion
- Applications in theatre



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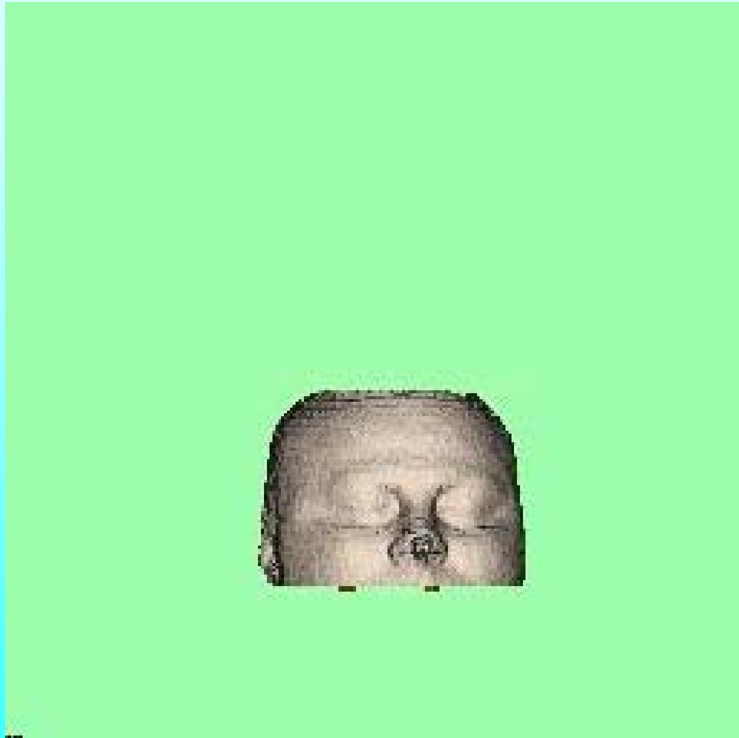
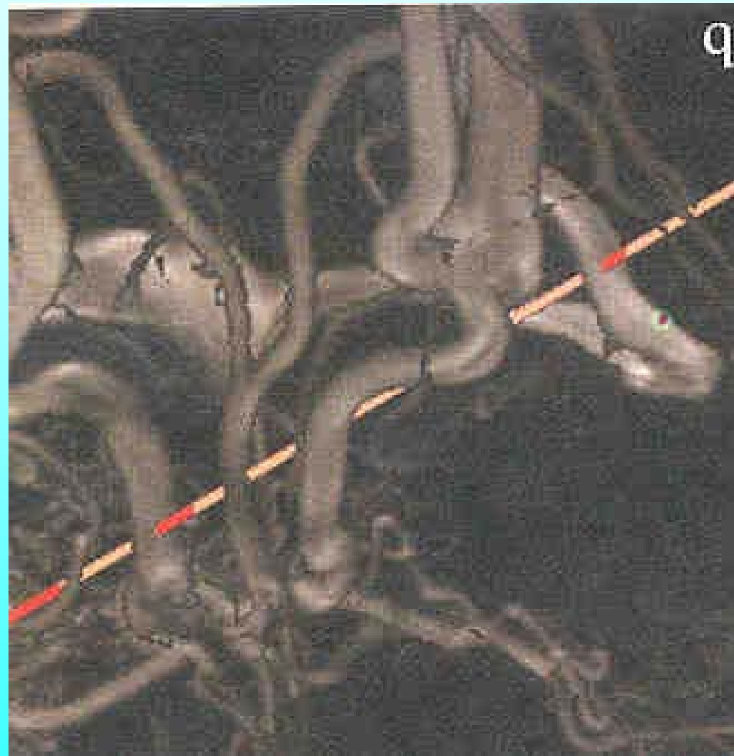
Surgical planning: the robot surgeon



Ack. Harvard



Ack. Zuiderfeld

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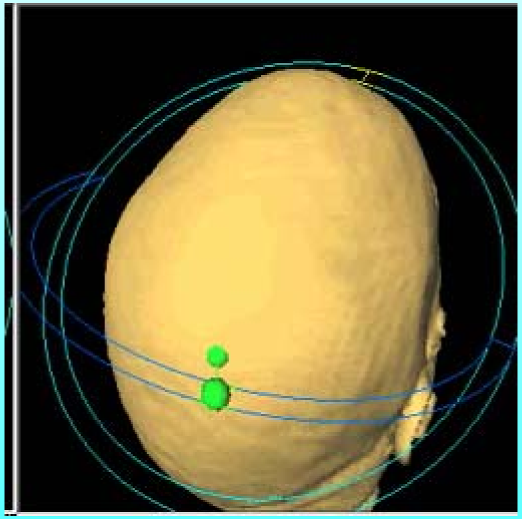
Simulated biopsy



Ack L Bidaut

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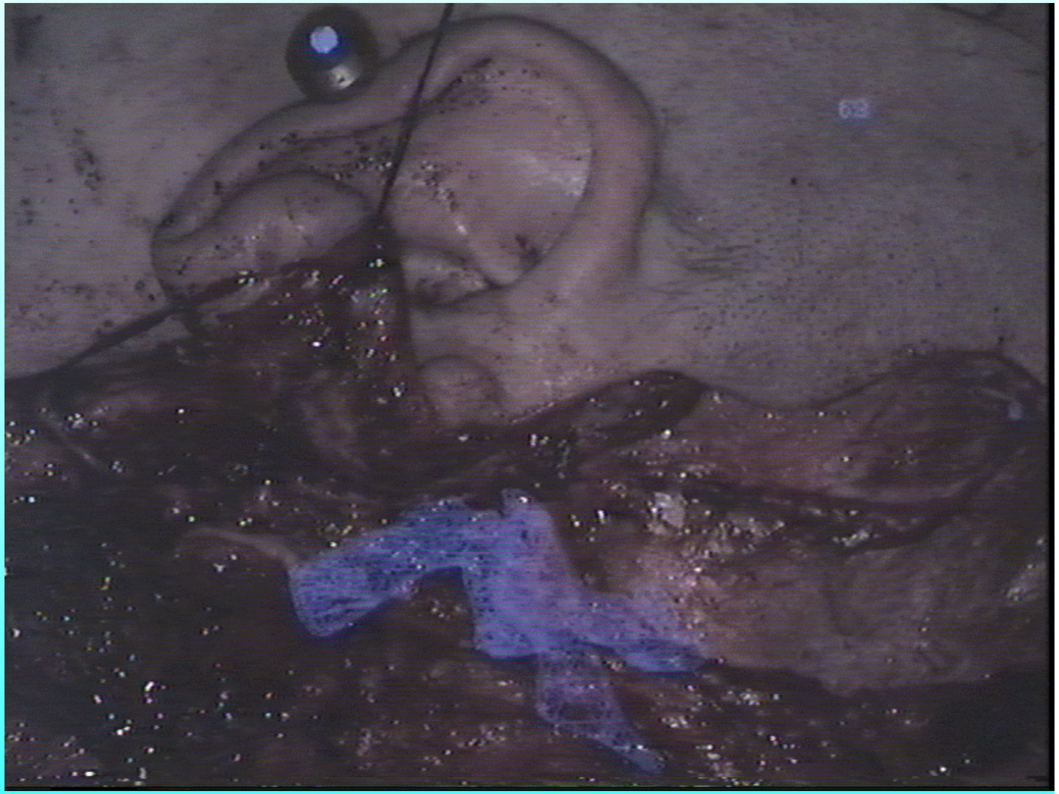
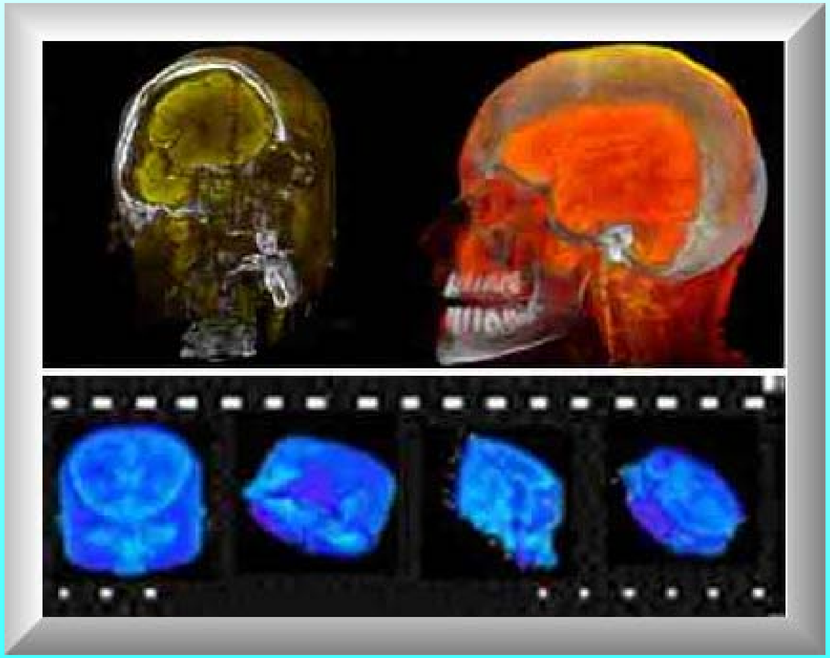
Image fusion in a surgical microscope



Ack Hawkes

Interaction and tools

3-D mouse and similar devices



3-D Displays

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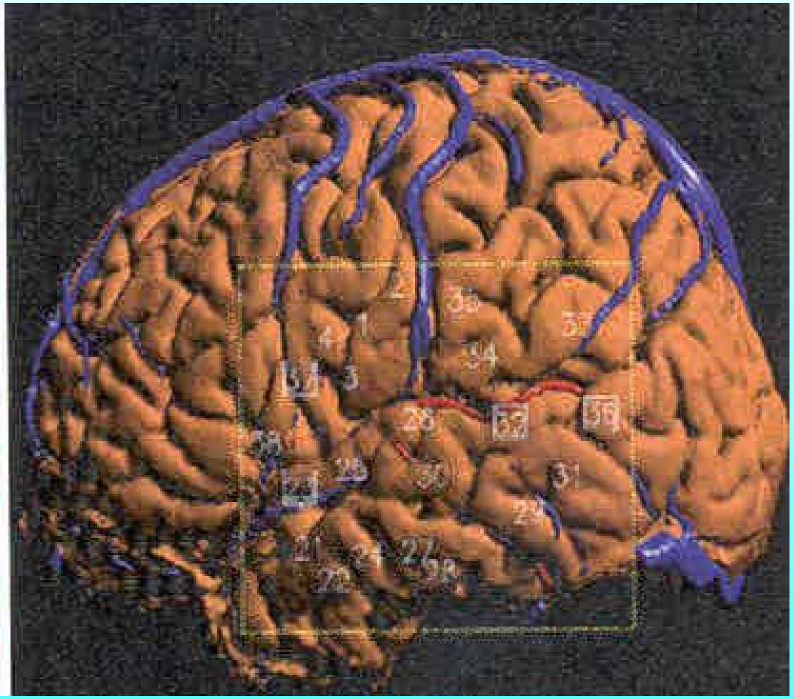
Achieving benefit: Stimulation during surgery



Limits of viable tissue during intervention

FEM models of brain to predicts brain movement

©

Do we need super-computers?

- Non-rigid registration
  - At present about 10-100 minutes
  - Can be made parallel
- Deformable tracking
  - At present almost real time!
- Real time signal correction
  - Requires 10x processing power
- Robot surgery
  - Smart algorithms and safer algorithms need to be developed, hence increase in computer power

How to make it cheap enough
How to make it robust/safe

GRID Computing

- Like electricity
- Distributed data
- Distributed processing

- Next generation of Internet

- **Intelligence ->Extelligence**


The End