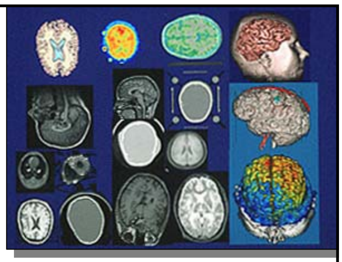

Medical Imaging :

Data Fusion in 3D Medical Imaging

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IRISA

VisAGeS U746 as a component of the "IRISA" Institute (http://www.irisa.fr)

- IRISA is a publicly funded research institute:
  - Co-funded by **INRIA**, **CNRS** and **Univ. of Rennes 1**.
  - a staff of **650** people, including **200** research faculty staff, **100** technical and administrative staff and **150** postgraduate students
  - Net revenues: **10 M€/year** (including 6.5 M€ from grants)
  - Per year around **500** publications, **40** PhD, **10** conferences
- Research Center on Information Technologies and Applied Mathematics:
  - Goal: bring together mathematicians, automated systems analysts, computer scientists and signal and image processing people
- 30 research teams centered around 5 major scientific topics:
  - networks and systems
  - software engineering and symbolic computation
  - man-machine interaction, images, data and knowledge
  - simulation and optimization of complex systems
  - Modeling of living organisms
- And their application in many fields :
  - telecommunications, multimedia, transport, medical science, genomic, emerging technologies applied to health, environment etc.

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IRISA in Rennes, Brittany (*Roazhon*) (http://www.ville-rennes.fr)

- Provincial Capital
- City area of around ~450 000 people
- One of the most fast growing city area in France
- 2 Universities and > 20 post-graduate schools (~60 000 students)
- World's smallest city to have a subway
- Founded around 57 BC (*Condate*)
- More than 80 large research centers (*public and privates*)
  - INSERM, CNRS, INRA, INRIA, Canon, France Telecom, Thomson, Lucent, Mitsubishi, Wandel & Goltermann

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VisAGeS U746 at Short

(http://www.irisa.fr/visages)

- 4 affiliations
  - INSERM (National Institute of Health and Medical Research)
  - INRIA (National Research Institute of Informatics and Automation)
  - CNRS (National Center for Scientific Research)
  - University of Rennes I
- The only team to be jointly affiliated to INSERM and INRIA
- ~**25** people, including **7** research faculty staff (incl. **2** MD's), **3** technical and administrative staff, **9** PhD, **2** Post-docs, **7** associate faculty
- Offices in 2 locations :
  - Univ. Hospital and IRISA/INRIA (*10mn by car*)
  - Transparent "virtual" office (*network, admin, agenda*)
  - People have office at both locations

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Plan of the presentation

- General Context
- Illustration of Data Fusion Issues
- Principal of Data Fusion in 3D Medical Imaging
- Image Registration
  - Basic Concepts
  - A Focus on Deformable Registration
    - Local, Global and Hybrid methods
- Cooperation between segmentation and registration tasks
- Perspectives
  - Deformable registration
  - Sharing heterogeneous and distributed resources

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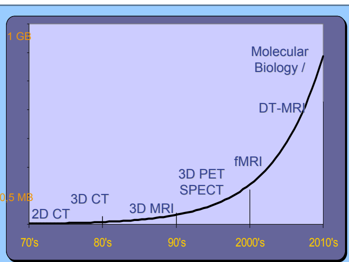
General Context and Challenges

- Context :
  - Expansion of the quantity of data produced and processed in medical imaging (« *from the volume to the mass* »)
  - Explosion of the IST and the electronic communication resources
- Challenges :
  - To guide the clinician (e.g. a neurologist) within the mass of information to integrate into the medical decision process
  - To guide the surgeon for the exploitation of the different sensors and effectors (e.g. robots) to use in the interventional theater



- MS lesions
  12000 images*/patient/year
- Epilepsy surgery
  7000 images*/intervention

*: 1 image = 1 2D MRI slice

05/09/2007 *C. Barillot, « Medical Imaging II »,* 6

Coming issues

- Conception of the surgical room of the future
  - Integration of intra-operative multimodal sensors and effectors (e.g. robots) at different scales (from the molecule to the organ through the cell)
  - Guidance of surgical information sources by observations and knowledge
- Better understand the behavior of normal and pathological systems, at different scales
  - Imaging the pathologies, from the organ level to the cell and the molecule
  - Modeling normal and pathological group of individuals (cohorts) from image descriptors
- Creation of virtual organizations of medical imaging actors thru the dissemination of GRID and semantic web technologies in e-health, for:
  - The creation of “virtual” cohorts
  - The research of new specific biomarkers from imaging
  - Data mining and knowledge discovery from image descriptors
  - Validation and certification of new drugs

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Research issues

- Need to interconnect medical information resources (data, programs, medical devices) together:
  - Data fusion of medical images
  - Merge semantic and computational Grid technologies
  - Development of new adaptive medical devices (*effectors, sensors, …*)

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Illustration of Data Fusion Issues

Epilepsy Surgery

- Patient selection
- Semiology of crisis and relations to anatomy
- « Static » Exams (*search of lesions*)
- « Dynamic » Exams (*search of epileptogenic status*):
  - Interictal : functional imaging, Electrodes Implant
  - Ictal : Crisis Recordings and labeling
- Presurgical Planning
- Cortectomy (surgery)

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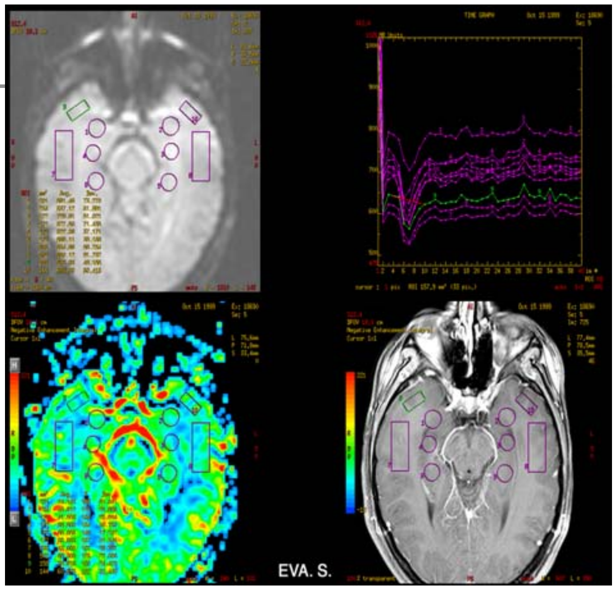
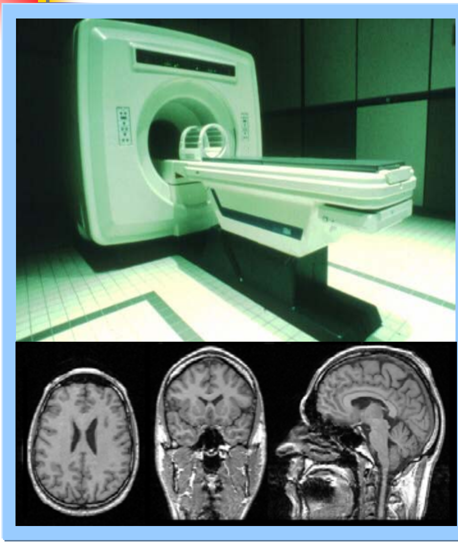
« Static » Exams

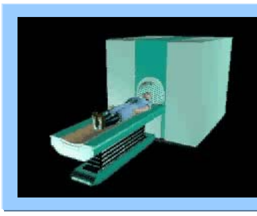


(Source: [A. Biraben *et al.*, CHU Rennes])

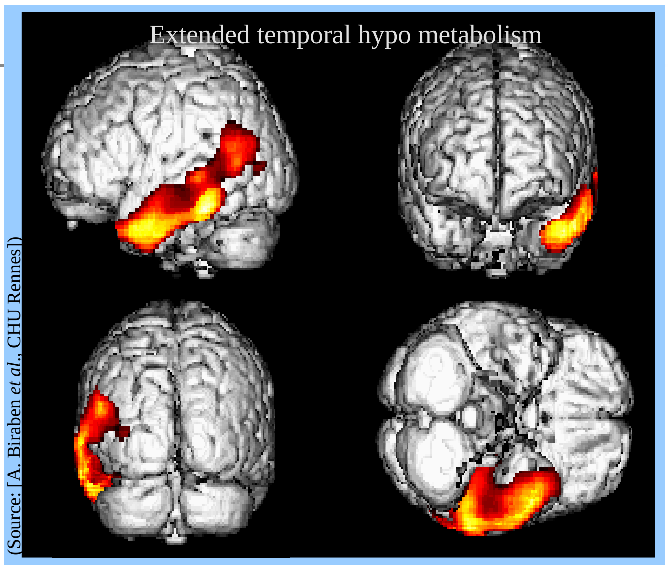
Magnetic Resonance Imaging (MRI)



- Proton Density - NMR
  - 256 x 256 pixels (1mm resolution)
  - From 20 to 120 slices along three axis



«Dynamic» Metabolic Exams



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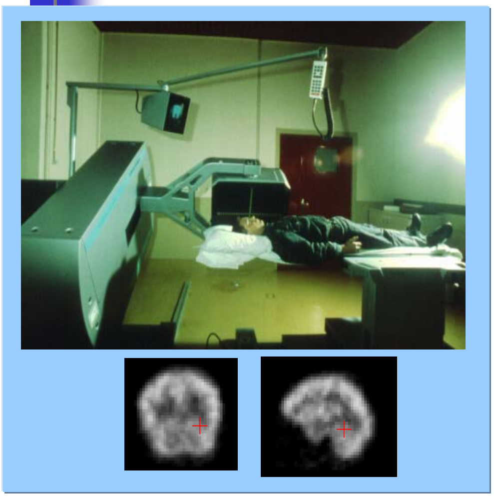
Single Photon Emission Computed Tomography (SPECT)



- Distribution of a radio tracer
  - Typical 64 x 64 à 128 x 128 pixels (resolution 3 to 5mm)
  - 64 to 128 slices per volume

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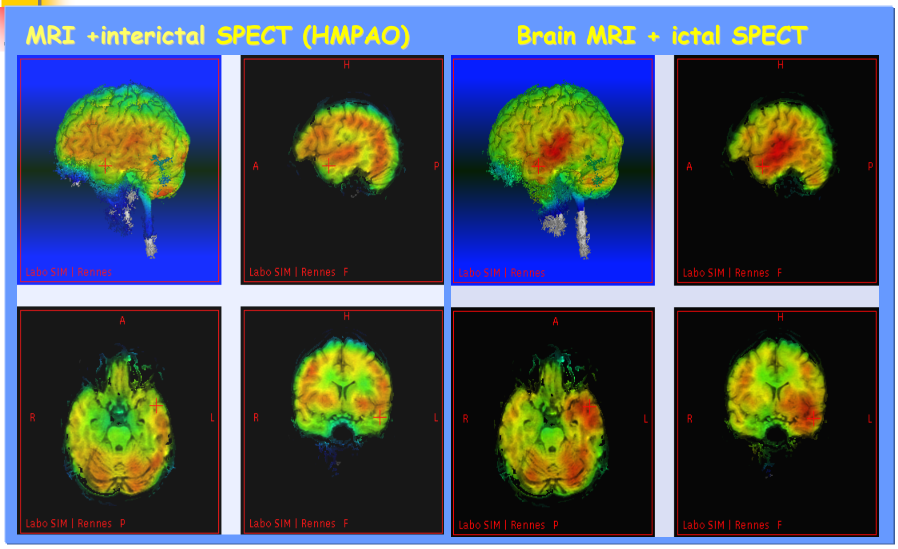
Fusion of “Static” and «Dynamic» Exams



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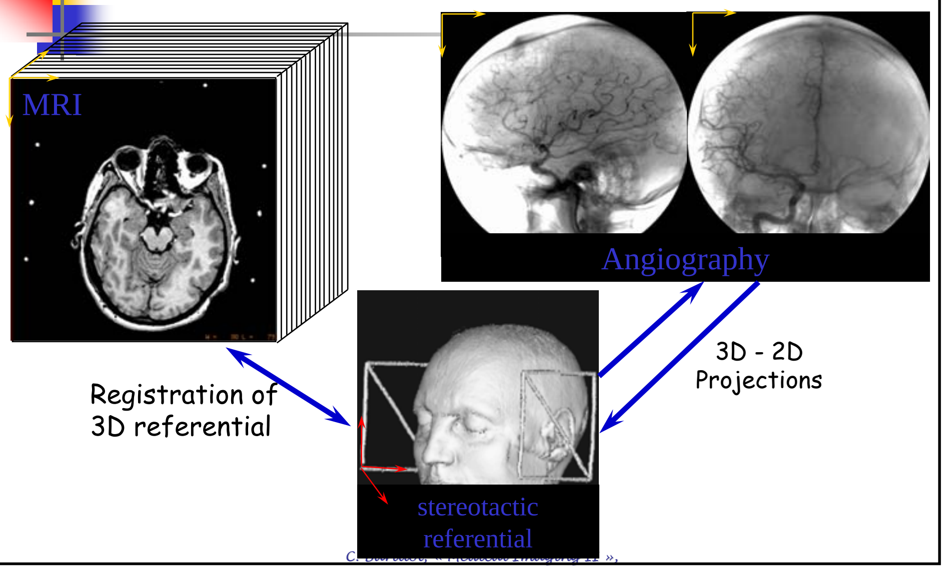
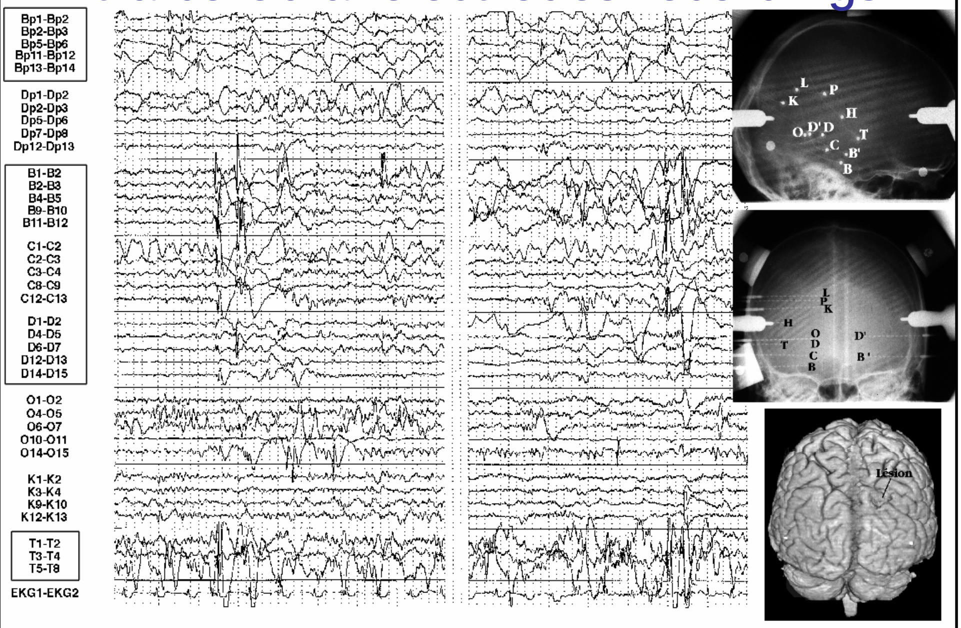
Intra cerebral electrodes implant in stereotactic conditions



Intra cerebral electrodes recordings



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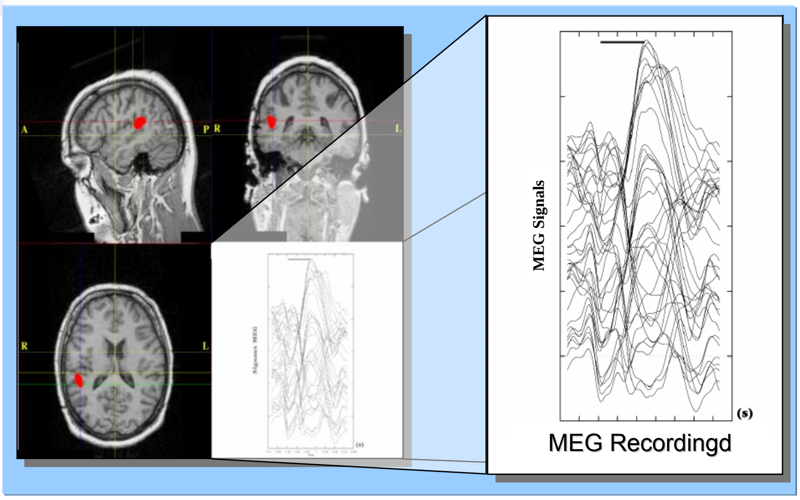
Dynamic Exams and Pre-operative Planning:

Functional recording of epileptic region environment



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Functional Imaging : MagnetoEncephaloGraphy (MEG)

- Measure of the magnetic field issued by the neuronal activity :
  - Brain : 10^{-13} Tesla
  - Hearth : 10^{-3} Tesla
  - MRI : 1 to 3++ Tesla
- 40 to 150+ sensors (SQUID)
- spontaneous and evoked potentials, e.g.:
  - motor
  - somesthesic
  - language
  - visual

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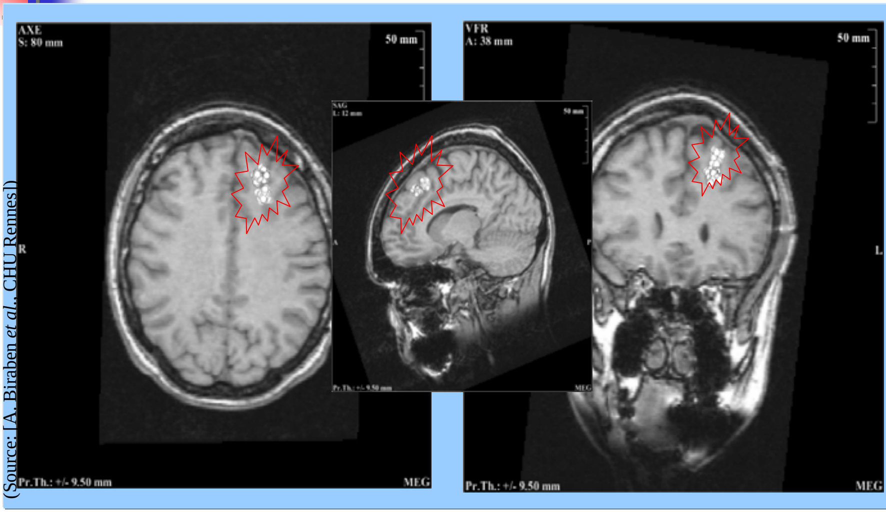
Interictal MEG



(Source: [A. Biraben *et al.*, CHU Rennes])

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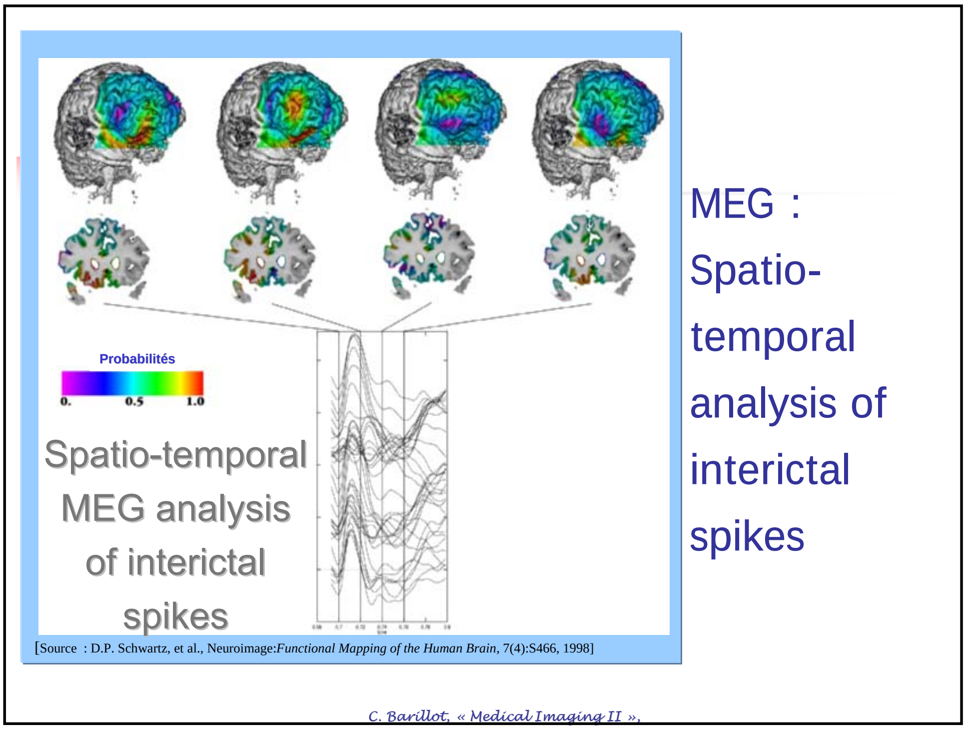
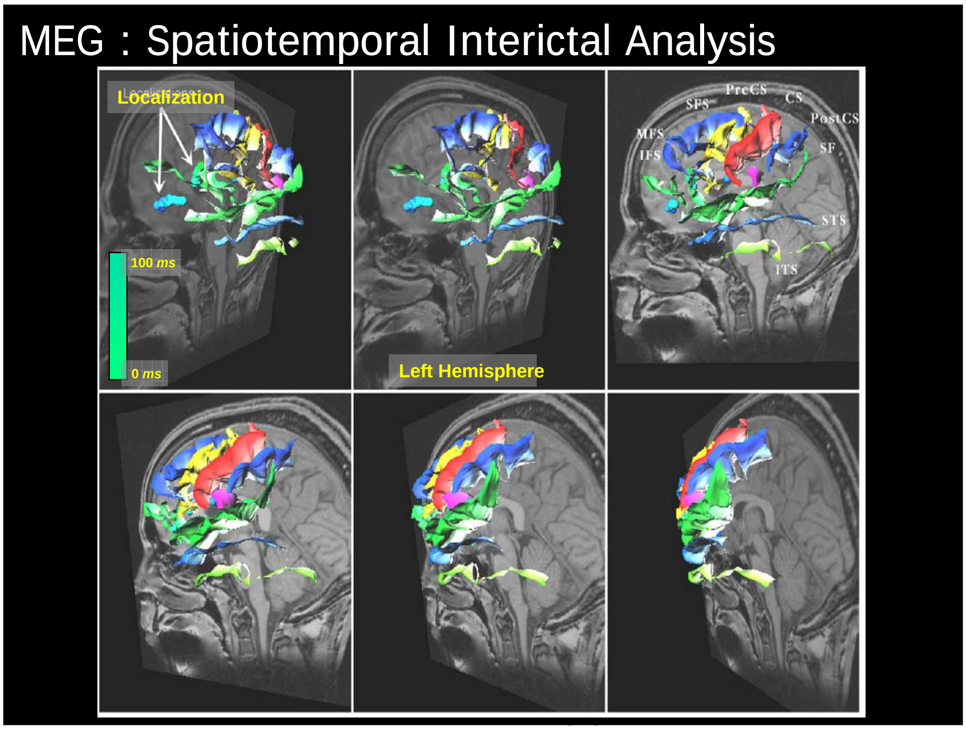
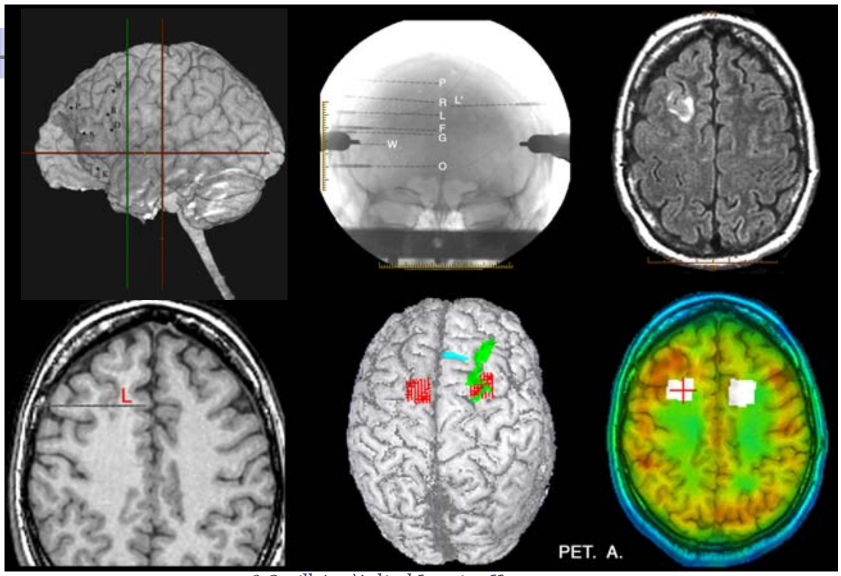
Diapositive 20

MSOffice1 ; 02/06/2002


MEG : Spatio-temporal analysis of interictal spikes
Probabilités
0. 0.5 1.0
Spatio-temporal MEG analysis of interictal spikes
[Source : D.P. Schwartz, et al., Neuroimage:Functional Mapping of the Human Brain, 7(4):S466, 1998]
C. Barillot, « Medical Imaging II »,


MEG : Spatiotemporal Interictal Analysis
Localization
100 ms
0 ms
Left Hemisphere
PreCS
CS
SFS
PostCS
MFS
IFS
SF
STS
ITS

Epilepsy Surgery : Preoperative Planning



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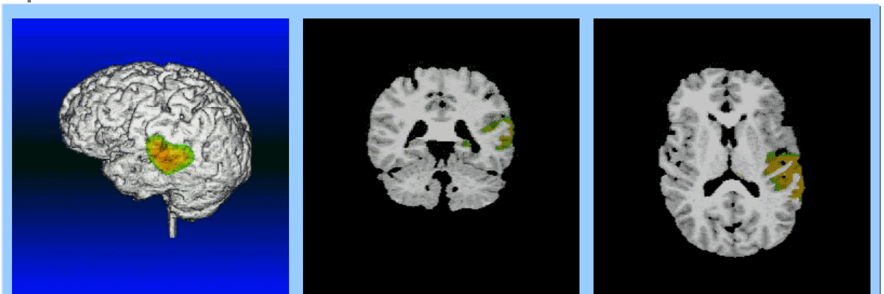
Functional Mapping of language areas



Silent *vs* Active Word Activation

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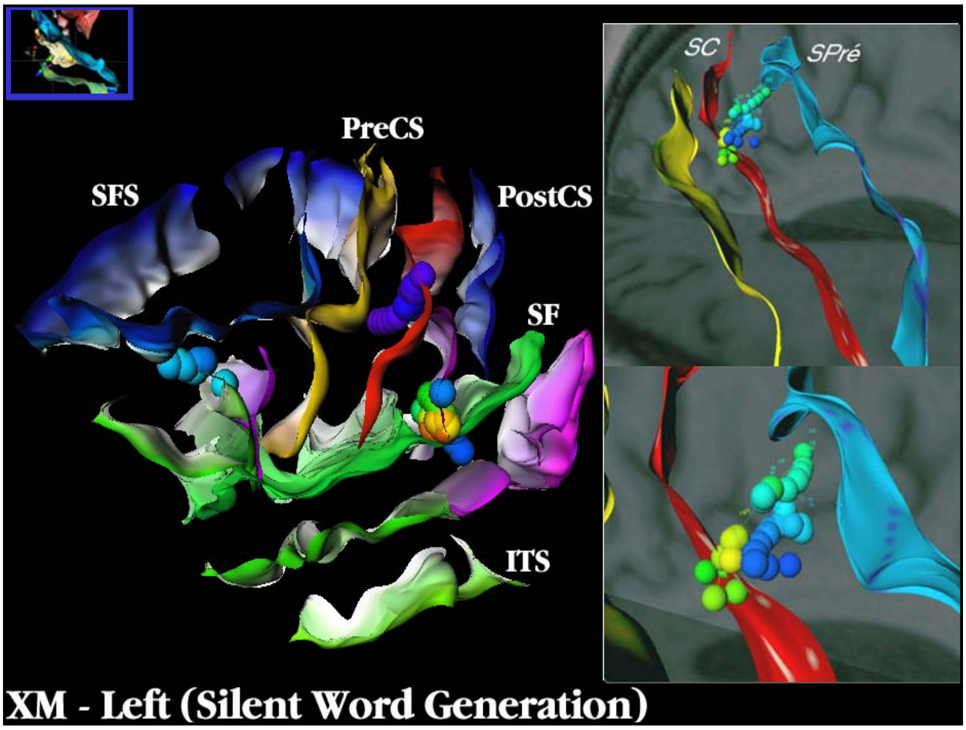
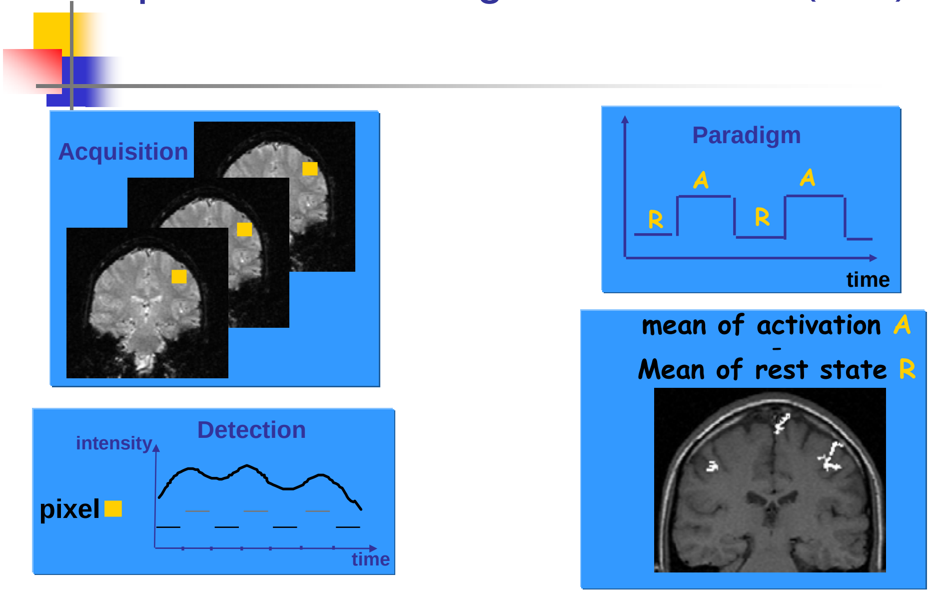


Preoperative Planning : functional MRI (fMRI)



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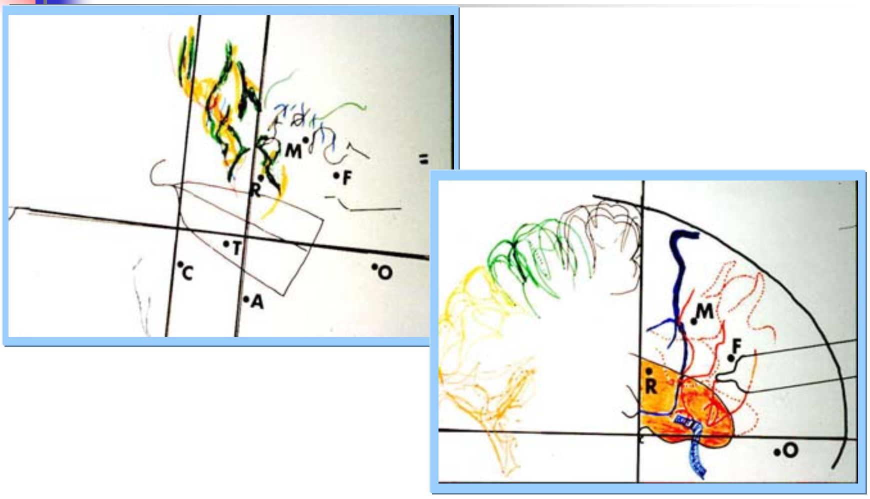
Epilepsy Surgery:
Superposition of graphical data



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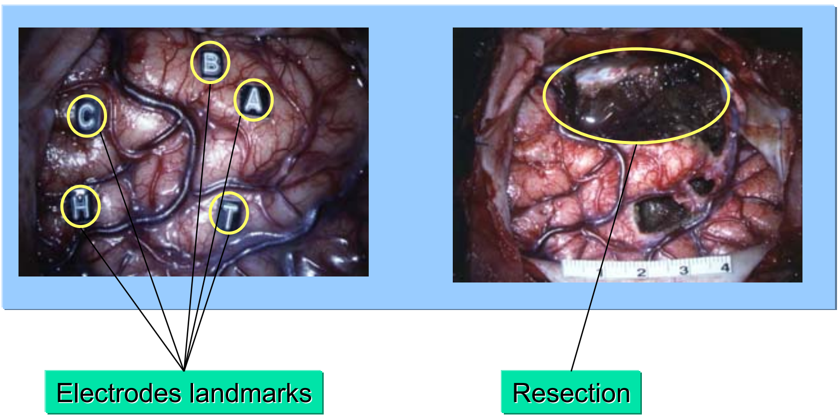
Surgical resection



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Evolution in Image Guided Neurosurgery

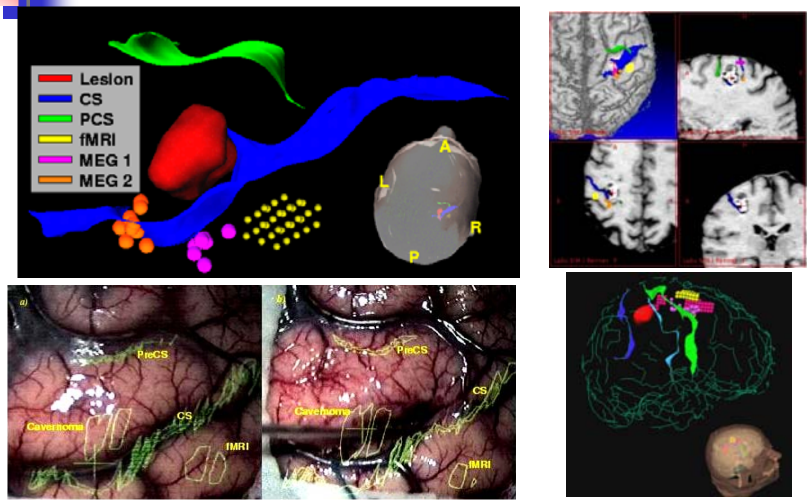

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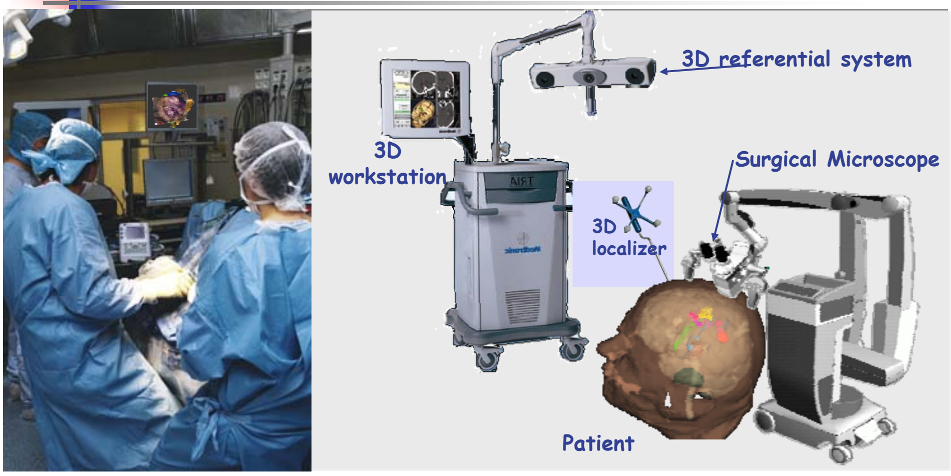
Image-Guided Neurosurgery:
Interventional procedure (Neuronavigation)



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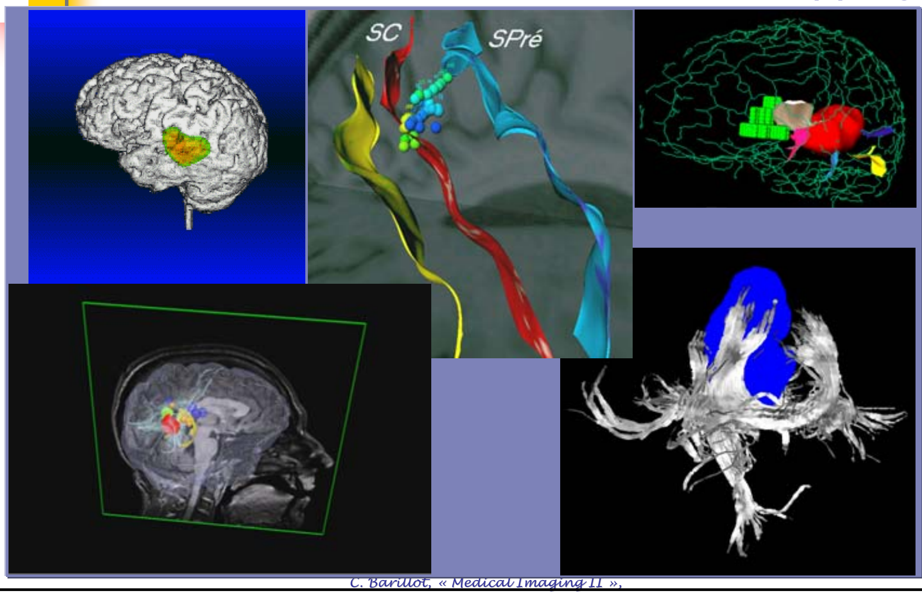
Evolution of Preoperative Planning : More Anatomical and Functional Mapping



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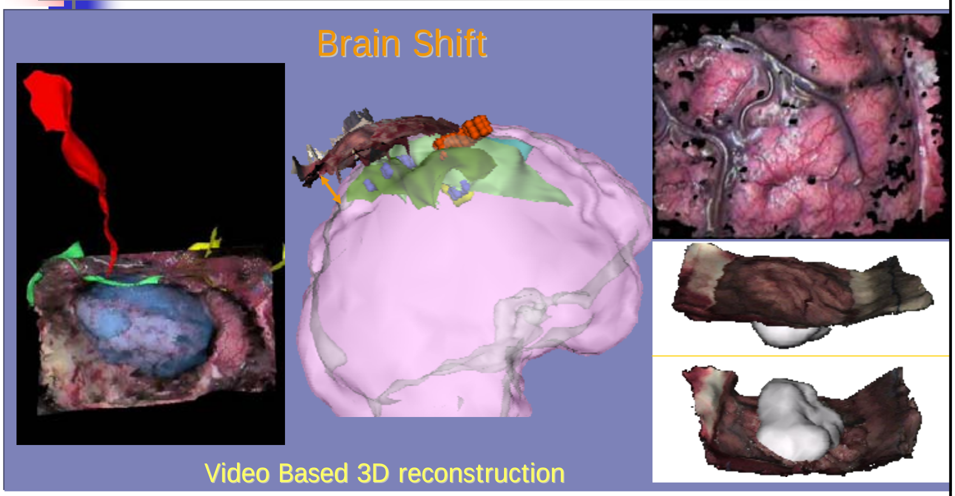
Adding observations during surgery: Video reconstruction



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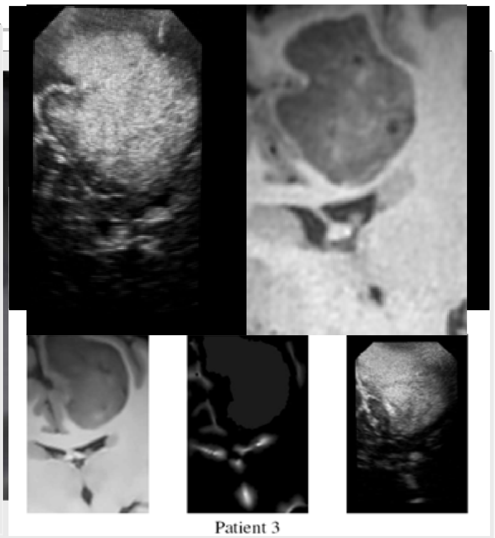
Registration of intraoperative 3D Ultrasound with pre-op MRI*

- Objective: Construct probability maps of hyperechogenic structures from MRI and Ultrasound images for registration.
- Principal: Find a function f relating the MRI intensity of a voxel X ($u(X)$) with its probability to be included in the set of hyperechogenic structures :

$$p(X \in \Phi) = f(u(X))$$

$$\hat{T} = arg\max_{T} \int_{\Omega} p(X \in \Phi_{US}, T(X) \in \Phi_{MR})\, dX$$

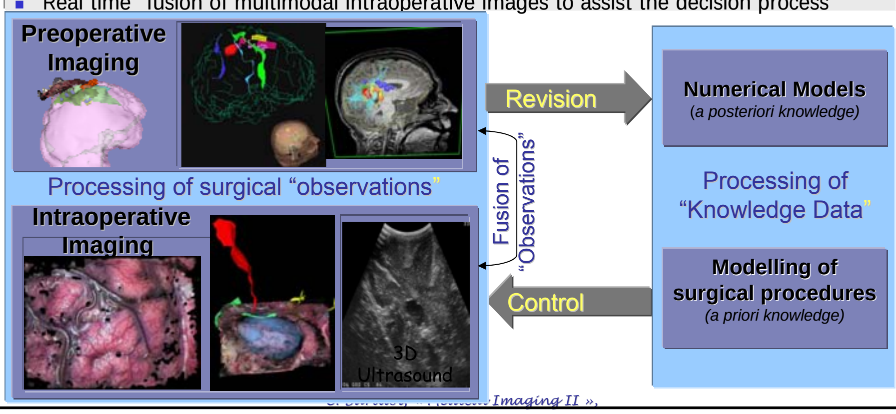


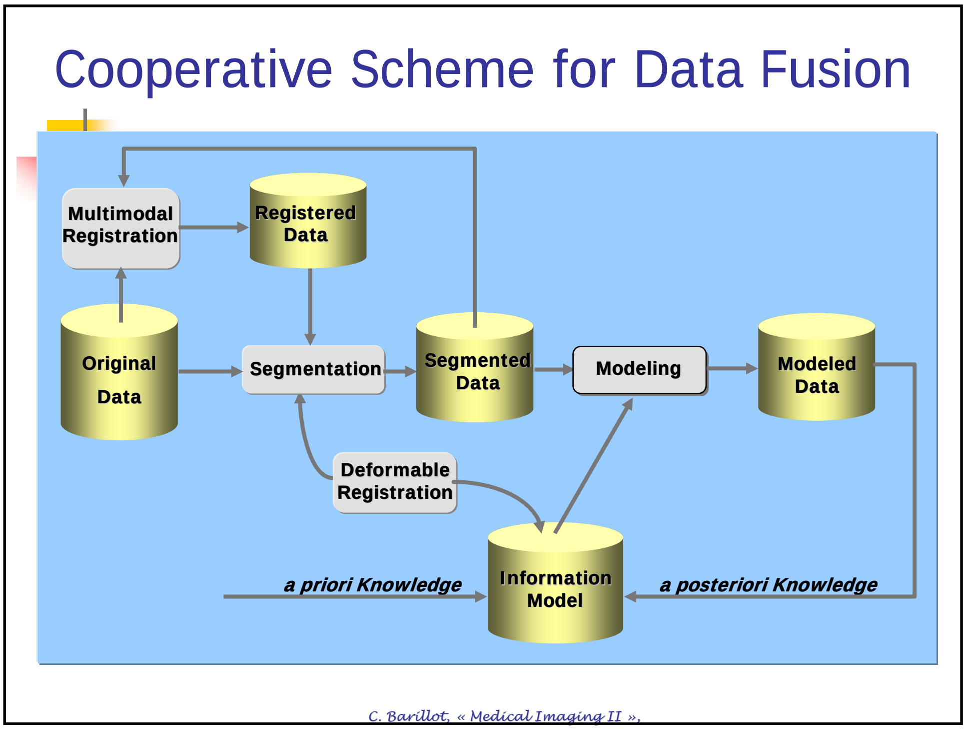
*: P. Coupe *et al.*, IEEE-ISBI 2007

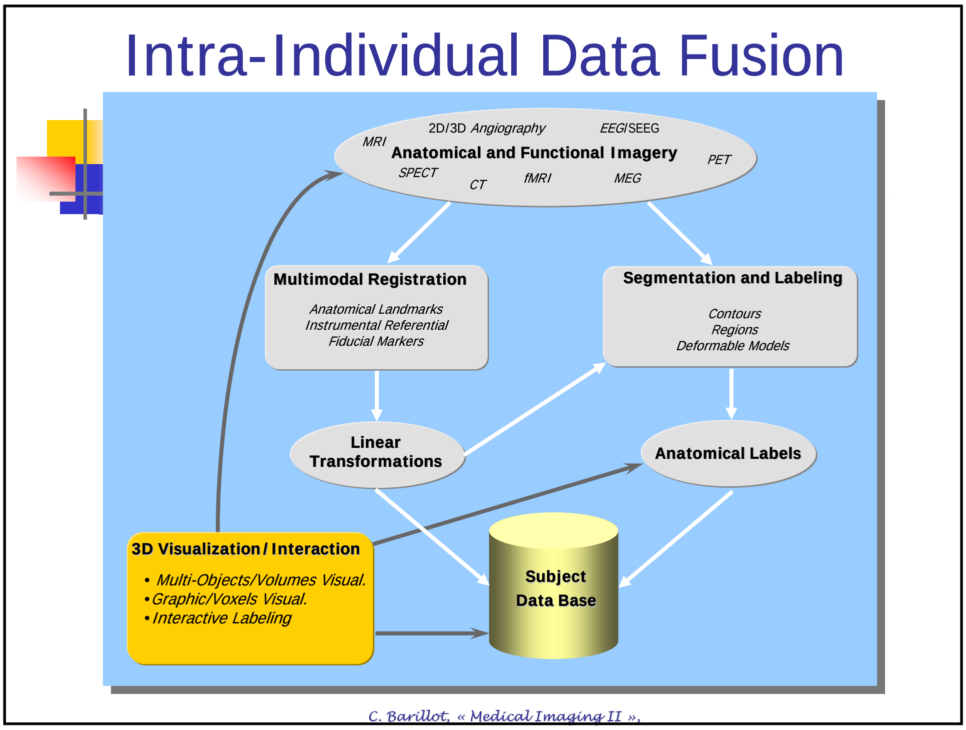
Image-guided neurosurgical procedures: Current and New Issues

Integration of new models and observations

- Take into account intraoperative brain deformation *(gravity, drugs, CSF leaks de LCS, exérèse ...)*
- Take into account additional preoperative data (DTI, molecular)
- New information sensors during surgery (*video, 3D ultrasound, iMRI, in-vivo microscopic biological imaging, molecular data*)
- "Real time" fusion of multimodal intraoperative images to assist the decision process




Cooperative Scheme for Data Fusion
Multimodal Registration
Registered Data
Original Data
Segmentation
Segmented Data
Modeling
Modeled Data
Deformable Registration
a priori Knowledge
Information Model
a posteriori Knowledge
C. Barillot, « Medical Imaging II »,


Intra-Individual Data Fusion
MRI
2D/3D Angiography
EEG/SEEG
Anatomical and Functional Imagery
PET
SPECT
CT
fMRI
MEG
Multimodal Registration
Anatomical Landmarks
Instrumental Referential
Fiducial Markers
Segmentation and Labeling
Contours
Regions
Deformable Models
Linear Transformations
Anatomical Labels
3D Visualization / Interaction
• Multi-Objects/Volumes Visual.
• Graphic/Voxels Visual.
• Interactive Labeling
Subject Data Base
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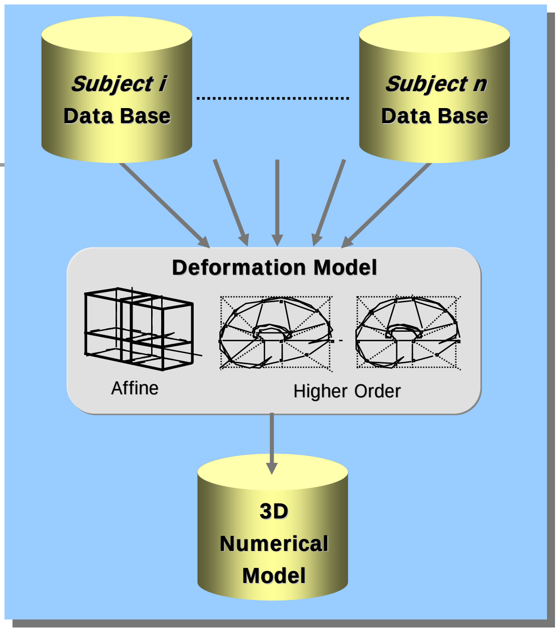
Inter-Individual Fusion



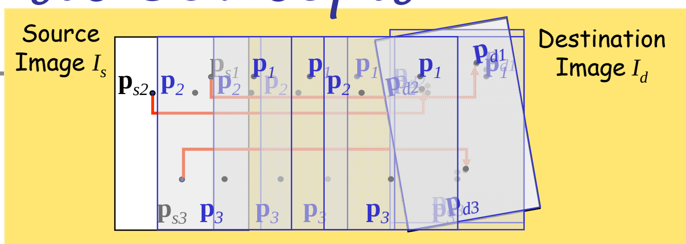
Data Fusion in medical imaging

- What is Data Fusion?
  - Joint Use of Heterogeneous Data
- Why?
  - Co-exploitation of multimodal data
  - Registration / Matching
- Which Context ?
  - Computer assisted image interpretation systems

Image Registration

Basic concepts

Image Registration : *Basic Concepts*



- The notion of registration is to:

  Find a matching between points in one space (an image) **and points in another space** (also called a referential).

Problem: Find a Transformation Φ

Such as $I_s \xrightarrow{\Phi} I_d$

$\Phi = f(\mathbf{R}, \mathbf{T}, \delta(\mathbf{p}))$: $\Phi(\mathbf{p}_s) - \mathbf{p} = \varepsilon \rightarrow$ Optimization

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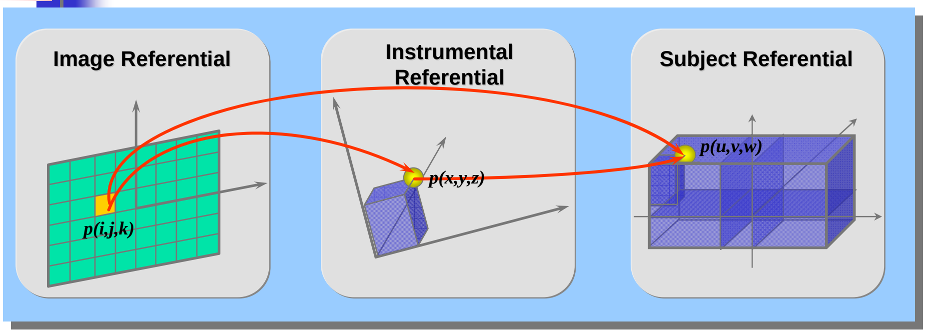
Basic Referential



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Class of registration domains

	ONE patient	SEVERAL patients
ONE modality	Intra-modality registration : - Post-operative control - Pathology tracking, Treatment probing	Intra-modality registration - Model-based segmentation - Registration/matching with an anatomical atlas - Spatial normalization, study of anatomical variability
SEVERAL modalities	Inter-modalities registration - Complementarities between sources of images - Computer assisted therapeutic planning - Computer assisted surgery - Anatomy-function correlation	Inter-modalities registration - Human brain mapping - Anatomo-functional normalization

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Medical Image Registration : *Basic Concepts*

Definition: Let I_s and I_t be two images (*source* and *target*) to match, Ω_s and Ω_t, two homologous structures extracted from these images. The registration procedure consists in finding the transformation $\Phi : \Omega_s \rightarrow \Omega_t$ which registers a landmark ω in Ω_s to its correspondent $\Phi(\omega)$ in Ω_t.

- By generalization, this transformation can be applied to the underlying images I_s and I_t : $(I_t(x_1, y_1, z_1) = \Phi[I_s(x_2, y_2, z_2)])$
- For a given optimization method Ψ, the transformation $\Phi_{\theta \in \Theta}$ is computed by the optimization of :

$$\underset{(\theta \in \Theta | \Psi)}{argmin} \; \Delta\left(\Phi_\theta(\Omega_s) - \Omega_t\right)$$

where Δ is the similarity measure and $(\theta \in \Theta)$ the transformation parameters

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Registration : The 4 basic stages

- Definition of homologous structures (Ω)
- Definition of the type of transformation (Φ)
- Definition of the cost function (Δ)
- Definition of the cost function optimization algorithm (Ψ)

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Types of Homologous Structures (Ω)

- Size of the manifold (D_h)
  - 0D : point ($\Omega = Constant$)
  - 1D : contour ($\Omega = f(u)$)
  - 2D : surface ($\Omega = f(u,v)$)
  - 3D : volume ($\Omega = f(u,v,w)$)
  - *n*D : hypersurface ($\Omega = f(u_1,\ldots,u_n)$)
- Size of the evolution (Euclidian) space (D_w)
  - 2D : surface, projection ($\Omega \in \mathbf{R}^2$)
  - 3D : discrete or continuous space ($\Omega \in \mathbf{R}^3$)
  - *n*D, *n*D+*t* : hypersurface, spatio-temporal (2D+t); ($\Omega \in \mathbf{R}^n$)

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Nature of Homologous Structures (Ω)

- External Referential :
  - Fiducial markers
  - Surgical frames (e.g. stereotactic)
- Anatomical Referential :
  - Anatomical landmarks (reference structures)
  - Image (*iconic*) features (gray levels, gradients, curvatures, …)
  - Segmented shape

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Which Transformation (Φ) ?

- Linear Transforms : $\begin{bmatrix} \begin{bmatrix} r_{11}s_1 & r_{12} & r_{13} \\ r_{21} & r_{22}s_2 & r_{23} \\ r_{31} & r_{32} & r_{33}s_3 \end{bmatrix} & \begin{bmatrix} t_x \\ t_y \\ t_z \end{bmatrix} \\ [\,0 \quad 0 \quad 0\,] & w \end{bmatrix}$
  - Rigid Transformation (rotation + translation)
  - Affine Transformation (rigid + scale)
  - Projective Transformation ($\Omega_s \in \mathbf{R}^n \rightarrow \Omega_d \in \mathbf{R}^{n-i}, i>0$)
- Non-linear Transformation (dense):
  - δ: $\mathbf{p}_d = \mathbf{p}_s + \delta(\mathbf{p}_s)$

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Similarity Function (Δ)

Definition: The similarity function defines the objective criteria (cost) used to estimate the quality of the registration between two homologous structures (Ω).

- Three big classes of measures:
  - Methods based on the definition of an intrinsic geometry (frame, external landmarks, reference planes, ...).
  - Methods based on Euclidian criteria (distances, surfaces, volumes).
  - Methods based on image intensities or their derivatives (correlation in the spatial or frequency domain, entropy, optical flow, ...)

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Image registration: Measure from joint histogram

Joint Histogram
($HIST[x,y]$)

Registered Images
($1/2*[X+\Phi(X)]$)

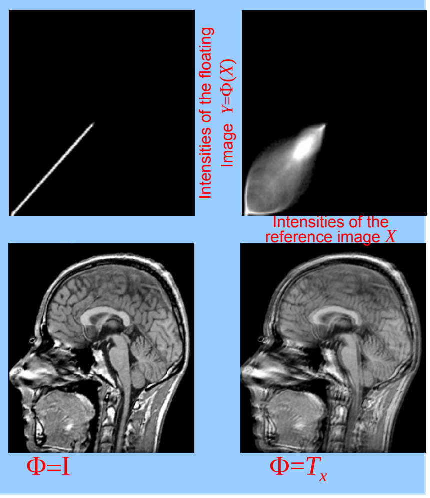

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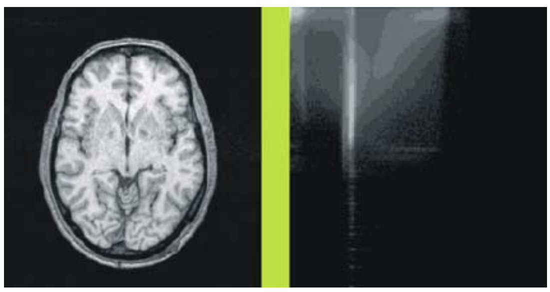
Image registration: Relation between the transformation and the joint histogram



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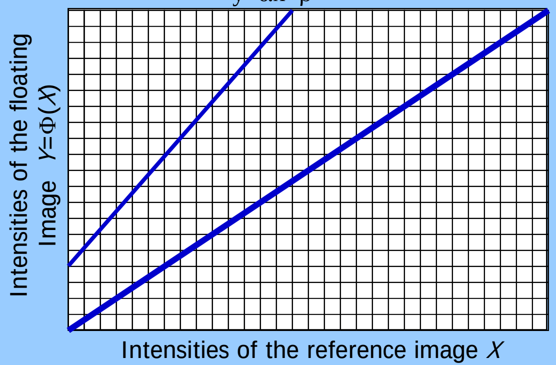
Joint Histogram:
Linear or Affine Dependencies

Optimum *Corr*(*x*,*y*)
y=αx+β

$$Corr(X,Y) = \frac{Cov(X,Y)}{\sqrt{\mathrm{var}(X).\mathrm{var}(Y)}}$$



Optimum SSD/SAD
y=x

$$SSD(X,Y) = \sum_{x\in X, y\in Y} (x-y)^2$$

$$SAD(X,Y) = \sum_{x\in X, y\in Y} |x-y|$$

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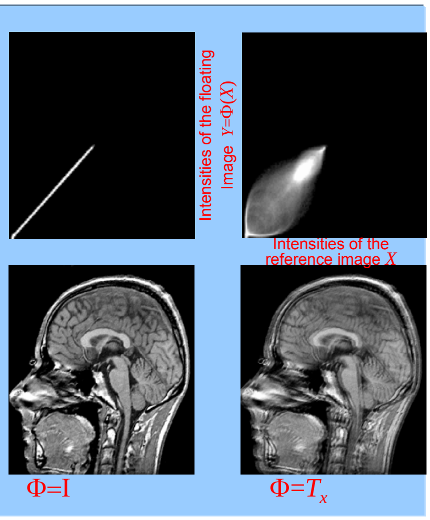
Joint Histogram:
Examples of Linear or Affine Dependencies

Joint Histogram
(*HIST*[*x*,*y*])

Registered
Images
(1/2*[$X+\Phi(X)$])



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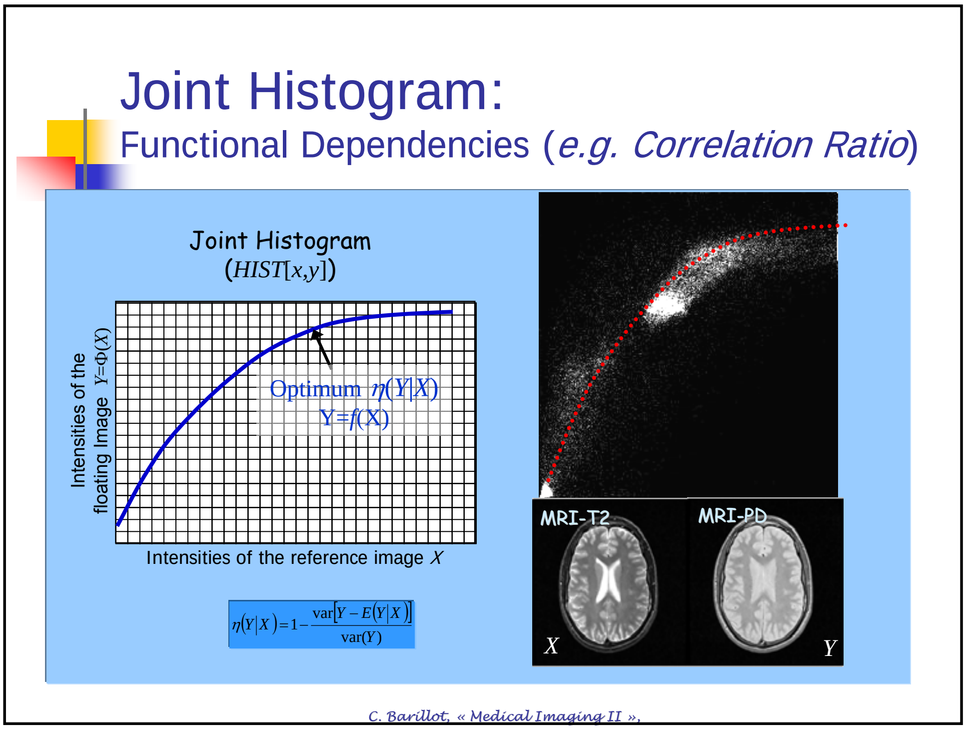
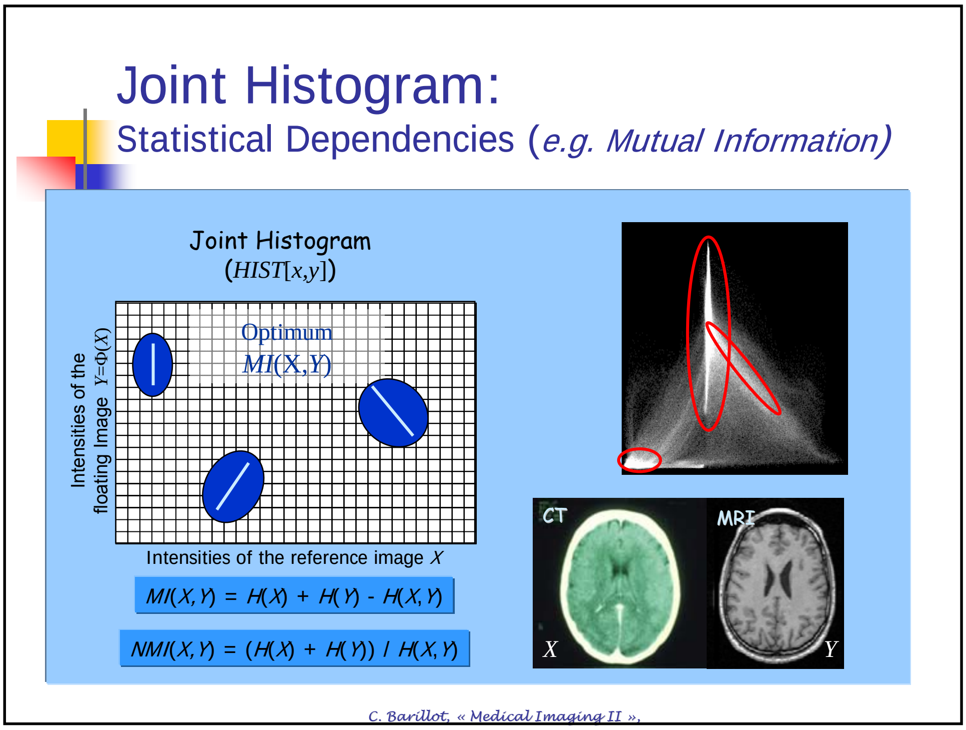
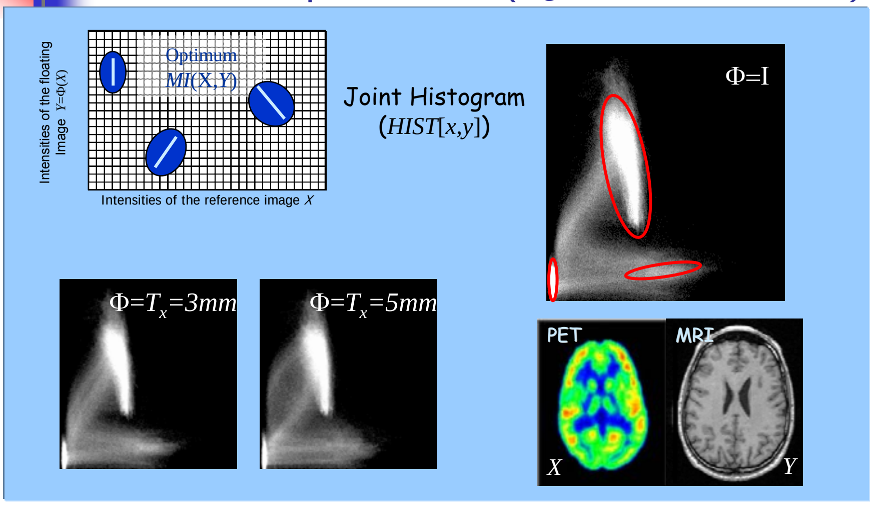

Joint Histogram:
Functional Dependencies (e.g. Correlation Ratio)
Joint Histogram
(HIST[x,y])
Intensities of the floating Image Y=Φ(X)
Optimum η(Y|X)
Y=f(X)
Intensities of the reference image X
η(Y|X) = 1 − var[Y − E(Y|X)] / var(Y)
MRI-T2
MRI-PD
X
Y
C. Barillot, « Medical Imaging II »,


Joint Histogram:
Statistical Dependencies (e.g. Mutual Information)
Joint Histogram
(HIST[x,y])
Intensities of the floating Image Y=Φ(X)
Optimum
MI(X,Y)
Intensities of the reference image X
MI(X,Y) = H(X) + H(Y) - H(X,Y)
NMI(X,Y) = (H(X) + H(Y)) / H(X,Y)
CT
MRI
X
Y
C. Barillot, « Medical Imaging II »,

Joint Histogram:
Statistical Dependencies (*e.g. Mutual Information)*



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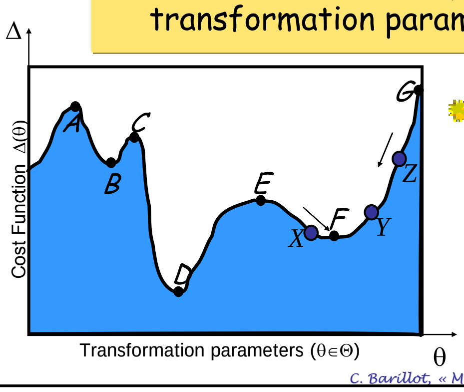
Optimization Issues (Ψ)

Definition: The optimization method defines how the cost function (Δ) will be minimized (or maximized) with respect to the set of transformation parameters $\theta \in \Theta$.



- **Idea**: the goal is to find the minimal value (i.e. *D* rather than *F*) of $\Delta(\theta)$ from any initialization point (e.g. *G*)

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Optimization Methods (Ψ)

- Non Global optimization methods:
  - Quadratic or semi-quadratic approaches
  - May need the estimation of partial derivatives of $\Delta(\theta)$.
  - Assume a quasi-convex energy around the desired solution
  - Need a hierarchical resolution scheme (multiscale, multi-resolution)
  - Examples:
    - Least square, ICP, Gradient Descent, Newton-Raphson, Levenberg-Marquardt, Simplex, Powell...

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Optimization Methods (Ψ) *(2)*

- Global optimization methods:
  - More robust approaches (proof of convergence at an infinite state)
  - Computational cost
  - Non applicable to high dimensional problems (*e.g. iconic registration*)
  - Examples:
    - Dynamic Programming, Simulated Annealing, Genetic Algorithms, Clustering Methods, Branch and Bound, Evolutionary Algorithms, Statistical Methods , ...

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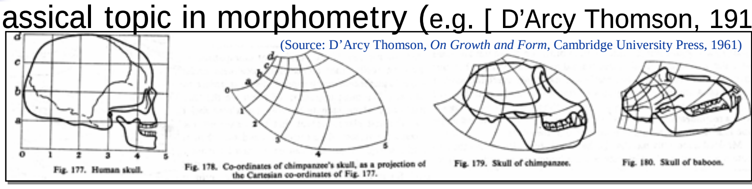
Deformable Registration

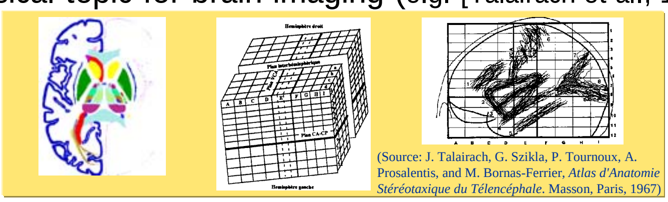
Deformable Registration: Not a new topic!

- Classical topic in morphometry (e.g. [D'Arcy Thomson, 1917])



(Source: D'Arcy Thomson, *On Growth and Form*, Cambridge University Press, 1961)

- Classical topic for brain imaging (e.g. [Talairach et al., 1967])


(Source: J. Talairach, G. Szikla, P. Tournoux, A. Prosalentis, and M. Bornas-Ferrier, *Atlas d'Anatomie Stéréotaxique du Télencéphale*. Masson, Paris, 1967)

- Introduction of computer based procedures in the 80's
  (R. Bacjsy, C. Broit and coll.; U. Grenander and coll.; F. Bookstein, …)

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Deformable Registration: evolution in a decade*

In IPMI (*oral*):

[86-88] F. Bookstein (*general morphometry, brain, TPS*)

[91] F. Bookstein (*general morphometry, brain, TPS*)
D. Lemoine *et al.* (*brain, Talairach Grid System*)

[93] F. Bookstein *et al.* (*general morphometry, brain, TPS*)
K. Shields *et al.* (*carotid plaques in US*)

[95] G. Christensen *et al.* (*brain, fluid model*)
L. Collins *et al.* (*brain, atlas based segmentation*)
J. Gee *et al.* (*brain, bayesian framework)*
S. Sandor *et al.* (*brain*, *atlas based segmentation*)

[97] P. Edwards *et al.* (*brain, interventional imaging*)
T. Schiemann et al. (*volume interaction*)

[99] A. Caunce *et al.* (*sulci shape model*)
G. Christensen *et al.* (*brain, homomorphism*)
H. Chui *et al.* (*brain cortical point*)
L. Collins *et al.* (*brain, atlas based segmentation*)
H. Lester *et al.* (*brain, fluid model*)
D. Rey *et al.* (*brain, growth of pathologies*)
K. Rohr et al. (*TPS*)
O. Skrinjar *et al.* (*brain, interventional imaging*)
M. Vaillant *et al.* (*brain cortical surface*)

** data collected from IPMI (Information Processing in Medical Imaging)*

Deformable registration: When?

	ONE patient	SEVERAL patients
ONE modality	▪ Registration of temporal sequences : ▪ Temporal deformation of anatomical structures (heart, chest, blood flow) ▪ Growth, Pathologies follow-up	▪ Model-based segmentation ▪ Building of digital atlases ▪ Registration/matching with an anatomical atlas ▪ Spatial normalization, study of anatomical variability
SEVERAL modalities	▪ Correction of fMRI acquisitions ▪ Constraints to reconstruction / restoration algorithms ▪ Computer Assisted Surgery ▪ registration between pre- and intra-operative images (e.g. MRI and Ultrasound)	▪ Human brain mapping ▪ Anatomo-functional normalization (aid for the study of functional variability)

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Deformable Registration : which transformation?

- Non-linear dense transformation:

Definition : The transformation can be represented as a dense deformation field: a displacement vector δ is associated to each point of the homologous structures Ω_s and Ω_t :

$$\delta: p_t = p_s + \delta(p_s)$$

- In an energetic framework, the general formulation becomes:

$$\underset{(\theta \in \Theta | \Psi)}{argmin} \; E\left[\Delta\left(p_s + \delta_\theta(p_s), p_t\right)\right] + E\left[\delta_\theta\right]$$

In a Bayesian context: Likelihood : $p((p_s, p_t)|\delta)$ Prior : $p(\delta)$

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Continuity of the transformation ($E[\delta_\theta]$)

- Piecewise linear (C^0 continuity) (e.g. Talairach)
- Splines (C^1, C^2 continuity) (e.g. RBF, Free-form deformation)
- Mechanical Models :
  - Linear elasticity models (Navier equations)
  - Fluid models (Navier-Stokes equations)

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Defomable Registration: Local and Global approaches

- Global, or "photometric" methods ($D_h = D_w$)
  - Rely on photometric similarity measures
  - Provide a dense deformation field
  - Anatomical coherence of the transformation?
  - High dimensional optimization problem
- Local, or "geometric" methods ($D_h < D_w$)
  - Rely on extracted features (point, curves, surfaces)
  - Interpolation necessary (e.g. thin-plate-spline, RBF, ...)
  - The transformation is mostly relevant in the neighborhood of the homologous features

➢ *Hybrid: use of both homologous structures*

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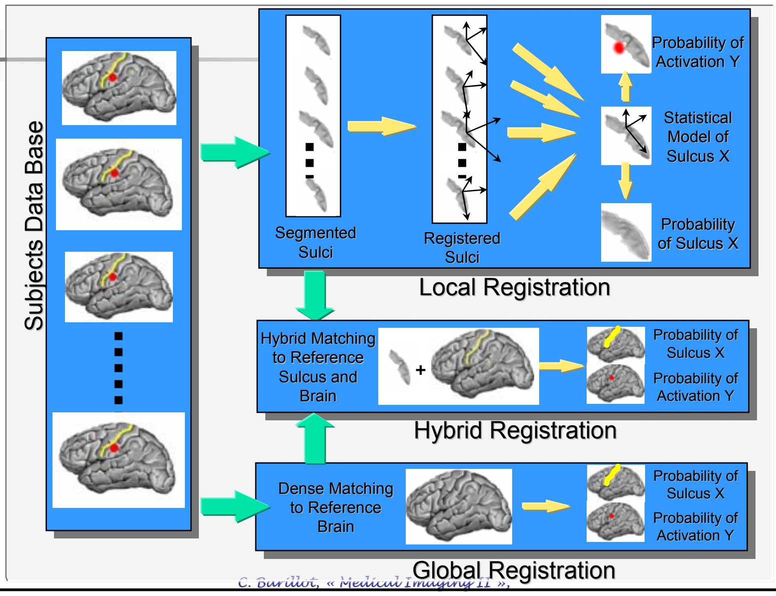
Image fusion in neuroimaging using Global, Local and Hybrid methods



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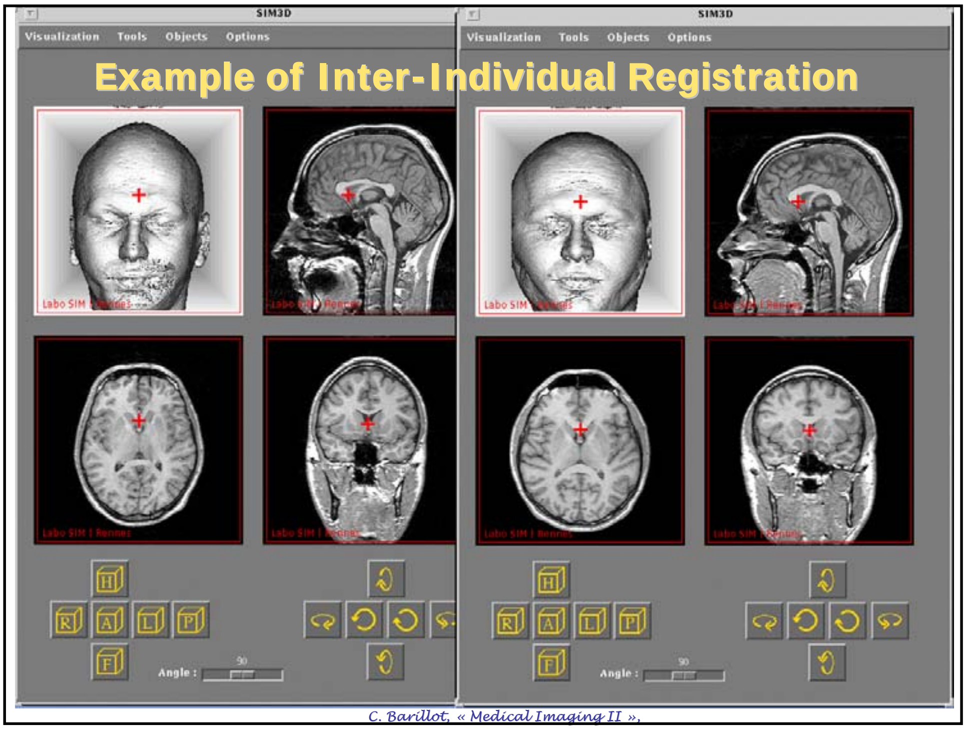
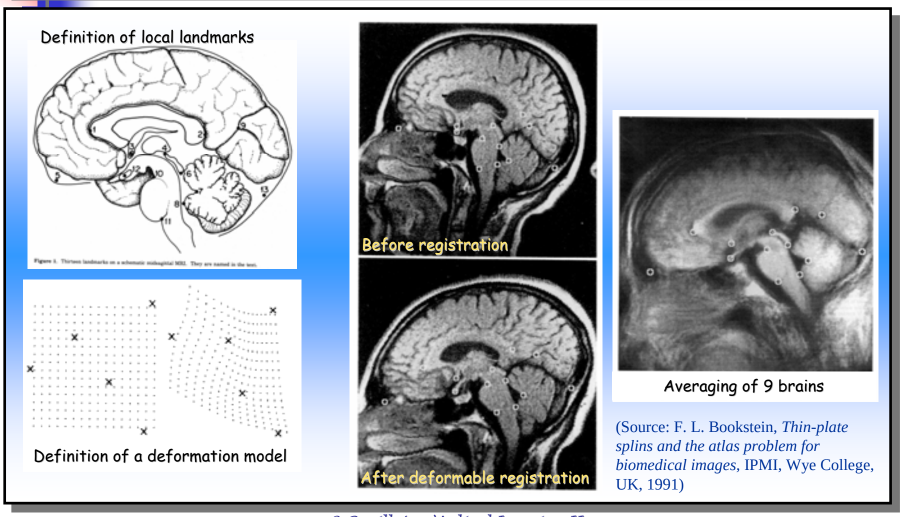


Deformable Registration: Local, or "geometric" methods



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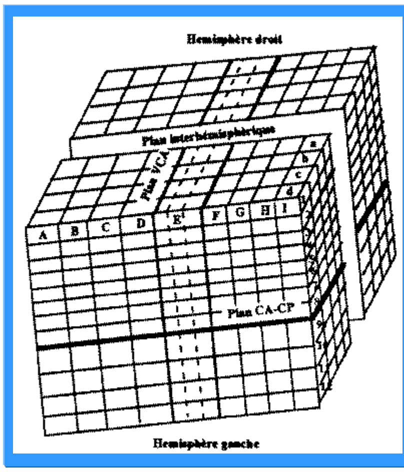
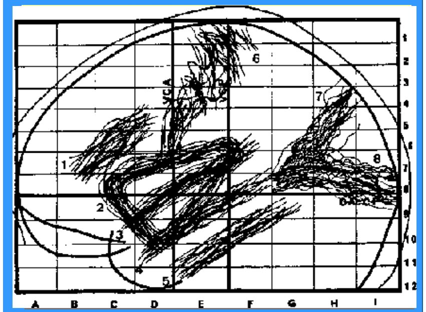
Talairach Stereotactic Proportional Grid System

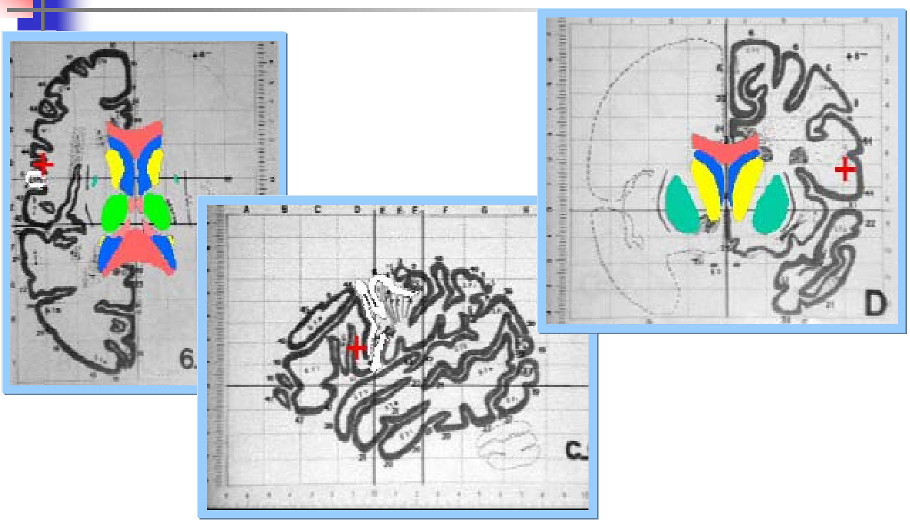




(Source: J. Talairach, G. Szikla, P. Tournoux, A. Prosalentis, and M. Bornas-Ferrier, *Atlas d'Anatomie Stéréotaxique du Télencéphale*, Masson, Paris, 1967)

C. Barillot, « Medical Imaging II »,

Talairach Atlas



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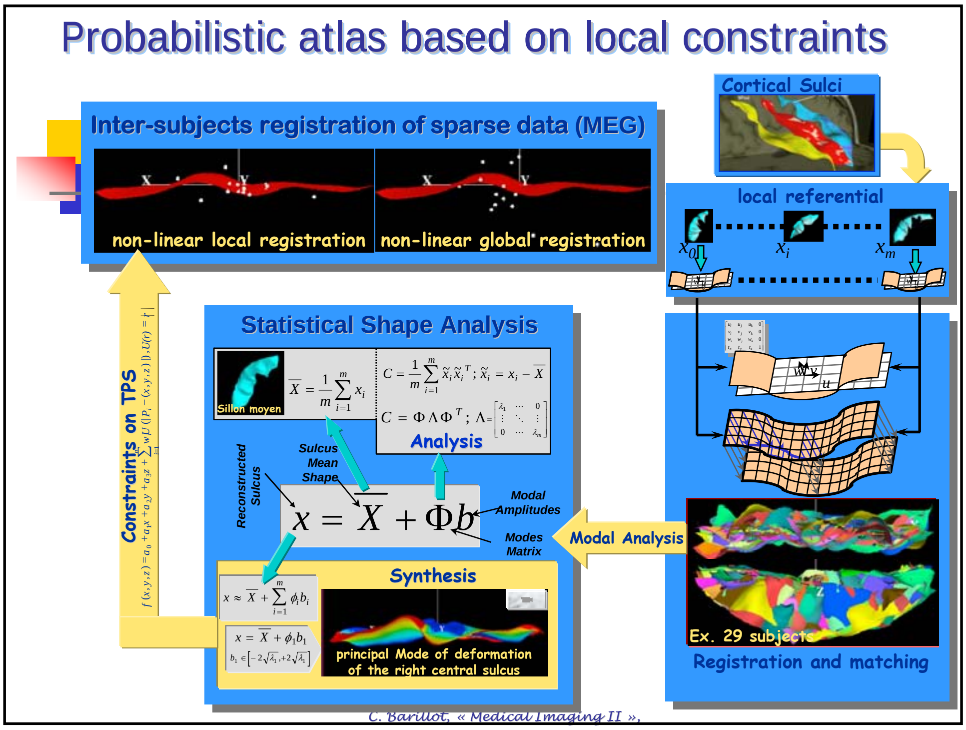
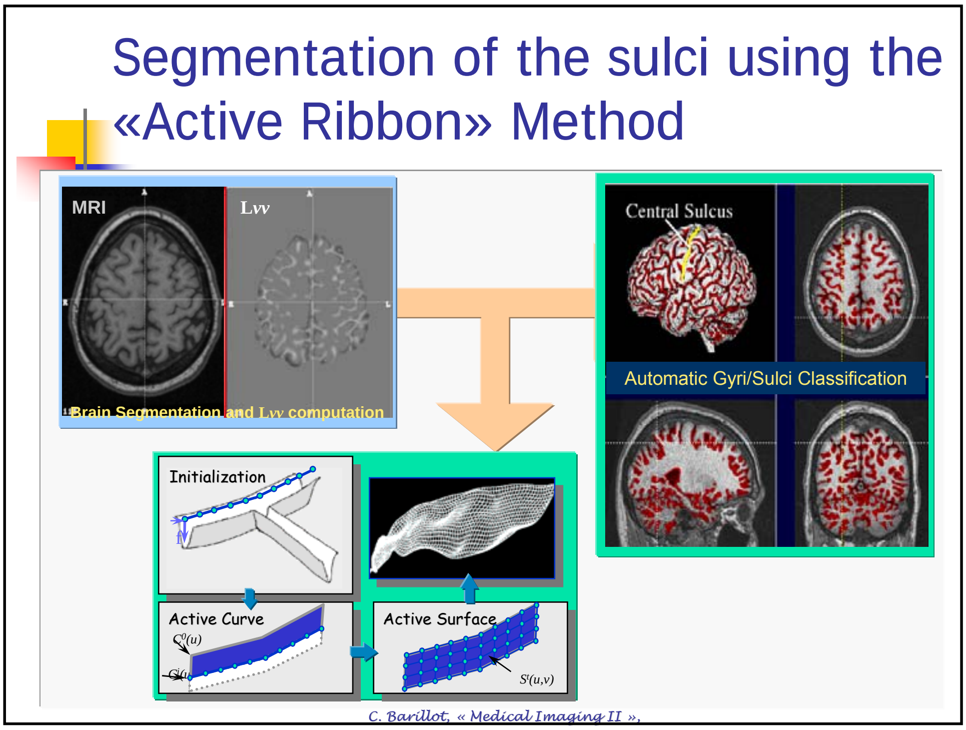
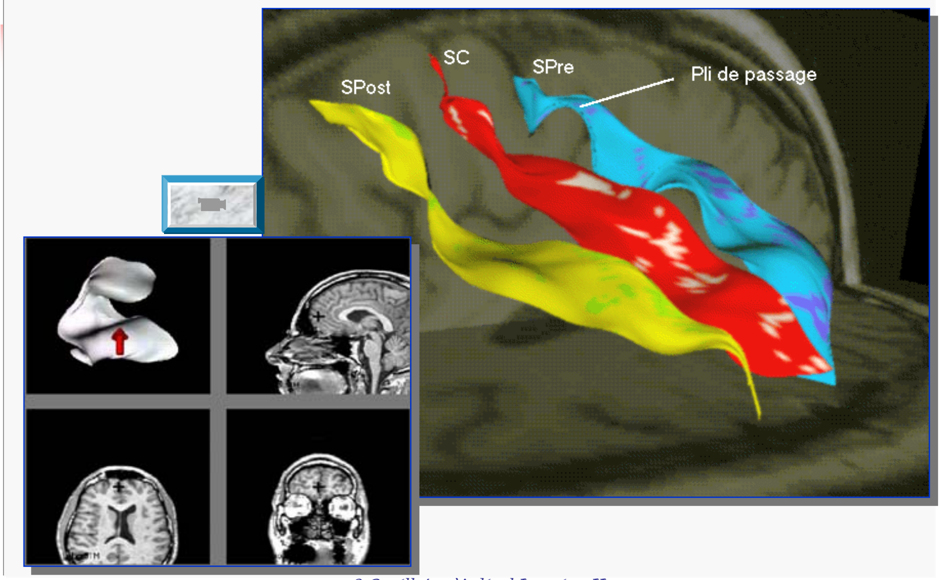

Probabilistic atlas based on local constraints
Inter-subjects registration of sparse data (MEG)
non-linear local registration
non-linear global registration
Cortical Sulci
local referential
Statistical Shape Analysis
Analysis
Synthesis
principal Mode of deformation of the right central sulcus
Modal Analysis
Ex. 29 subjects
Registration and matching
Constraints on TPS
C. Barillot, « Medical Imaging II »,


Segmentation of the sulci using the «Active Ribbon» Method
MRI
Lvv
Brain Segmentation and Lvv computation
Central Sulcus
Automatic Gyri/Sulci Classification
Initialization
Active Curve
Active Surface
C. Barillot, « Medical Imaging II »,

Extraction of the local features



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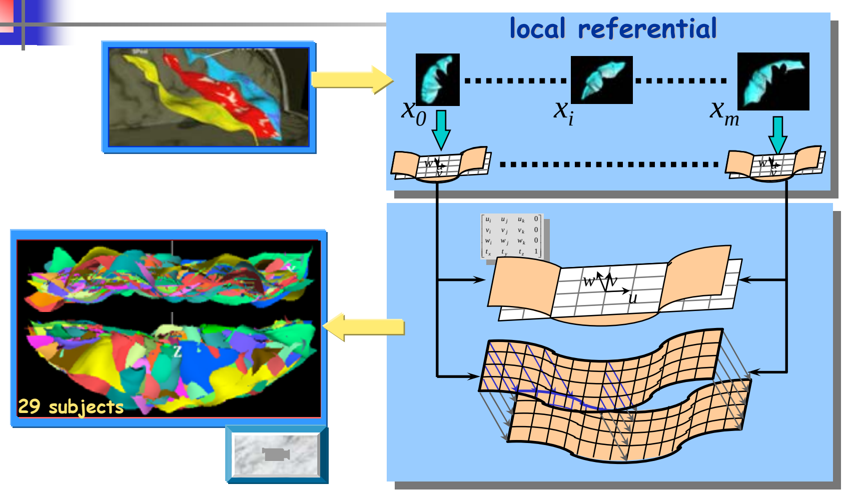
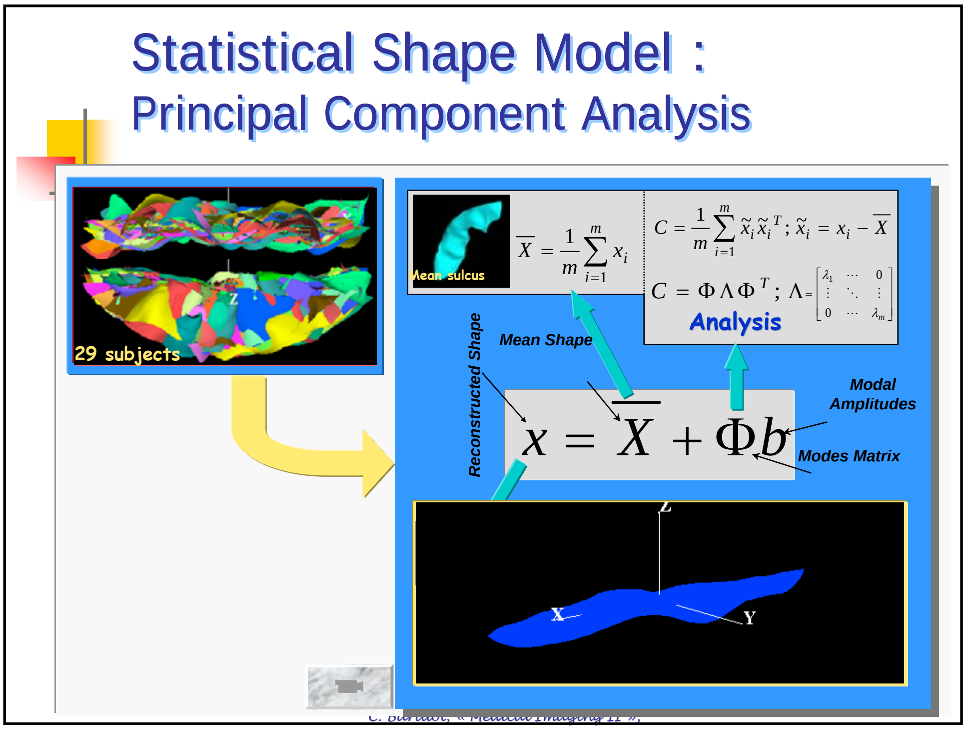
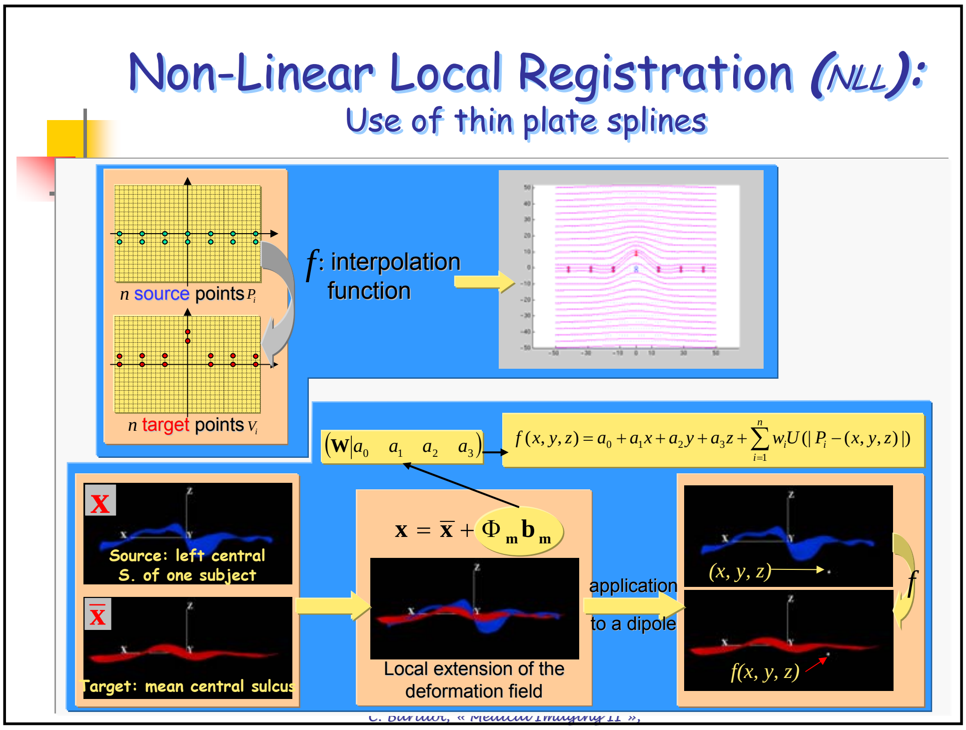
Linear Local Registration (*LR*)



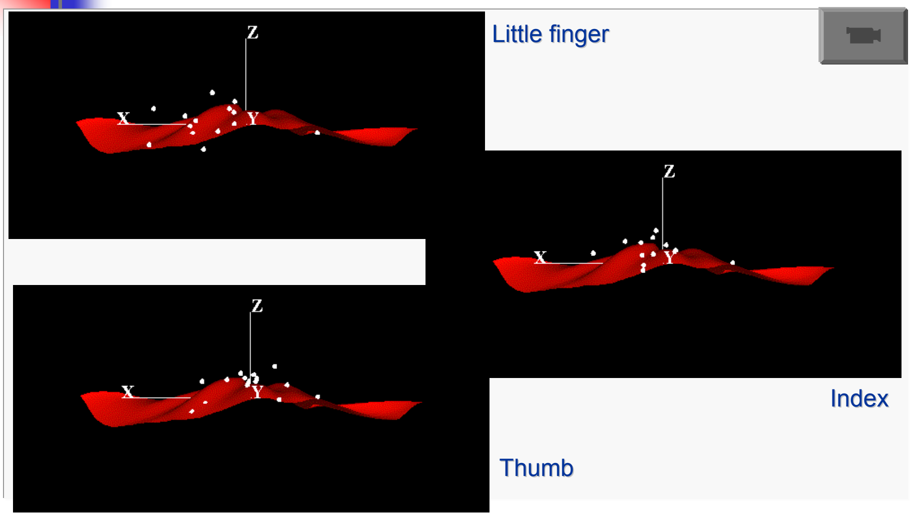
C. Barillot, « Medical Imaging II »,





Christian BARILLOT, Visages U746
INSERM/INRIA, IRISA, Rennes, France

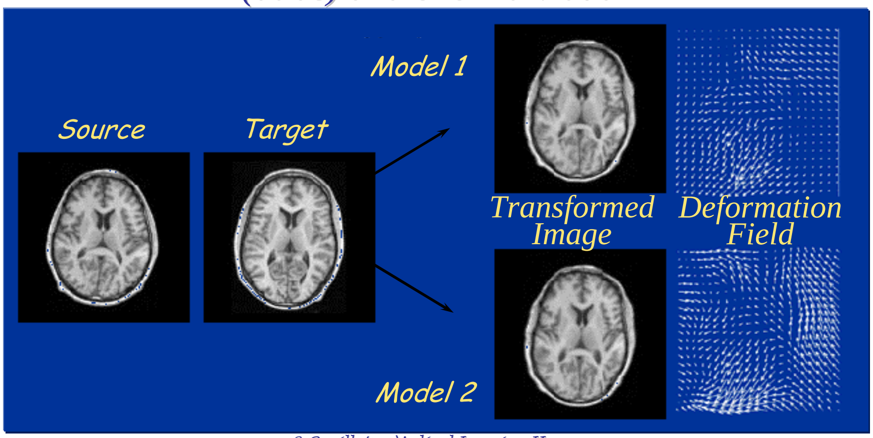
Somatotopy around the principal mode using the non-linear local method (NLL)



C. Barillot, « Medical Imaging II »,

Deformable Registration: Global, iconic or photometric methods

Find a the transformation between one reference (atlas) and one individual



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Adaptive Non Rigid Registration:

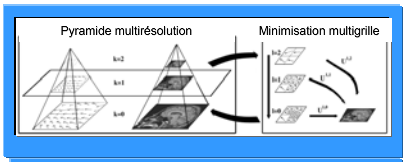
Using optical flow and robust estimators (RoMEO©)

- General formulation (optical flow estimation):

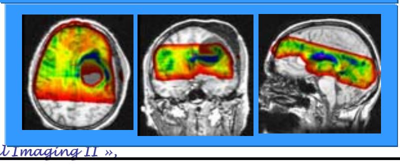
$$U(\omega; f)=\sum_{s\in S}\left[\nabla f(s,t)\cdot\omega_s + f_t(s,t)\right]^2 + \alpha \sum_{\langle s,r\rangle\in C}\left\|\omega_s-\omega_r\right\|^2$$

- Robust estimation of the deformation field :
  - ⇨ Reduce the sensitivity to noise and preserve the deformation discontinuities: $U(\omega,\delta,\beta; f)=\sum_{s\in S}\delta_s\left(\nabla f(s,t)\cdot\omega_s + f_t(s,t)\right)^2 + \varphi_1(\delta_s) + \alpha\sum_{\langle s,r\rangle\in C}\beta_{sr}\left\|\omega_s-\omega_r\right\|^2 + \varphi_2(\beta_{sr})$

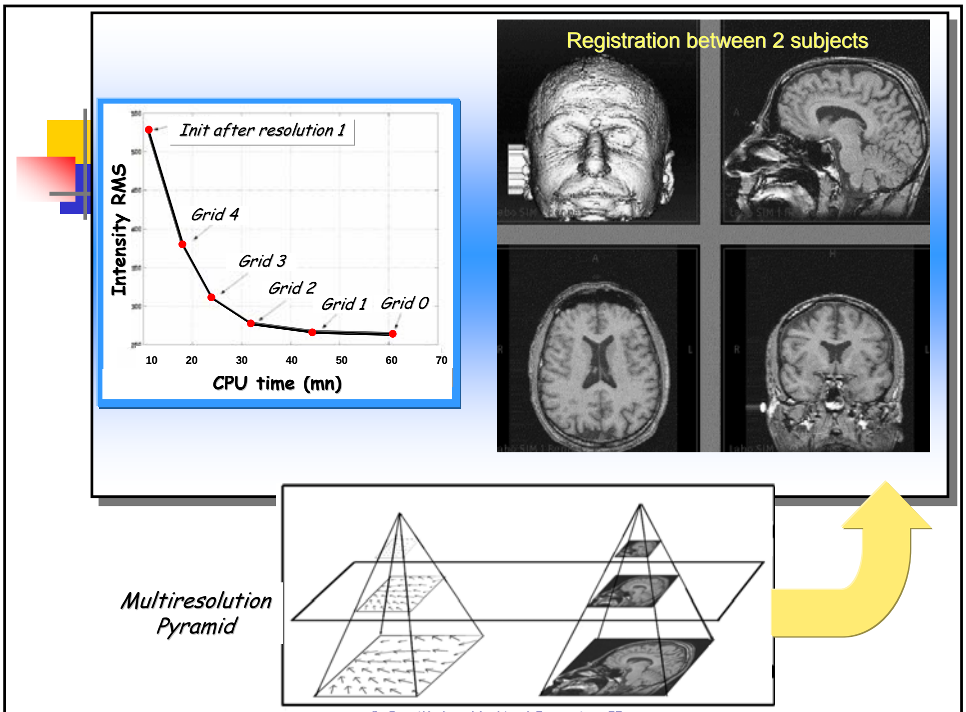
- Adaptative multigrid algorithm:



⇨ Extensible to other similarity functions (e.g. fMRI registration):

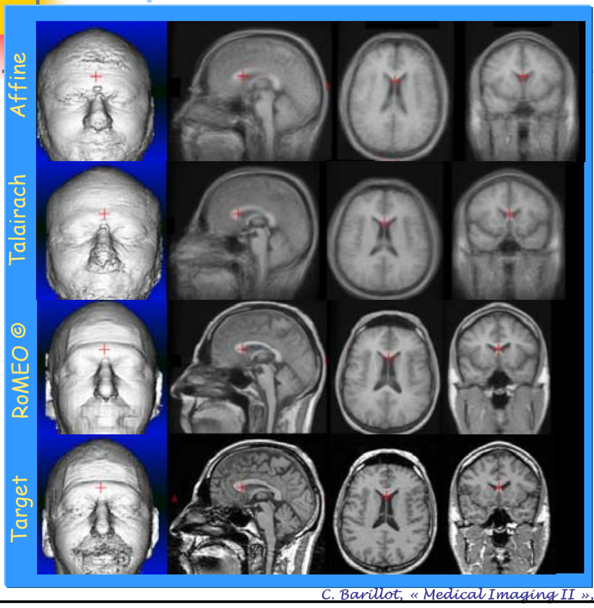


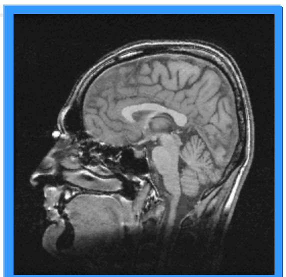
C. Barillot, « Medical Imaging II »,



C. Barillot, « Medical Imaging II »,

Deformable Registration : Spatial Normalization





Averaging of 18 subjects

C. Barillot, « Medical Imaging II »,

Hybrid Approach

Hybrid approach:
Cooperation between local and global approaches

- Global, or “photometric” method:
  - Image registration based on image information
  - Provides a dense deformation field
- Local, or “geometric” method:
  - Rely on landmarks (points, surfaces, ...)
  - Use an interpolation function (e.g. TPS)

Cooperative approach, where geometric and photometric information are combined into the same framework

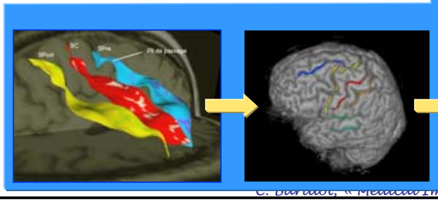
C. Barillot, « Medical Imaging II »,

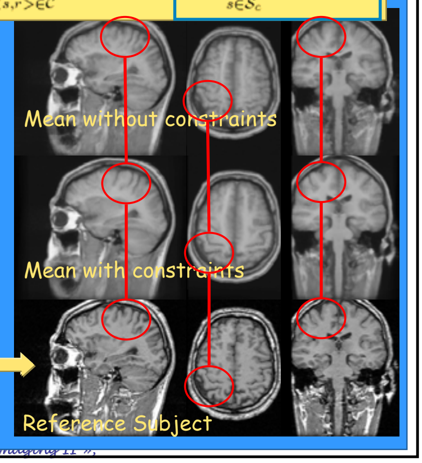
Hybrid deformable registration :
Introduction of sparse constraints (JULIET©)

- Use of global constraints (e.g. optical flow) :

$$U(w; f, w^c) = \sum_{s\in S}[\nabla f(s,t)\cdot w_s + f_t(s,t)]^2 + \alpha \sum_{<s,r>\in C} ||w_s - w_r||^2 + \alpha^c \sum_{s\in S_c} ||w_s - w_s^c||^2$$

- Matching of homologous structures (e.g. sulci)
- Taking into account possible interruptions between sulci





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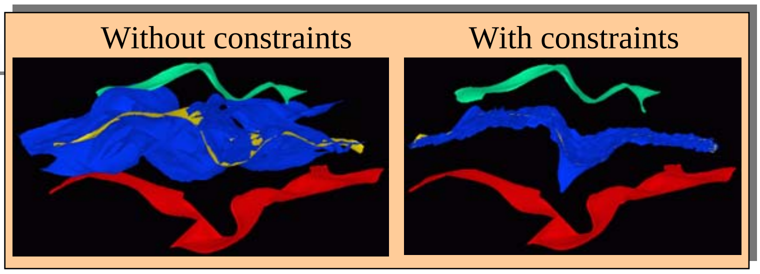
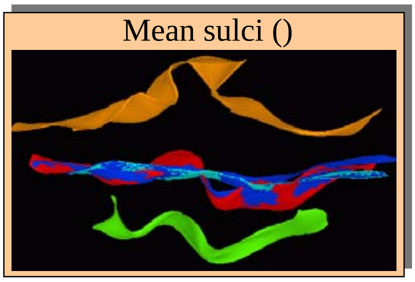
Deformed central sulci (from 18 subjects)





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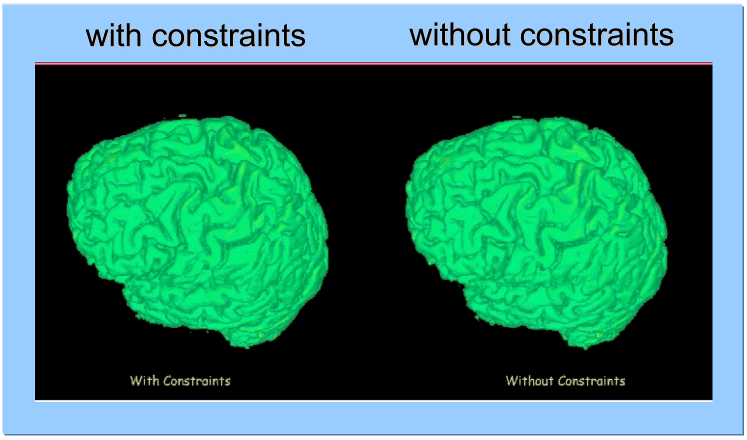
Visualization of the cortical deformation



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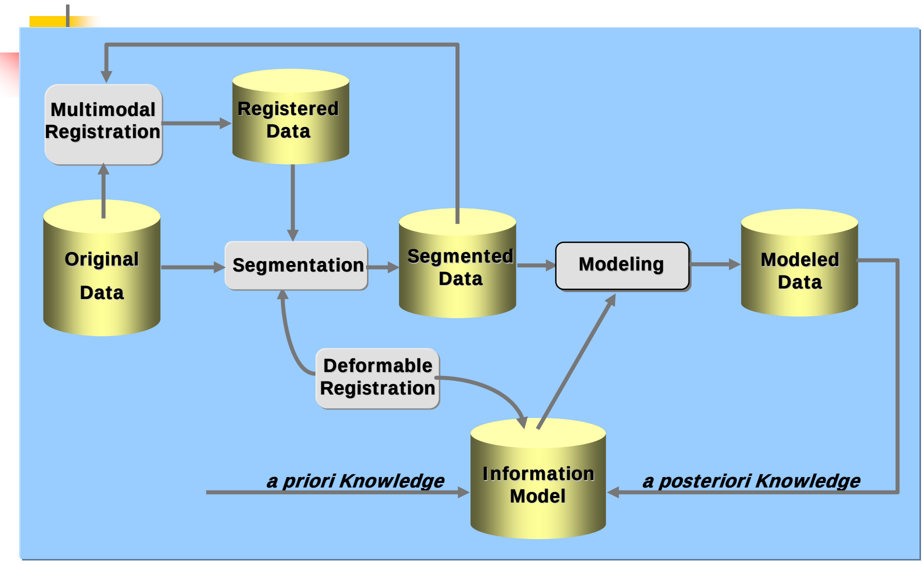
Cooperation between Segmentation and Registration Tasks

Cooperative scheme for Data Fusion



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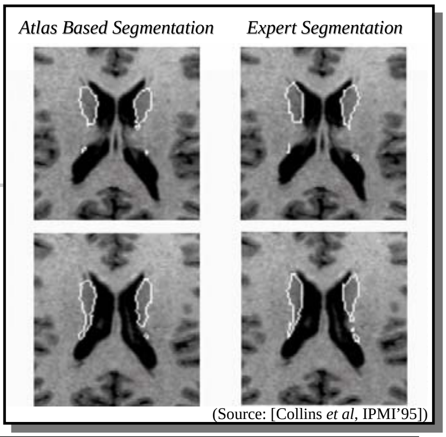
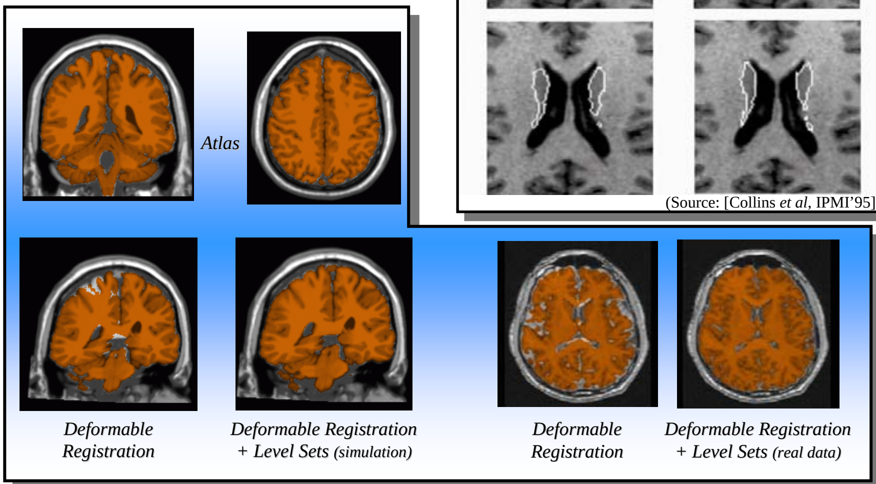
Deformable Registration and Segmentation

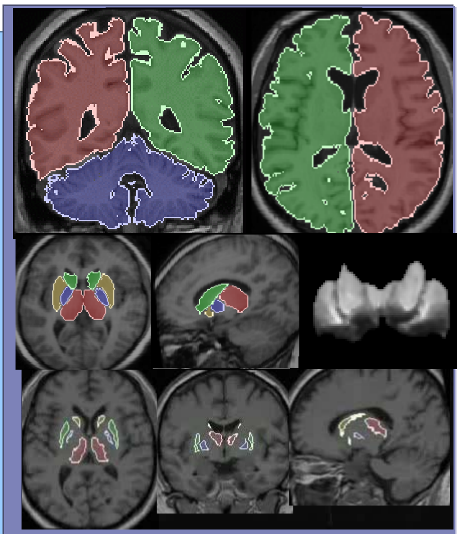




C. Barillot, « Medical Imaging II »,

Model-Guided Segmentation and Labeling: Integration of fuzzy control and level sets*

- Objective : Segmentation of brain structures close, with similar intensities and hardly defined contours
- Method :
  - Statistical analysis of shape and localization of structures
  - Concurrent evolution of several level sets
- Contribution :
  - Integration of fuzzy control to constrain the competitive evolution of level sets
  - Utilization of a statistical shape models to define the fuzzy control variables



*: C. Ciofolo, C. Barillot, IPMI 2005, ECCV 2006

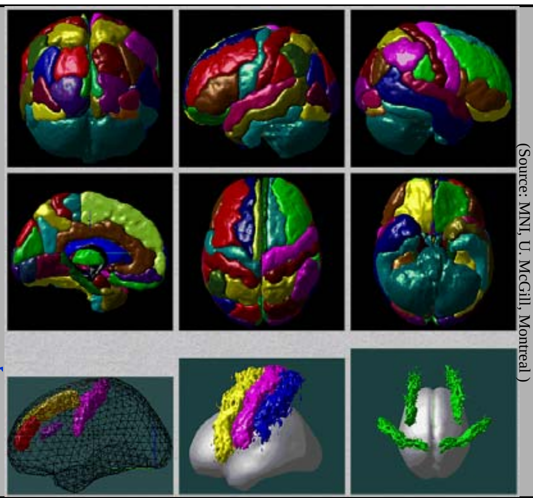
C. Barillot, « Medical Imaging II »,

05/09/2007 90

Deformable Registration: Study of the Anatomical Variability

Probabilities of cortical labels
(max proba)

Probabilities for Sulci Occurrence
(> 10%)



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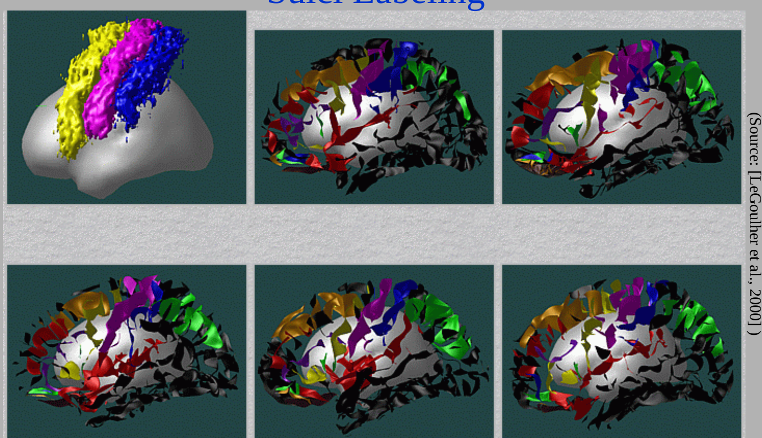
Deformable Registration: Labelling from atlas

Sulci Labeling



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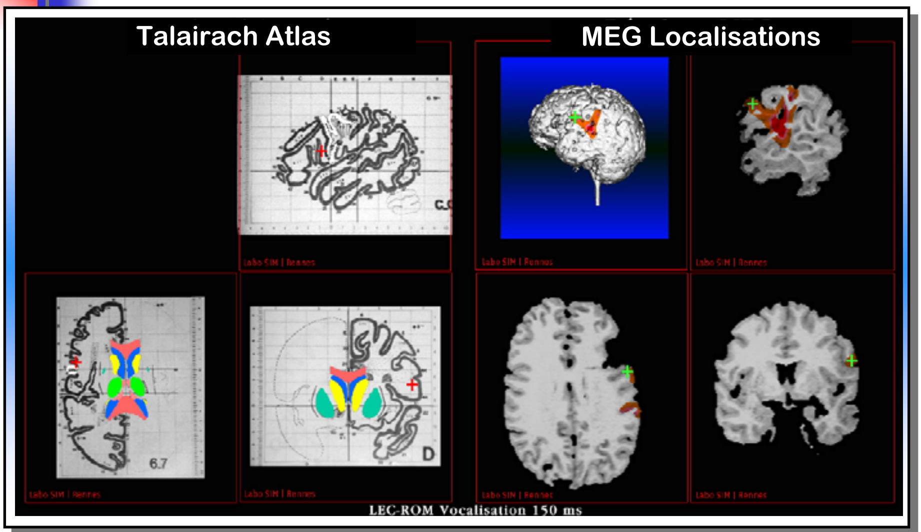
Data Fusion of Anatomical and Functional Brain Images

Deformable Registration for Anatomo-Functional Imaging



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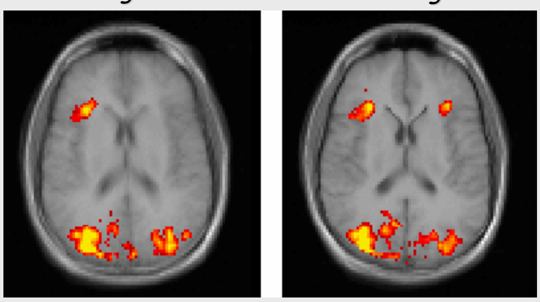
Spatial Normalization for the Analysis of Functional Data

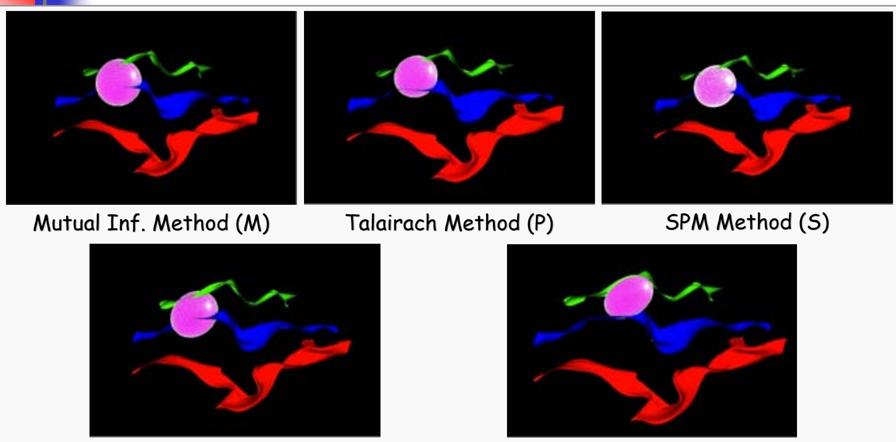
Example of comparison of average activation responses



Illustrations courtesy from J.C. Gee, GRASP Lab., Univ. of Pennsylvania

C. Barillot, « Medical Imaging II »,

Mapping of the somatotopy using global and hybrid deformable registration methods



Gaussian Ellipsoid at 3σ for 15 subjects

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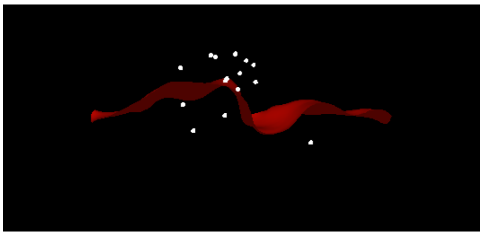
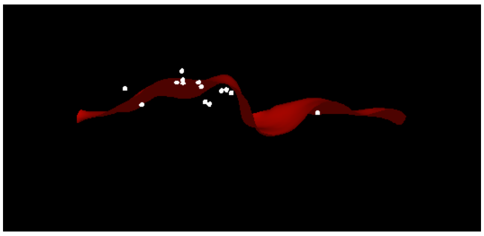
Comparative Somatotopy : local method *vs* hybrid method

Juliet
(hybrid deformable registration method)



Non-Linear Local deformable registration method



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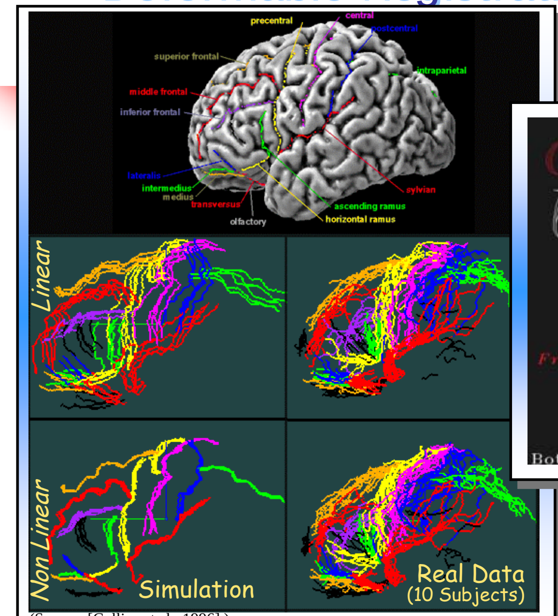
Deformable Registration : Limits

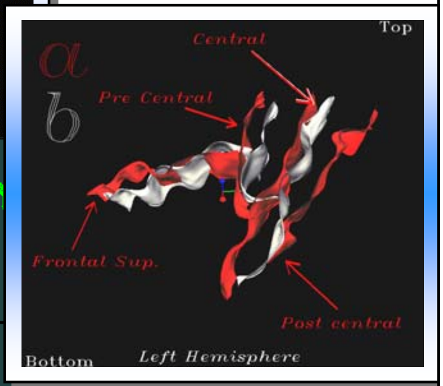
- In General
  - Validation/Generality of methods
- Segmentation/Labeling
  - Labeling of highly variable structures (e.g. marginal cortical sulci)
- Atlas matching methods using global/intensity-based methods
  - Barely efficient on cortical anatomy
  - Template dependent (unless diffeomorphism)
  - Not yet real-time (Towards GPU implementation)

C. Barillot, « Medical Imaging II »,

Deformable Registration: Limits



(Source: [Collins et al., 1996])



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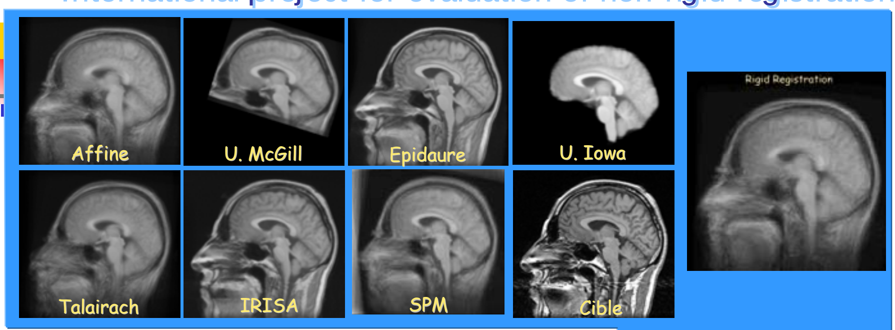
Deformable Registration:

International project for evaluation of non-rigid registration



- Aim of the study
  - Anatomical and functional validity of the registration
  - On the same corpus (18 subjects)
- Others Participants:
  - U. McGill (L. Collins), Epidaure Project INRIA, U. Iowa, (G. Christensen), SPM, (J. Ashburner)
- Criteria
  - Anatomically meaningful
  - Local and global measures
  - Not related to the similarity used to perform the registration

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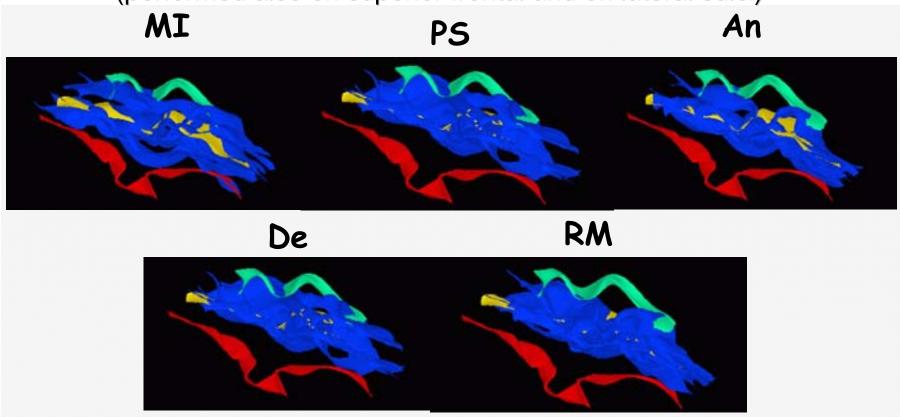
Local Criteria on sulcal matching (highly variable)

- Use of cortical sulci (anatomical and functional landmarks)
- Visualization of overlapping deformed left central sulci (performed also on superior frontal and on lateral sulci)



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Perspectives

Data Fusion and Registration Perspectives

- Needs to take into account local and global constraints in the deformable registration process (hybrid registration)
- More concerns about the clinical practice
  - pre-surgical mapping
  - intra-operative and real time imaging
  - Cope with missing tissues (registration of dissipative material)
- Introduction of statistical information for the guidance of the deformation
- Tighter links between registration and segmentation thru joint observation models and numerical optimization schemes (e.g. active shape formulation)

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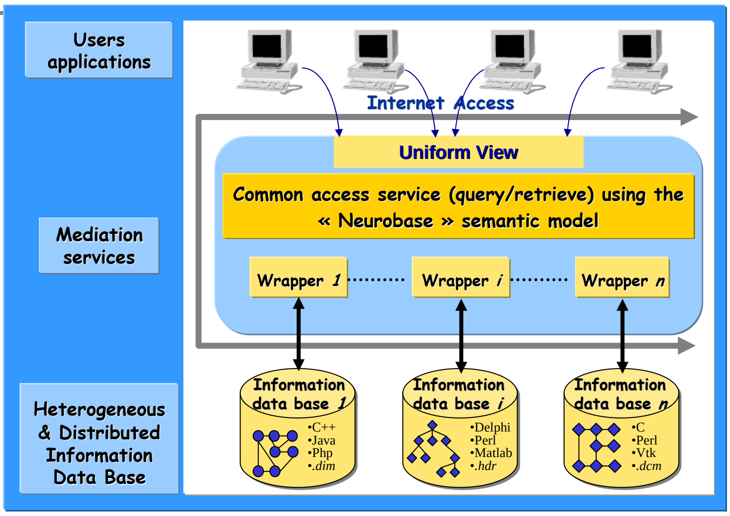
Towards virtualization of medical imaging resources:

Share heterogeneous and distributed data and image processing tools



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Sharing of medical imaging resources: Main Issues

- Objectives:
  - Follow the growth of the communication and exchange infrastructures (e.g. Internet)
  - Follow the emergence of "virtual" networks of users (e.g. clinical groups of research)
- Applications of information and grids technologies in health:
  - Creation of "virtual" cohorts
  - Research on the singular diseases (search for « unlikely facts »)
  - Validation / certification of new drugs
- Research Issues
  - Combine Grid Computing and Semantics Grids technologies in the field of medical imaging
  - Evolutive and adaptive workflows in Medical Imaging (user interactions, heterogeneity, ...)
  - Integrate the semantic web technologies into clinical research

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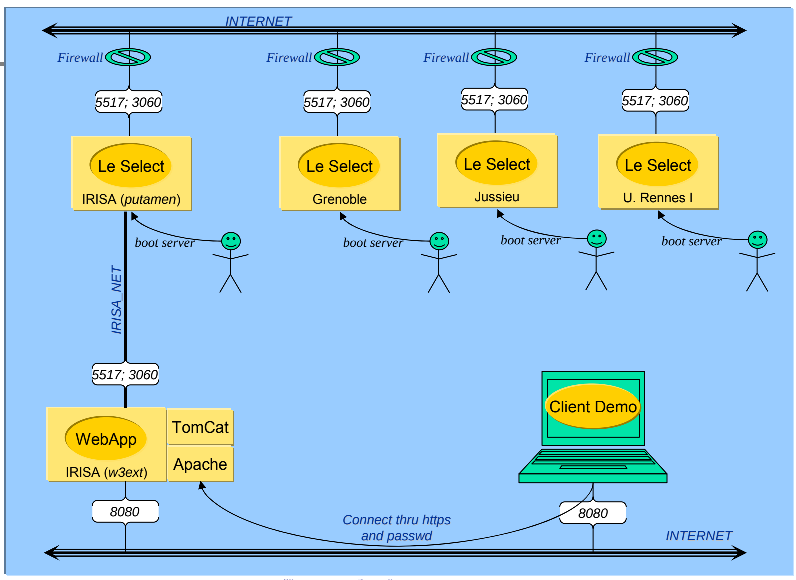
"Neurobase" Test Bed Architecture: Exploitation



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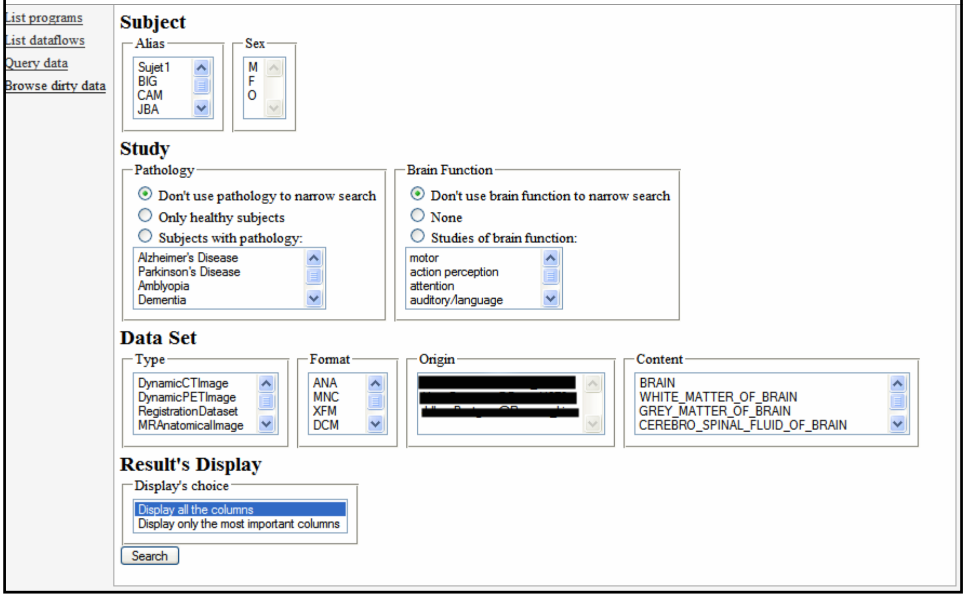
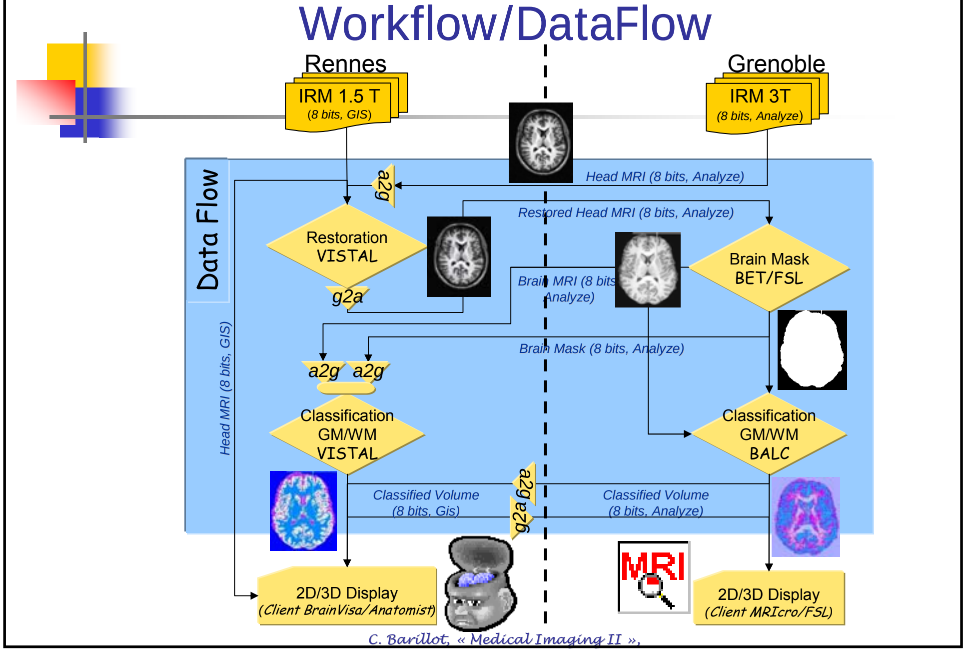
NeuroBase Web Application: Query

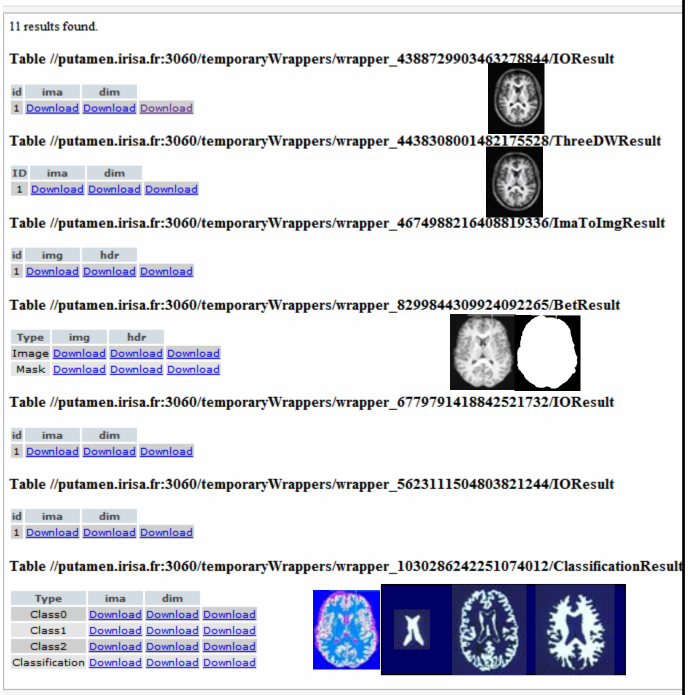


Heterogeneous and Distributed Workflow/DataFlow



NeuroBase WebApp:

Data Flow Results



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