Basic principles of MR image analysis

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Prof. Mooijaart, Dr. Rombouts and Dr. Crone (course organization)
Dr. Grol (course organization and help with the slides)

LKEB

Basic principles of MR image analysis

- Terminology of fMRI
- Brain extraction
- Registration
  - Linear registration
  - Non-linear registration

LKEB

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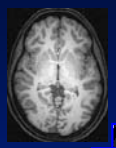
LKEB

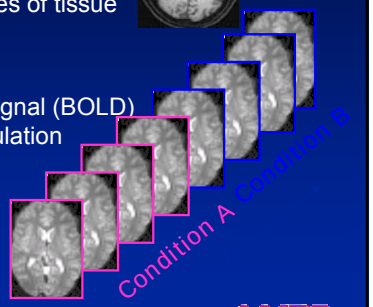
Terminology of fMRI

Structural (T1) images
- high resolution
- to distinguish different types of tissue



Functional (T2) images*
- lower spatial resolution
- to relate changes in MR signal (BOLD) to an experimental manipulation

Time series
A large number of images acquired in temporal order at a specific rate



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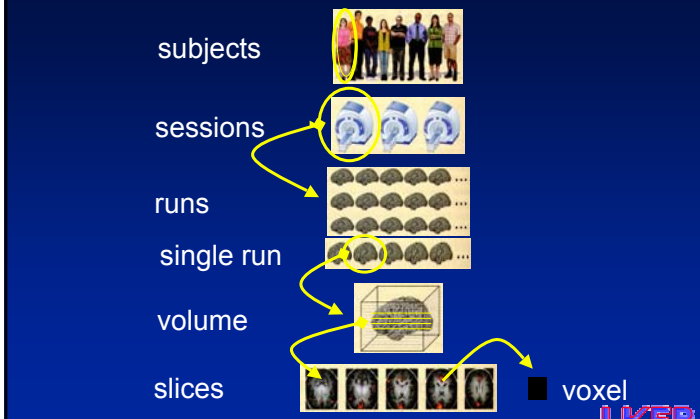
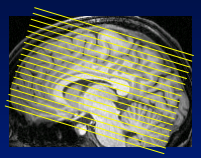
Terminology of fMRI

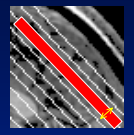


Terminology of fMRI

Volume:
Field of View
(FOV),
e.g. 192x192 mm

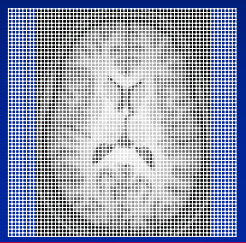


Axial slices

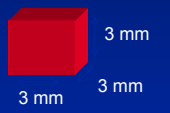


Slice thickness
e.g., 3 mm

Matrix Size
e.g., 64 x 64



In-plane resolution
192 mm / 64
= 3 mm



Voxel Size
(volumetric pixel)

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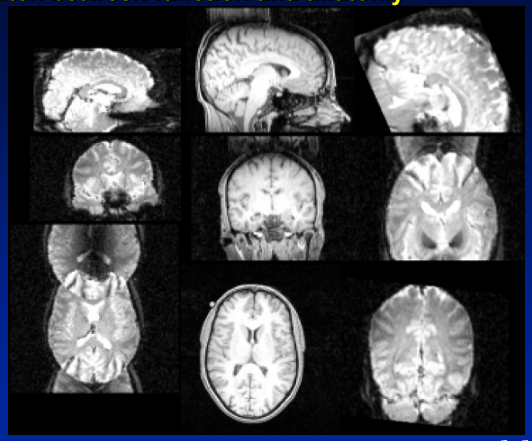
- Registration
  - Linear registration
  - Non-linear registration

Brain extraction: Why?

- Surrounding tissues and acquisition artefacts can hamper subsequent data processing
- Structural images present most type of tissues
- Functional image present little non-brain tissue

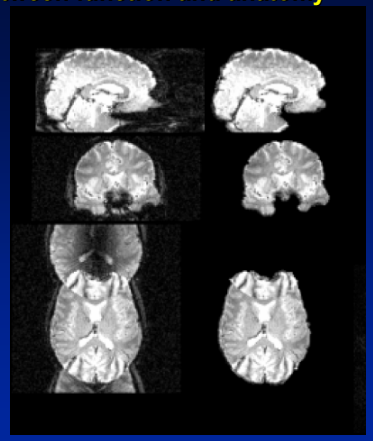
→ **High chance of mismatch between function and anatomy**

Mismatch between function and anatomy

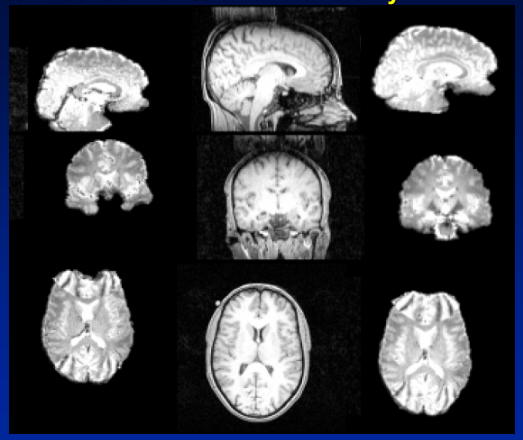


Jenkinson and Smith, *Medical Image Analysis*, 2001

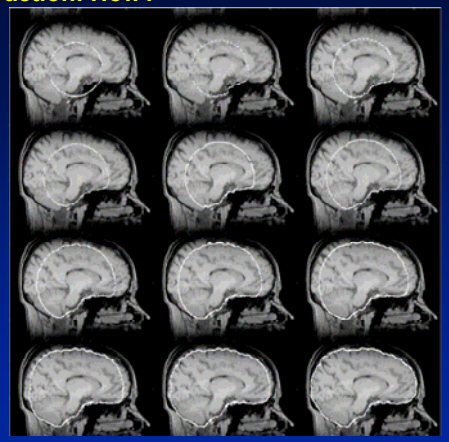
Mismatch between function and anatomy



Mismatch between function and anatomy



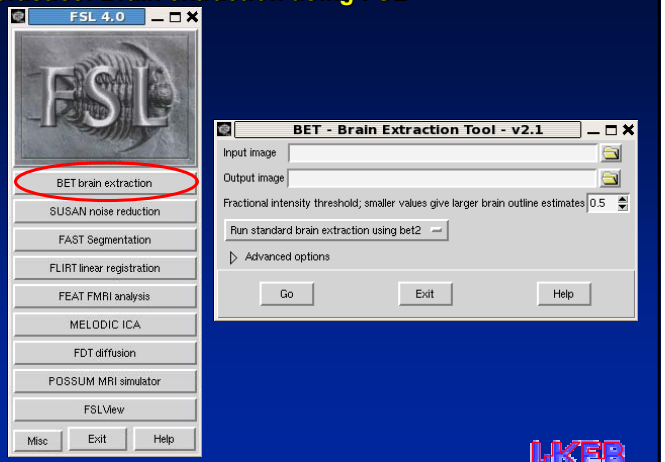
Brain extraction: How?



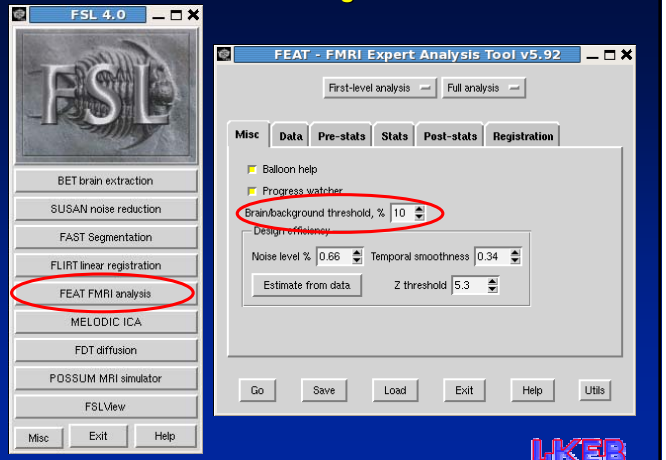
Brain extraction

- Pre-process structural data (with BET)
- Process functional data (included in FEAT and MELODIC)
- Always double-check your results!

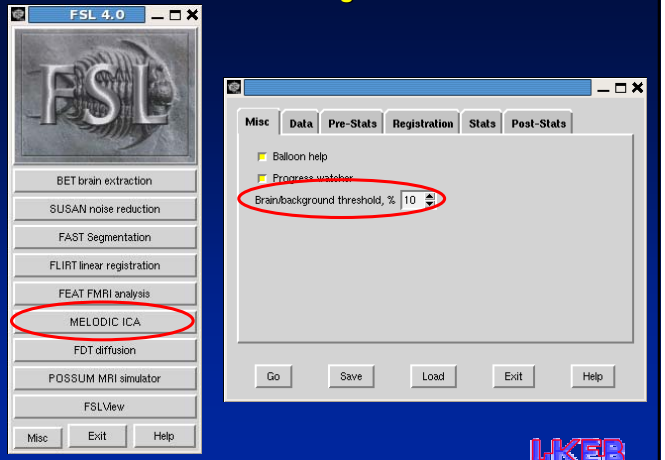
In practice: Brain extraction using FSL



In practice: Brain extraction using FSL



In practice: Brain extraction using FSL



Basic principles of MR image analysis

- Terminology of fMRI
- Brain extraction
- Registration (re-alignement)
  - Linear registration
  - Non-linear registration

Image registration: Why?

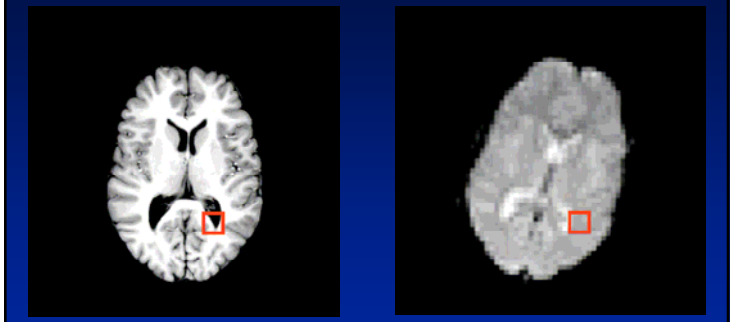
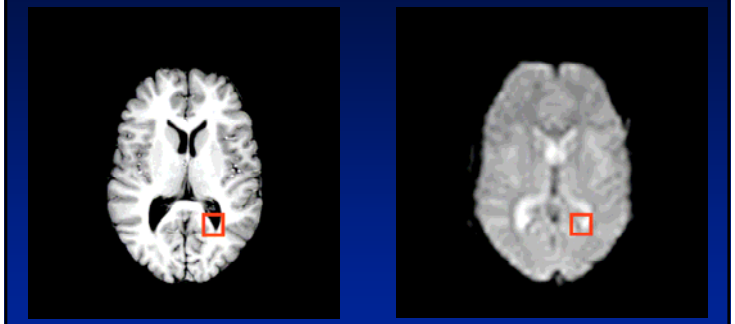


Image registration: Why?



Registration uses

- Single-subject studies:
  - Compensate for movement of the subject during an acquisition
  - Compensate for displacement of the head in follow-up studies
- Group studies:
  - Compensate inter-subject anatomical differences

Registration uses

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Linear registration

- Group studies:
  - Compensate inter-subject anatomical differences

Registration uses

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- Group studies:
  - Compensate inter-subject anatomical differences

Non-linear registration

During an acquisition, prevention is the best medicine

- Always constrain the subject's head
- Instruct him/her to remain as calm as possible and to talk and swallow as little as possible
- Do not scan for too long – everybody moves after a while

Post-acquisition motion correction: Linear registration

- Assumes that all movements are those of a rigid body, i.e. the shape of the brain does not change
- Registration optimises a number of parameters that describe a transformation between the source and a reference image
  - How to measure the goodness of fit?
  - What transformation to use?
- Resampling consists in applying the estimated transformation

Registration: Evaluating goodness of fit

Different measures can be used:

- Sum of squared differences:
  - If the two images are aligned, their difference is (close to) zero
    - Similar spatial representation of the anatomical structures
    - Similar contrast needed
  - Ex: MRI with T1 contrast vs MRI with T1 contrast
- Correlation:
  - If the two images are aligned, their spatial variations are similar
    - Similar spatial representation of the anatomical structure
  - Ex: MRI with T1 contrast vs MRI with T2* contrast
- Mutual information:
  - If the two images are aligned, their joint p.d.f. is well localized
    - No need for similar spatial representation or contrast
  - Ex: MRI with PET/CT

3D linear transformations available in FSL

- Translation only (3 parameters)
- Rigid body (6 parameters)
- Global rescale (7 parameters)
- Traditional (9 parameters)
- Affine (12 parameters)

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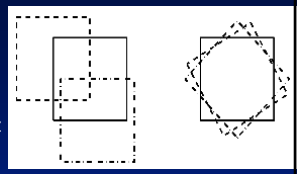
Rigid body

Possible object movement:
Translations
Rotations (around the origin)

In 2 dimensions, translations and rotations:
$x_1 = \cos(\theta)\, x_0 + \sin(\theta)\, y_0 + t_x$
$y_1 = -\sin(\theta)\, x_0 + \cos(\theta)\, y_0 + t_y$



In 3 dimensions:
Translations by t_x, t_y and t_z
Rotations by θ, Φ and Ω

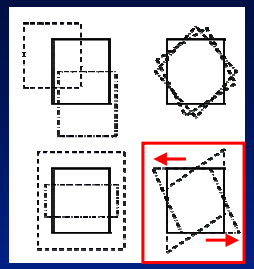
6 parameters: t_x, t_y, t_z and θ, Φ, Ω

Used for intra-subject registration

Affine

Possible object movement:
Translations
Rotations (around the origin)
Scalings (zooms)
Shears

In 2 dimensions, shear is defined by:
$x_1 = x_0 + h_y.y_0$
$y_1 = y_0$



Affine

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In 2 dimensions, shear is defined by:
$x_1 = x_0 + h_x.y_0$
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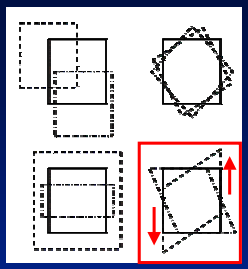
Or

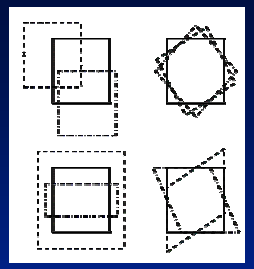
$x_1 = x_0$
$y_1 = h_y.x_0 + y_0$



Affine

Possible object movement:
Translations
Rotations (around the origin)
Scalings (zooms)
Shears

In 3 dimensions:
Translations by t_x, t_y and t_z
Rotations by θ, Φ and Ω
Scaling by s_x, s_y and s_z
Shears by h_x, h_y and h_z



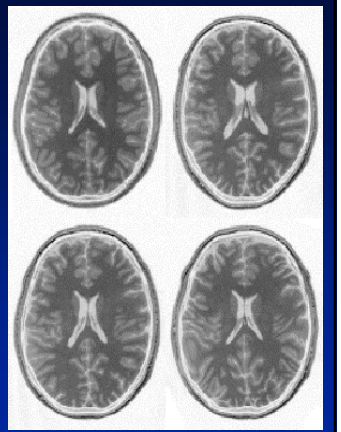
12 parameters: t_x, t_y, t_z, θ, Φ, Ω, s_x, s_y, s_z and h_x, h_y, h_z

Used as a first step in normalisation

Non-linear registration

- More than 12 parameters
- Can be purely local
- Based on different constraints
  - Piecewise rigid
  - Basis functions (spline, etc)
  - Fluid

Used for inter-subject registration
Second step of normalisation



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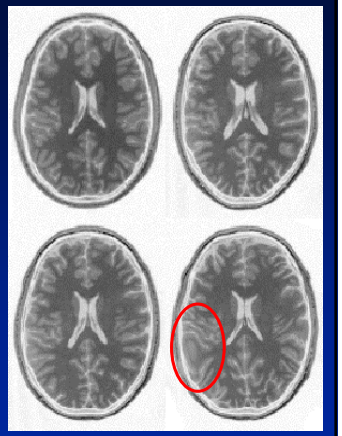
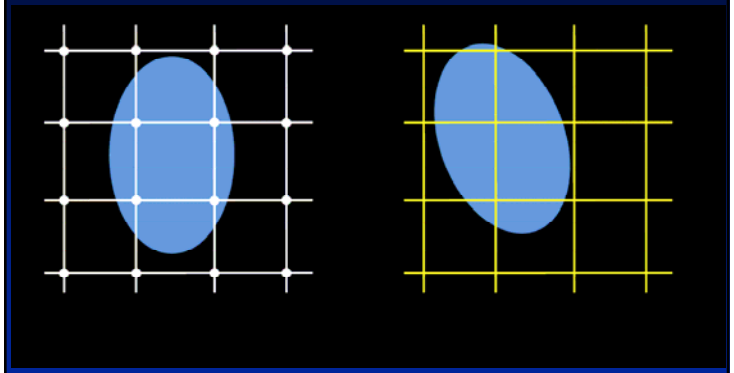


Used for inter-subject registration
Second step of normalisation
Less robust than linear registration

LKEB

Interpolation



LKEB

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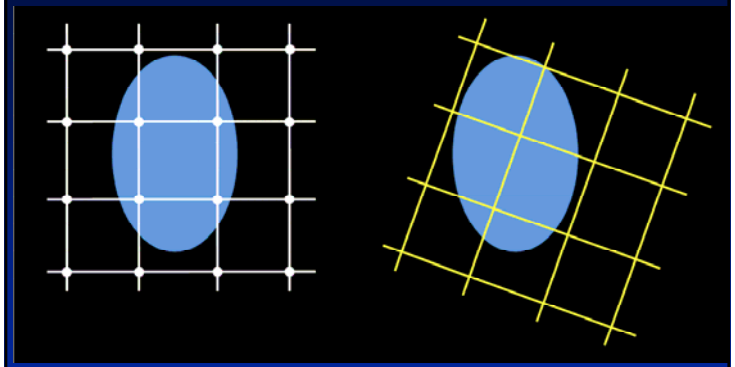

LKEB

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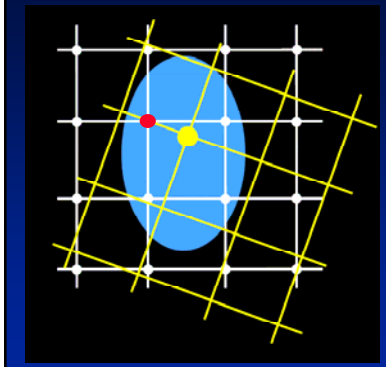
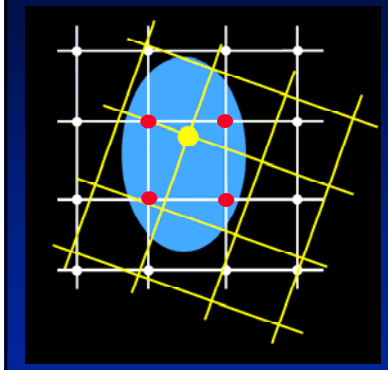


Various types of interpolation:

- Local
  - Nearest neighbour
  - Trilinear
- Global
  - Sinc
  - Spline
  - Fourier-based

LKEB

Interpolation



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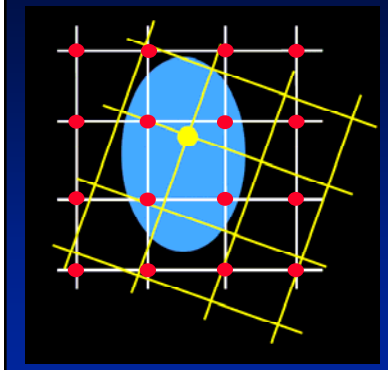

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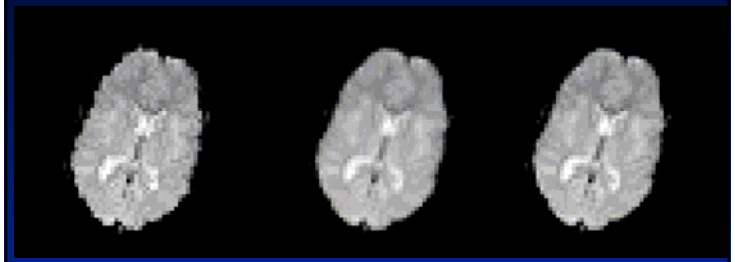

Various types of interpolation

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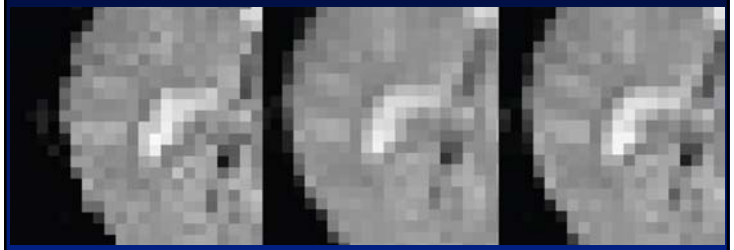
Various results

Interpolation



Various types of interpolation

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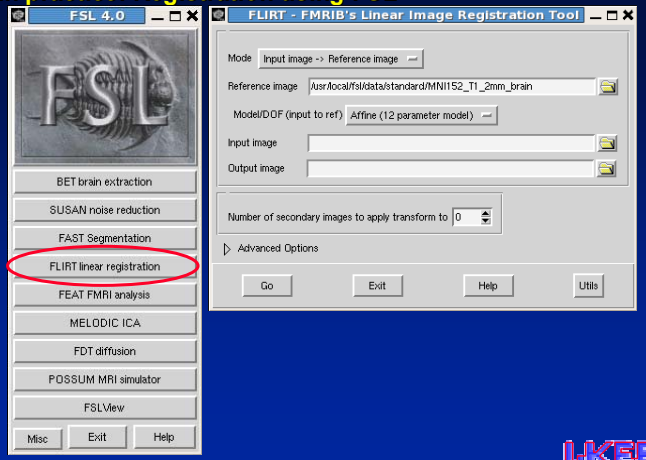
Various results

Registration

- Registration implies in the choice of
  - A similarity measure
  - A type of transformation
- Intra-subject registration:
  - Rigid body (6 parameters) transform
- Inter-subject registration:
  - 1st step: affine transform
  - 2nd step: non-linear registration
- Double-check the registration results!

In practice: Registration using FSL



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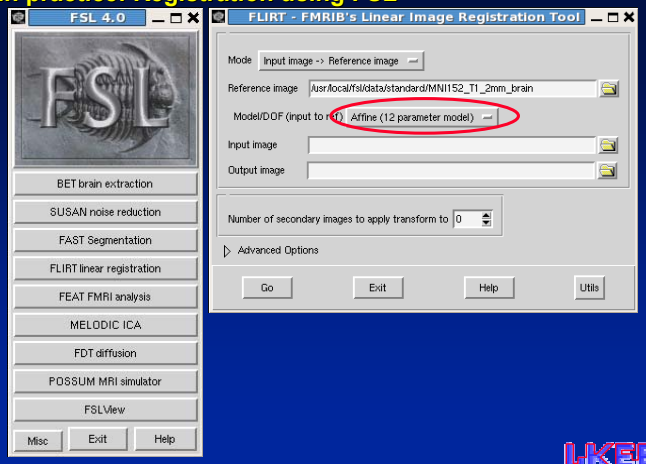

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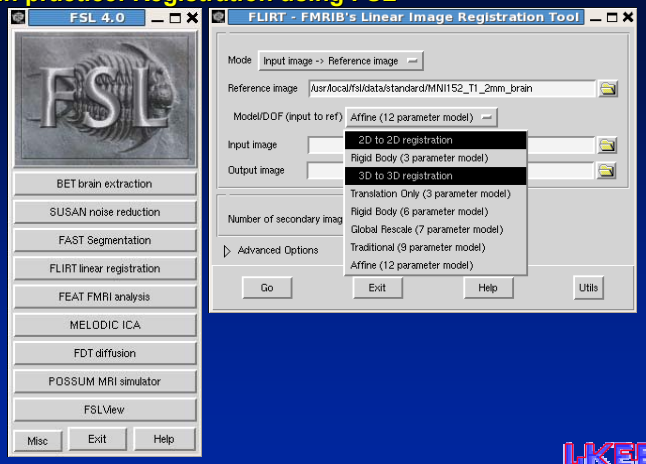

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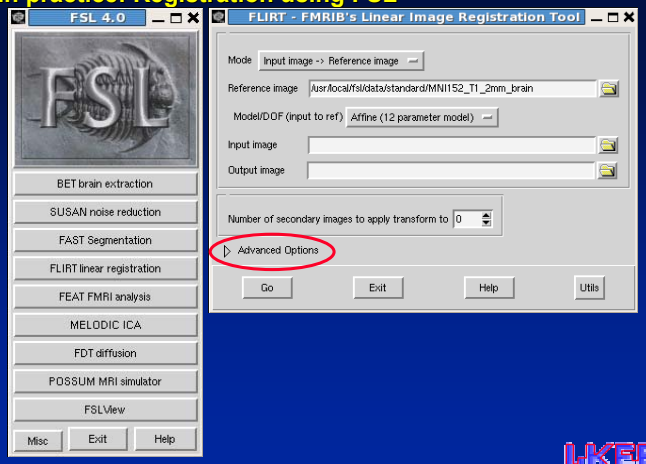

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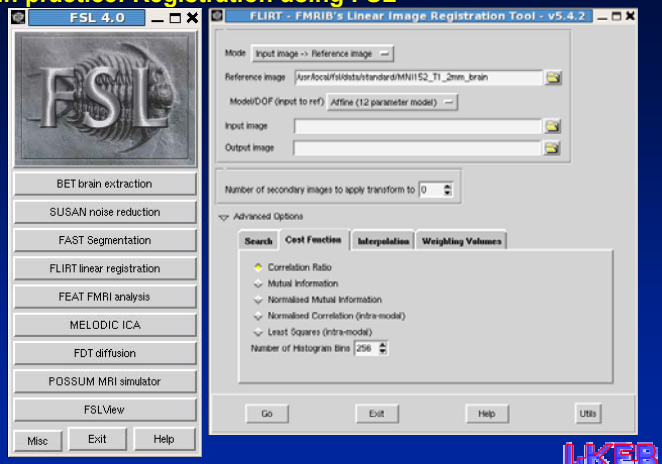

Thank you for your attention

Questions?