NeuroImaging Training Program

Data Preprocessing

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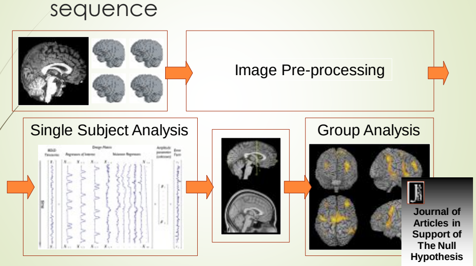
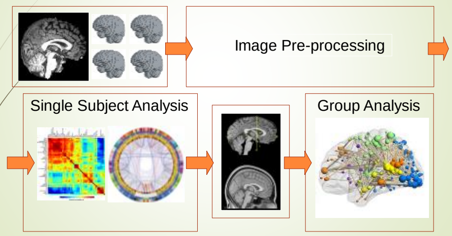
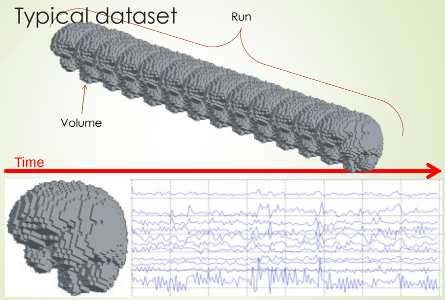
Typical (task-based) fMRI analysis sequence



Typical (task-free) fMRI analysis sequence



Typical dataset



Preprocessing: what/why?

Preprocessing is a series of data transformations ("data conditioning") aimed at reducing sources of noise

In task-based analyses the preprocessing filters applied to the data (and their order) are somewhat standardized (though still not trivial).

In task-free analyses which step to apply and in what order is much less clear.

Sources of noise in fMRI

- 1. Hardware & acquisition related:
  - Thermal noise (intrinsic noise)
  - System noise
  - Slice acquisition timing
- 2. Subject related
  - Oscillatory physiological noise (heartbeat, respiration)
  - Field inhomogeneities
  - Head motion
  - Psychological (alertness, learning)
- 3. White noise

Correcting for noise in fMRI

- Before scanning (maximize SNR):
  - Choose good technology (field strength, coils, ...)
  - Choose good sequence (TE, voxel size, ...)
  - Be informed about the health of your scanner (QA)
- After scanning (detect & correct):
  - Look at your data (i.e., data quality check)
  - Look at your data (again and again)
  - Pre-processing ("standard", ICA)
  - Re-look at your data

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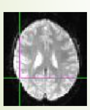
Preprocessing: what/why?

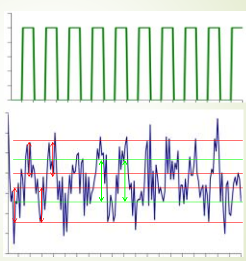
Preprocessing is a series of data transformations (“data conditioning”) aimed at reducing sources of noise

1. Increase sensitivity of the analysis (SNR)
2. ”Ensuring” the validity of the statistical model

Sample Experiment: SNR

TR = 2s
Vols = 160
10 AB Cycles
Cycle = 8A + 8B





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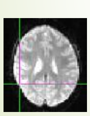

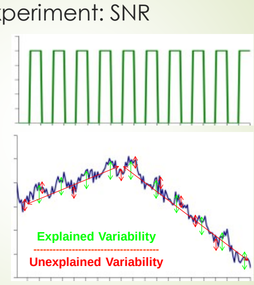

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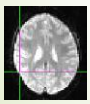

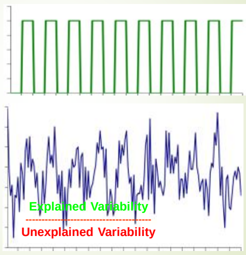

The General Linear Model (GLM)

$$y = X \times \beta + \varepsilon$$

fMRI Signal		Design Matrix		Parameter		Residuals
"our data"	=	*"what we CAN explain"*	×	*"how much of it we CAN explain"*	+	*"what we CANNOT explain"*

Preprocessing*

i. Slice timing correction
ii. Motion correction
iii. Spatial filtering
iv. Temporal filtering
v. Intensity normalization
vi. (Brain extraction)
vii. (Transformation to a reference space)

*Order for a typical ***task based*** analysis

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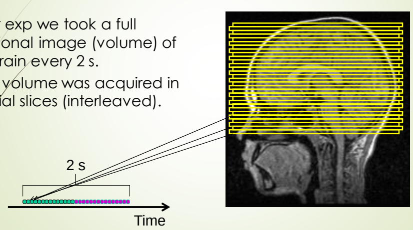
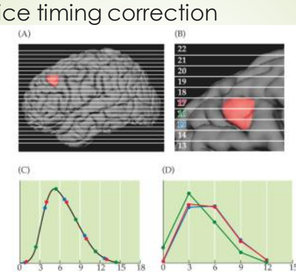
Slice timing correction

In our exp we took a full functional image (volume) of the brain every 2 s.

Each volume was acquired in 30 axial slices (interleaved).



Slice timing correction

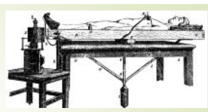


Huettel et al. Functional Magnetic Resonancel Imaging

Slice timing correction

- In task-based analyses most people **do not** do it
  - (-) Not that helpful (though might depend on experimental design) and requires interpolation of data
  - (-) May worsen artifacts (e.g., smearing spikes)
  - (-) Can interact unpredictably with motion correction
  - (+) Spatial smoothing attenuates in part the effect (depending on the acquisition order)
  - (+) Mismatch between TR and task attenuates the issue (according to how well the task 'samples' the spectrum of slices)
  - (+) The temporal derivative of task regressors HRF is usually included in design matrices
- In task-free analyses most people **do** it

Preprocessing*



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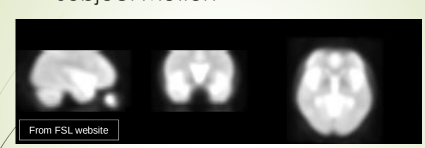
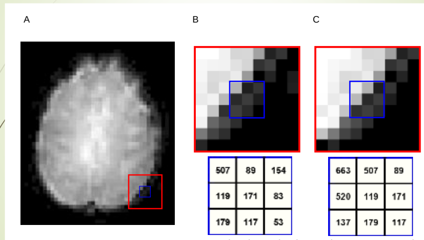
Subject Motion



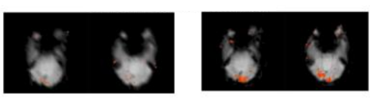
Motion within a time-series can have several unwanted consequences:
- Motion can produce signal changes of a greater magnitude than the BOLD signal
- Lose the correspondence between a voxel and anatomical location

Subject Motion



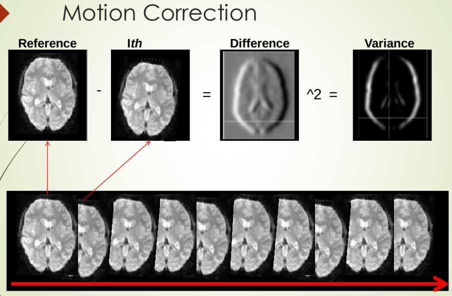
Huettel et al. Functional Magnetic Resonancel Imaging

Effect of Motion Correction

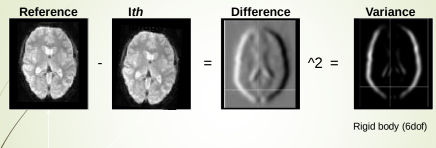


Without MC   With MC

Motion Correction



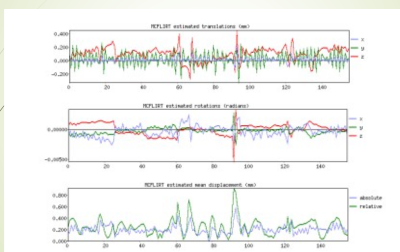
Motion Correction



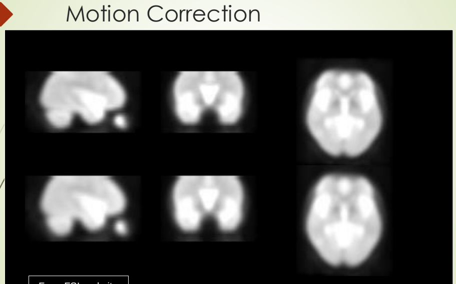
Rigid body transformations parameterised by:

$$
\underset{\text{Translations}}{\begin{pmatrix} 1 & 0 & 0 & X_{trans} \\ 0 & 1 & 0 & Y_{trans} \\ 0 & 0 & 1 & Z_{trans} \\ 0 & 0 & 0 & 1 \end{pmatrix}} \times \underset{\text{Pitch}}{\begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & \cos(\Phi) & \sin(\Phi) & 0 \\ 0 & -\sin(\Phi) & \cos(\Phi) & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix}} \times \underset{\text{Roll}}{\begin{pmatrix} \cos(\Theta) & 0 & \sin(\Theta) & 0 \\ 0 & 1 & 0 & 0 \\ -\sin(\Theta) & 0 & \cos(\Theta) & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix}} \times \underset{\text{Yaw}}{\begin{pmatrix} \cos(\Omega) & \sin(\Omega) & 0 & 0 \\ -\sin(\Omega) & \cos(\Omega) & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix}}
$$

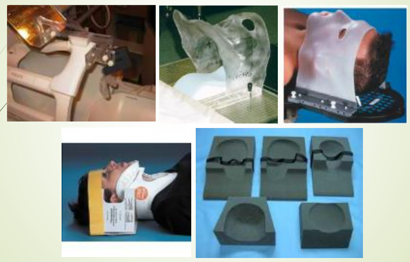
Viewing motion correction



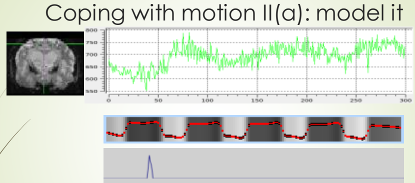
Motion Correction



Coping with motion I: prevent it

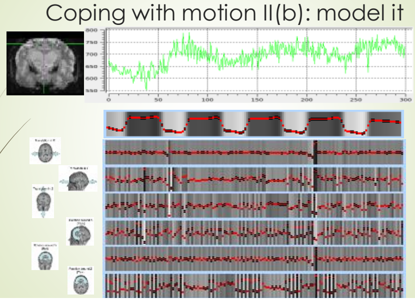


Coping with motion II(a): model it



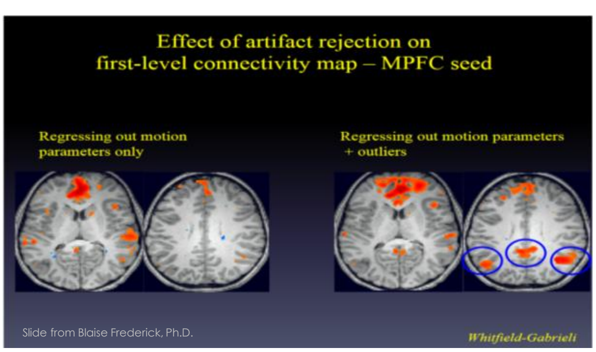
fsl_motion_outliers will generate a vector (i.e., regressor) for each large jump in image intensity based on any of a number of measures (e.g., RMS, FD, DVARS). A better option than splicing out bad TRs (which is a no-no!)

Coping with motion II(b): model it

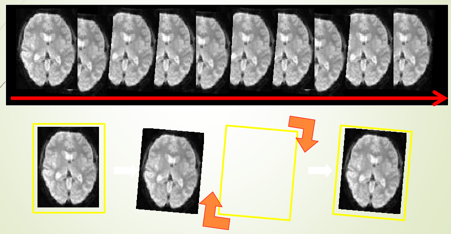


Coping with motion

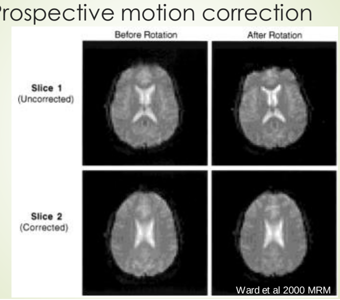
- In task-based analyses most people **use**
  - 6 motion regressors, often with up to 18 "expanded" motion regressors
  - Not many use single time-point modeling (though AFNI users often use censoring, which has the same goal)
- In task-free analyses most people **use**
  - 6-24 motion regressors (whether he additional 18 are that useful is unclear)
  - Single time-point modeling used fairly often
  - Scrubbing (more in the next days)
  - Global signal regression (at the cost of having a hard time interpreting apparent negative associations)



Coping with motion III: Prospective MC



Prospective motion correction



Motion correction is good, however:

- Even after all this, movement artifacts still remain
  - Residual (uncorrected) motion
  - There's no way of detecting rapid movements within a scan
  - Spin history effects*
  - Voxels will be in different magnetic fields as a result*
  - Task correlated motion

The moral of the story…

- ***Stop people from moving***
  - Make sure they're comfortable to begin with
  - Tell them that motion is a big problem
  - Train subjects?
  - Reward them?
- Decouple motion-prone tasks from cognitive event of interest
- Model motion out
- Reject run/subject

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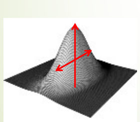
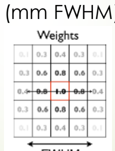
*Order for a typical ***task based*** analysis

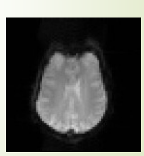
Spatial Filtering

Replace each voxel's value with a weighted average of its value and the value of it's neighbouring voxels.

Gaussian kernel (mm FWHM)







Spatial Filtering

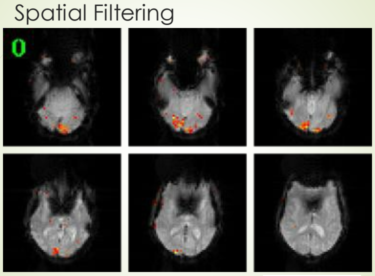
Advantages

- Increases Signal to Noise Ratio (SNR)
  - *Matched Filter Theorem*: Maximum increase in SNR by filter with same shape/size as signal
- Allows application of Gaussian Field Theory
- May improve comparisons across subjects

Disadvantages

- Reduces spatial resolution
- May reduce your signal if smaller than your filter size!

Spatial Filtering



Source FSL website

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Temporal Filtering

In task-based as well as task-free analyses you are interested in signal oscillations at **specific** frequencies (i.e., your task; low amplitude fluctuations [0.01-0.1Hz])

But there is a lot of activity at many other frequencies (particularly at low ones, 1/f):

- **Equipment related** could be any freq but most typicaly is <0.1Hz
- **Physiological**
  - Cardiac 40-120 bpm (0.66-4.0Hz, including harmonics)*
  - Respiration 12-20 breaths/min (0.2-0.33Hz)*
  - → at a 2s TR both alias to low freq (as TRs get faster, better sampling, better cleaning?)
- **Motion** all over the place (see previous slides)

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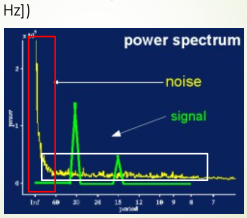
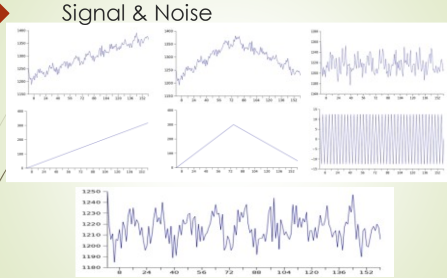
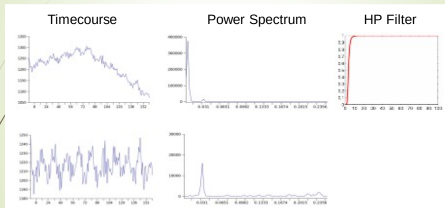


Signal & Noise



High-Pass Filtering



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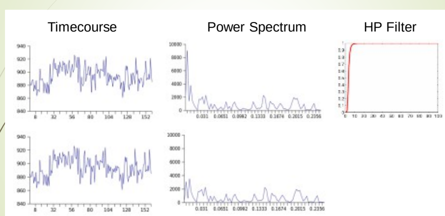
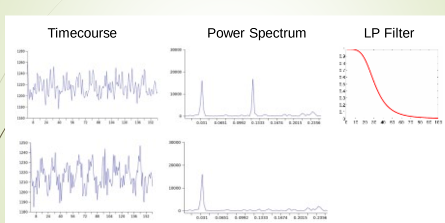
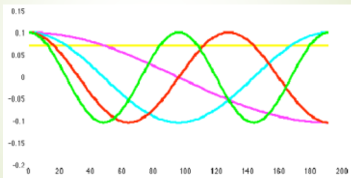


Low-Pass Filtering



HP Filtering Strategy I: SPM

- Model low drifts to "soak up" their variance (using a discrete cosine transform basis set).



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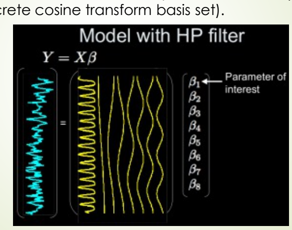
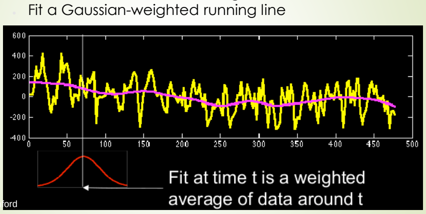


HP Filtering Strategy II: FSL

- Remove low drifts from the signal:
- Fit a Gaussian-weighted running line



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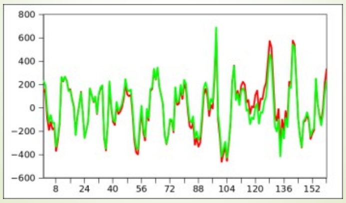
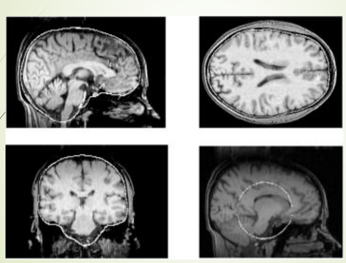
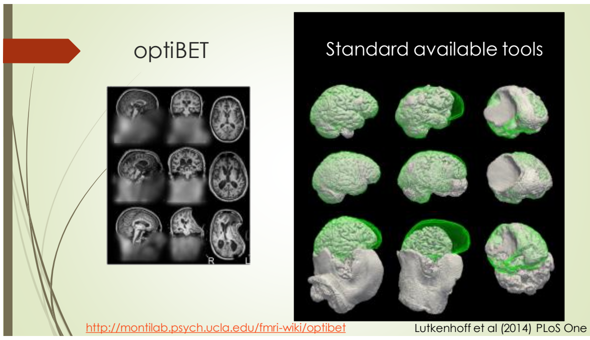
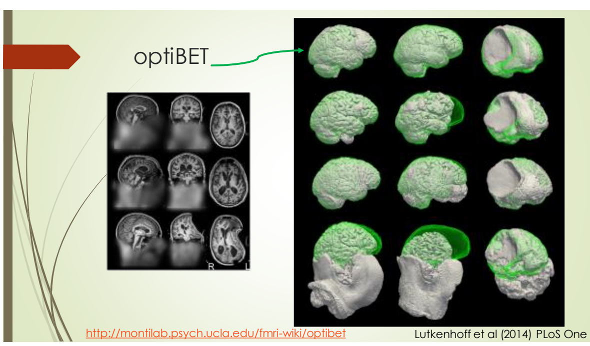


Bonus slides

Brain extraction




optiBET
Standard available tools
http://montilab.psych.ucla.edu/fmri-wiki/optibet
Lutkenhoff et al (2014) PLoS One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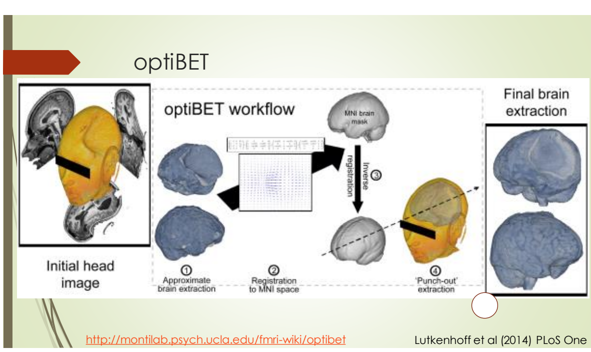
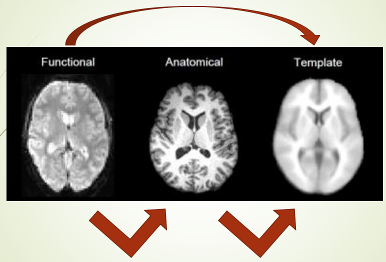
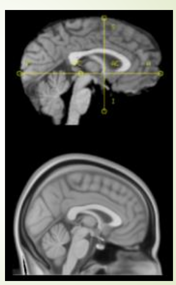

optiBET
optiBET workflow
Final brain extraction
Initial head image
1 Approximate brain extraction
2 Registration to MNI space
3 Inverse registration
4 'Punch-out' extraction
http://montilab.psych.ucla.edu/fmri-wiki/optibet
Lutkenhoff et al (2014) PLoS One

Registration

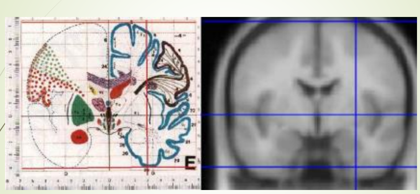


Standard Space

- Common reference frame
  - Talairach & Tournoux 1988, based on post mortem dissection of 1 brain
  - MNI (152) non linear average of multiple individuals



Standard Space



Registration

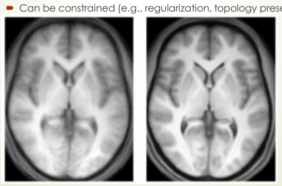
- Transformation: How to manipulate an image to fit it from its native space into a different space?
- Cost function: How to assess the quality of the manipulation?
- Interpolation: How create the intensity values to be assigned to the new "grid"?

Transformation

- Rigid body (6dof):
  - 3 rotations, 3 translations
  - Typically used for intra-subject registration
- Rigid body + global scaling (7dof)
  - 3 rotations, 3 translations, global scaling
  - Typically used for within subject/between modalities (i.e., functional to structural)
- Affine (12dof)
  - 3 rotations, 3 translations
  - 3 scalings, 3 sheers/skews
  - Typically used for registering a subject to the template

Transformation

- Non linear (>12dof):
  - Can be local
  - Can be constrained (e.g., regularization, topology preservation)



Transformation

- Non linear (>12dof):
  - Can be local
  - Can be constrained (e.g., regular[illegible]tion)

$$A = \begin{pmatrix} a_{11} & a_{12} & a_{13} & a_{14} \\ a_{21} & a_{22} & a_{23} & a_{24} \\ a_{31} & a_{32} & a_{33} & a_{34} \\ 0 & 0 & 0 & 1 \end{pmatrix}$$

An affine transformation is represented by these 12 numbers.
This matrix multiplies coordinate vectors to define the transformed coordinates.

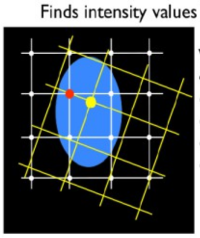
FLIRT: Cost Functions

Important: Allowable image modalities
Less important: Details

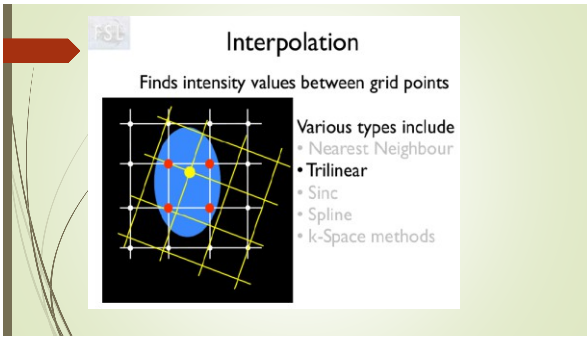
Least Squares	***Same modality*** (exact sequence parameters)
Normalised Correlation	***Same modality*** (can change brightness & contrast)
Correlation Ratio	***Any MR modalities***
Mutual Information	***Any modalities*** (including CT, PET, etc.)
Normalised Mutual Info.	***Any modalities*** (including CT, PET, etc.)

Interpolation

Finds intensity values between grid points



Various types include
- Nearest Neighbour
- Trilinear
- Sinc
- Spline
- k-Space methods


Interpolation
Finds intensity values between grid points
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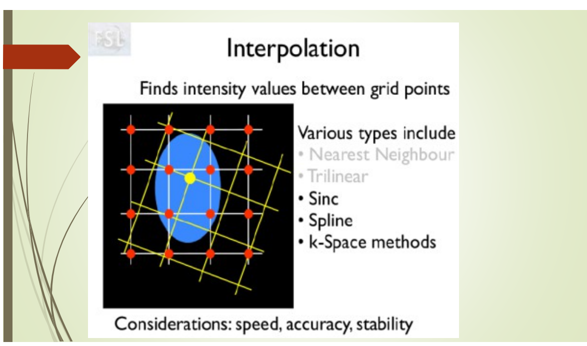
• Sinc
• Spline
• k-Space methods


Interpolation
Finds intensity values between grid points
Various types include
• Nearest Neighbour
• Trilinear
• Sinc
• Spline
• k-Space methods
Considerations: speed, accuracy, stability