

# functional Magnetic Resonance Imaging – Methods

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3/4

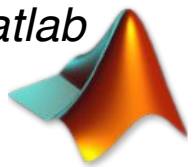
1

## Next 3 2 lectures

1. Spatial and temporal properties of fMRI (+ linearity, convolution)
2. Signal and Noise (+ Fourier domain, convolution)
3. Preprocessing of fMRI data (+ common software tools, registration)
4. Statistics + experimental design (+ linear regression, GLM, multiple comparisons)

2

## Matlab



- >> demo % opens demo window
- >> help stats % statistics toolbox
- >> help images % image proc toolbox
- >> why % Provides succinct answers to almost any question.

3

## Recap: last lecture

4

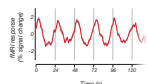
## Data: indexing

- multi-dimensional (n-dimensional) arrays
- we can **slice** data in different ways, e.g.

```
>> data(:, :, 12, 1)
% get image at z=12 at t=1
image processing, spatial filtering, ...
```

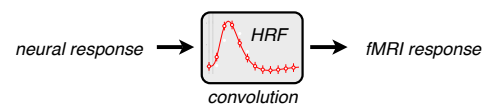
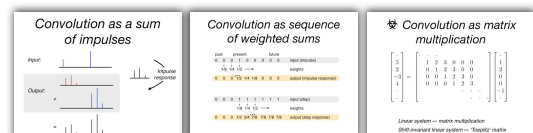


```
>> data(1, 1, 12, :)
% get timeseries at [1,1,12]
"voxel-wise" statistics, temporal filtering, ...
```



5

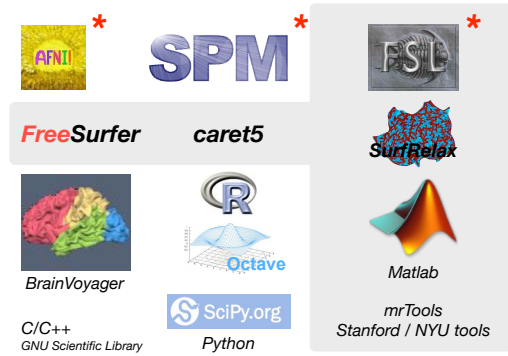
## Convolution, 3 Ways



6



## Many software packages...



12

## Steps in Analysis

1. **Get data off scanner** & into right file format  
PAR/REC, Nifti, Analyze, DICOM, MINC
2. **Preprocess** (motion-correction, slice-time correction, filtering, ...)
3. Do some statistics to get a **statistical map**
4. ? **Register / combine data** across subjects
5. **Render maps** in different formats  
(on high-resolution anatomy, flat maps, ...)
6. ? **Plot curves**, compare data + fits, look at data in many different ways, ...

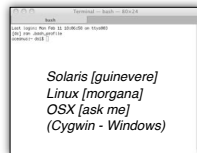
13

## Get data off scanner

1. ... not always as trivial as you might think
2. **PAR/REC** is a Philips data format that can handle complicated data (>1 stacks, echos, echos, mag + ph, ...)
3. many fMRI analysis tools expect **NIFTI** format

ds1\$ ptoa

conversion tool written by  
**Dr Paul Morgan**  
(UoN, Academic Radiology; now  
MUSC, South Carolina)



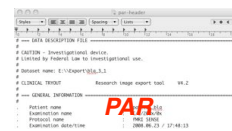
14

## PAR/REC

- data comes in **pairs** of files: `fname.PAR`, `fname.REC`
- the **PAR** part is a text file that contains information about the session, how slices were prescribed, TE, flip angles, reconstruction sizes,...
- the **REC** part is a binary file that contains the data

**Text editor**

**UNIX Terminal**



ds1\$ more fname.PAR

15

## NIFTI/Analyze

- data comes in **pairs** of files: `fname.hdr`, `fname.img`
- or as a single file (header is inside file): `fname.nii`
- or even compressed: `fname.nii.gz`
- less information than in PAR/REC files, **but more** programs use it

**Text editor**

**UNIX Terminal**



ds1\$ fslinfo fname.img  
ds1\$ fslhd fname.img

16

## Terminal

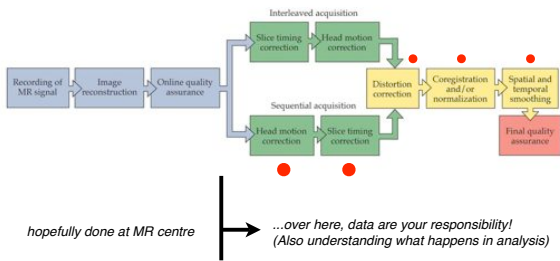
ds1\$ <some unix command>

ds1\$ <file that contains a bunch of unix commands>

- many analysis tools: can type a command in a shell/terminal, rather than clicking buttons.
- for large datasets or repetitive tasks, it is often faster to write a **script** than to click the mouse 10<sup>6</sup>
- e.g. all commands for FSL tools can be accessed that way

17

## Data Preprocessing



18

## case study FMRIB Software library (FSL)

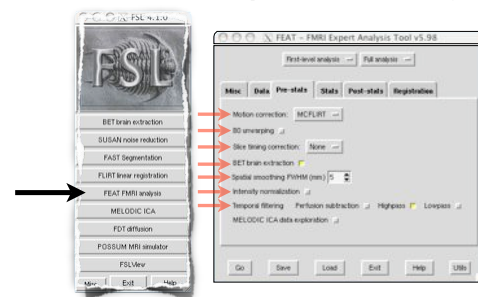
19

## Data Preprocessing

- most software packages implement a very similar set of preprocessing steps (because they make sense)
- ... may be called different things (specific jargon)
- check SPM, BrainVoyager, AFNI documentation for details:
  - links on my webpage <http://tinyurl.com/5kcvqv>
  - Google: SPM, BrainVoyager, AFNI

20

## Data Preprocessing



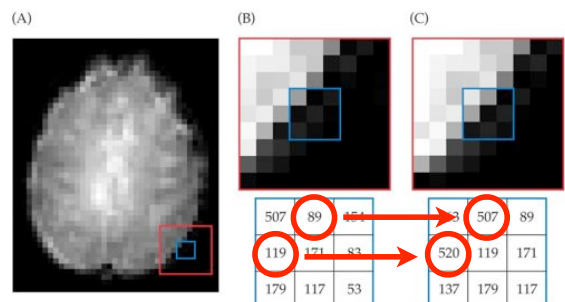
21

## Data Preprocessing

- **Aim 1:** reduce unwanted variability in the data (this increases functional SNR)
- **Aim 2:** prepare data for statistical analysis (e.g. spatial smoothing can reduce the effective number of statistical tests).
- **Additional aim:** get data ready for display / averaging across subjects

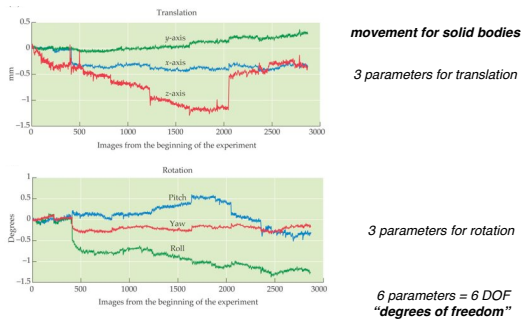
22

## Motion correction



23

## Motion correction



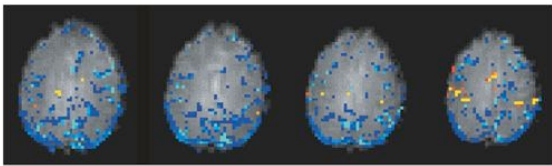
24

## Motion Correction

- AIR automated image registration (Woods)
  - SPM (Ashburner)
  - FLIRT / FSL (Jenkinson)
  - Robust alignment (Nestares & Heeger)
  - ... ..all try to minimize some **error term between a reference image** (say, the first image acquired) and **the image at each other time point.**
- ! By definition the algorithm finds a minimum – make sure the algorithm's solution is reasonable.*

25

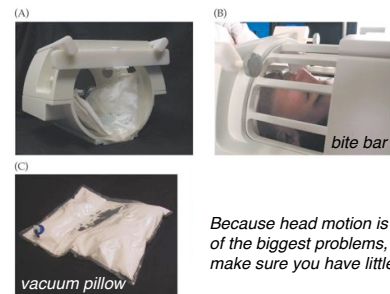
## Motion Correction



Typical edge artefact in statistical images, due to (residual) motion...

26

## Avoid Motion!



Because head motion is one of the biggest problems, make sure you have little

27

## $B_0$ unwarping

- correct geometric *distortions* in EPI data (caused by inhomogeneities in local magnetic field) **fugue**
- data for this (phase images) often show wrapping, i.e. jumps from  $2\pi$  back to 0 (need to correct for those jumps first...) **prelude**



fieldmap (image intensity  $\propto$  local field)  
units: [Hz], [rad/s], [T]

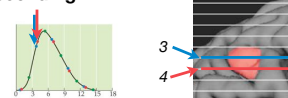
<http://www.fmrib.ox.ac.uk/fsl/fugue/>



28

## Slice (acquisition) time correction

- example: repetition time (TR) 2s, 10 slices
- slice order **a- / de-scending**



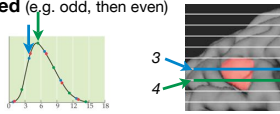
Time (s)	0.2	0.4	0.6	0.8	1.0	1.2	1.4	1.6	1.8	2.0
ascending	1	2	3	4	5	6	7	8	9	10

0.2s

29

## Slice (acquisition) time correction

- example: repetition time (TR) 2s, 10 slices
- slice order **interleaved** (e.g. odd, then even)



Time (s)	0.2	0.4	0.6	0.8	1.0	1.2	1.4	1.6	1.8	2.0
interleaved	1	3	5	7	9	2	4	6	8	10

1.0s

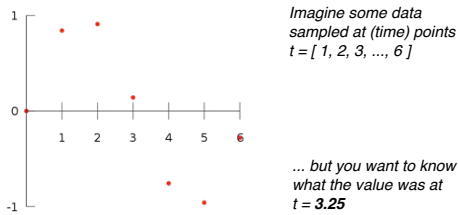
30

## Slice (acquisition) time correction

1. Do nothing!
2. Deal with difference in timing at the time of statistical analysis (bookkeeping nightmare?)
3. Resample / interpolate data to "realign" data in time. Then proceed as before, ... (but this step might **blur** your data)

31

## Interpolation

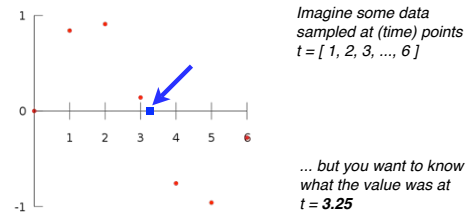


<http://en.wikipedia.org/wiki/Interpolation>  
also Numerical Recipes in C (Press et al.)



32

## Interpolation

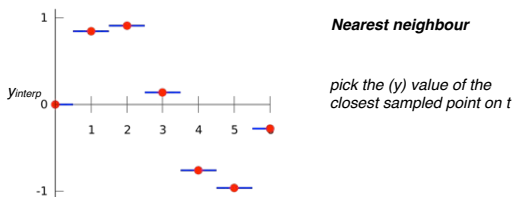


<http://en.wikipedia.org/wiki/Interpolation>  
also Numerical Recipes in C (Press et al.)



32

## Interpolation

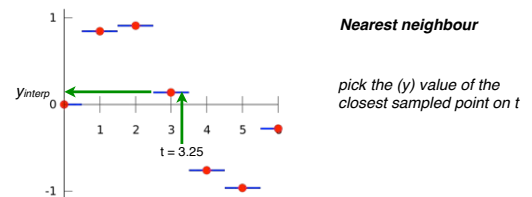


<http://en.wikipedia.org/wiki/Interpolation>  
also Numerical Recipes in C (Press et al.)



33

## Interpolation

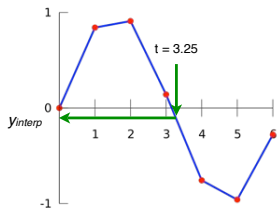


<http://en.wikipedia.org/wiki/Interpolation>  
also Numerical Recipes in C (Press et al.)



33

## Interpolation



linear

### Linear interpolation

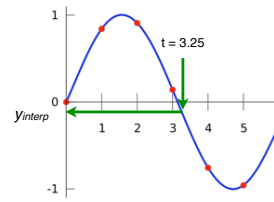
pick the (y) value on a line segment that joins adjacent sampled points on t

<http://en.wikipedia.org/wiki/Interpolation>  
also *Numerical Recipes in C* (Press et al.)



34

## Interpolation



### Polynomial interpolation

pick the (y) value on a polynomial that goes through sampled points on t

... you may also see  
**Spline interpolation**  
**Sinc interpolation**  
(highest quality, but slow)

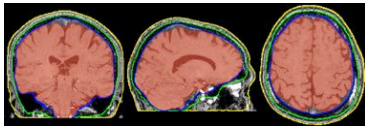
<http://en.wikipedia.org/wiki/Interpolation>  
also *Numerical Recipes in C* (Press et al.)



35

## Brain extraction

- remove skull / skin / fat before further processing (which are *a priori* not interesting for most fMRI)
- may improve alignment across subjects (but ! within subject alignment... there is information in the skull!)



S.M. Smith. (2002) Fast robust automated brain extraction. *HBM*, 17(3):143-155

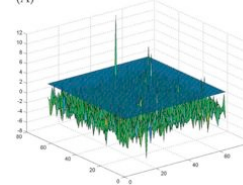
<http://www.fmrib.ox.ac.uk/fsl/bet2/>



36

## Spatial smoothing

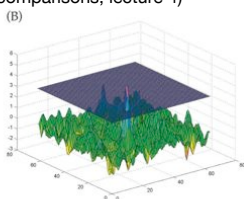
1. reduce noise in images
2. introduce **known** spatial correlations, e.g. with gaussian blurring (gaussian random fields, lecture 4)
3. ...reduce number of 'independent' samples in image (multiple comparisons, lecture 4)



37

## Spatial smoothing

1. reduce noise in images
2. introduce **known** spatial correlations, e.g. with gaussian blurring (gaussian random fields, lecture 4)
3. ...reduce number of 'independent' samples in image (multiple comparisons, lecture 4)



38

## Terminal

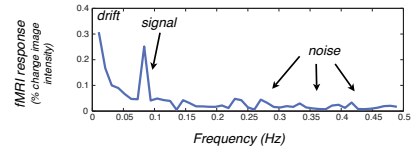
```
ds1$ fslmaths
ds1$ fslstats
ds1$ fslsplit
ds1$ fslmerge
ds1$ fsl<bla>
```

39

## Temporal filtering

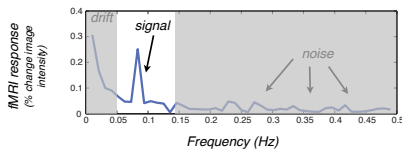
1. If we know the characteristics of **unwanted variability** (noise), then we can try to filter it out.
2. trend-removal, high-pass filtering (to get rid of drift)
3. smoothing, low-pass filtering (to get rid of high-frequency ripples)

40



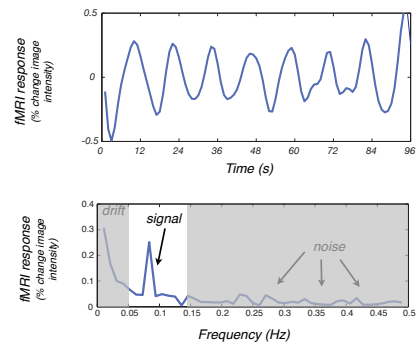
$F$

41



$F$

41



$T$   
 $\mathcal{F}^{-1}$

$F$

41

## Temporal filtering

1. If we know the characteristics of **unwanted variability** (noise), then we can try to filter it out.
2. trend-removal, high-pass filtering (to get rid of drift)
3. smoothing, low-pass filtering (to get rid of high-frequency ripples)

**Make sure not to remove signal...**

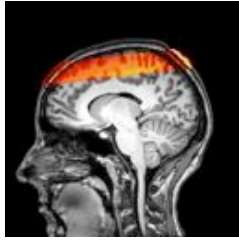
**Check that filtering doesn't introduce statistical dependencies that might hurt you later...**

42

## Registration / Flat maps

43

## Aligning across sessions (same subject)



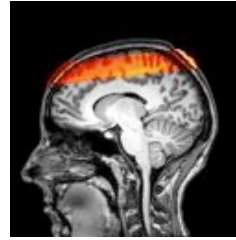
EPI data is blurry

image contrast different:  
anatomy and functional data

consider collecting anatomy  
data with the same slice  
prescription

44

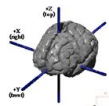
## Aligning across sessions (different subject)



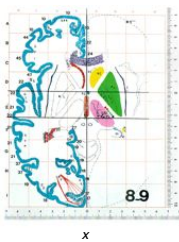
?

45

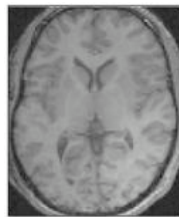
## Talairach coordinates



Atlas



Matching slice

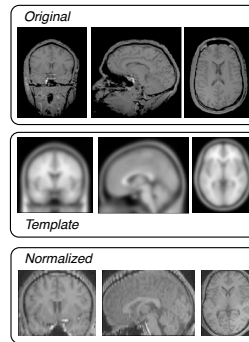


+x (right), +y (front), +z (top)

Talairach & Tournoux (1988)

46

## Transforming to Talairach coordinates



**Find landmarks**  
anterior/posterior commissure  
AP, LR, inf-sup borders

match

**Talairach template**  
MNI templates  
Montreal Neurological Institute

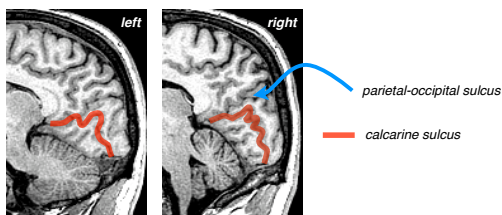
warp

**Find landmarks**  
anterior/posterior commissure  
AP, LR, inf-sup borders

47

## A word of caution: Problem with Talairach coordinates

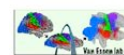
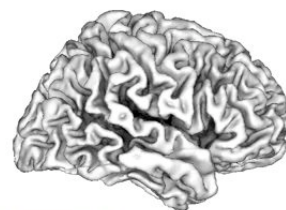
Individual differences & asymmetries:



Sagittal slices of the two hemispheres in one subject.

48

## Flat maps of cortical surface

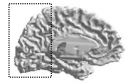


caret software

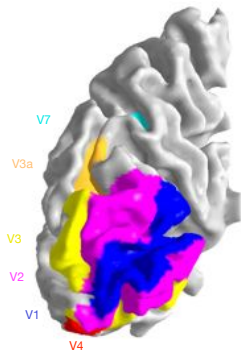
Google: Van Essen lab

49

## Human visual areas



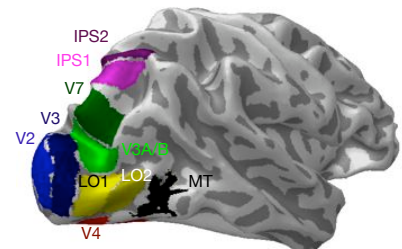
Left hemisphere  
medial view



50

## Human visual areas

Lateral view



**LO1 and LO2:**  
Larsson & Heeger, J Neurosci (2006)  
**IPS1 and IPS2:**  
Schluppeck, Glimcher, & Heeger, J Neurophysiol (2005)  
Silver, Ress, & Heeger, J Neurophysiol (2005)

51

## Summary

- recap
- **Matlab (... + Unix, terminals, ...)**
- software packages
- preprocessing steps, how, why?
- registration / flat maps

52