functional Magnetic Resonance Imaging – Methods

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BOLD?

Physiology of BOLD

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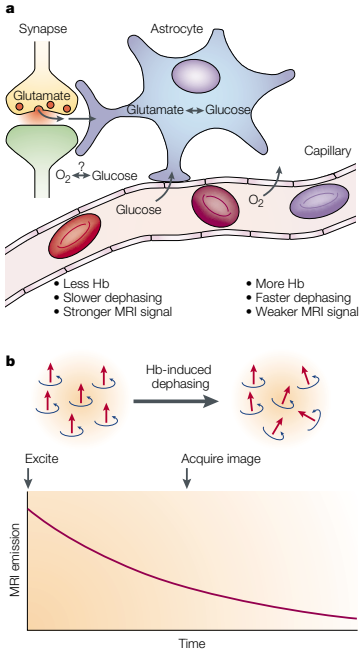
17. Nov

BOLD



Logothetis & Wandell.
Interpreting the BOLD signal.
Annu Rev Physiol (2004) vol. 66 pp. 735-69

Heeger & Ress.
What does fMRI tell us about neuronal activity?
Nat Rev Neurosci (2002) vol. 3 (2) pp. 142-51

Next 4 lectures

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

Preamble

Argh!

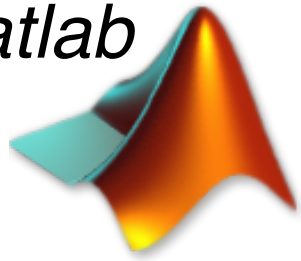
I saw some equations and weird mathematical symbols in the course materials...

$$A\hat{u} = \left[\mathbf{A}(\mathbf{A^T A})^{-1}\mathbf{A^T}\right]b$$

$$\beta, \epsilon, \int_0^\infty f(x)dx \qquad\qquad \bar{y} = \frac{1}{n}\sum_{i=1}^{n} y_i$$

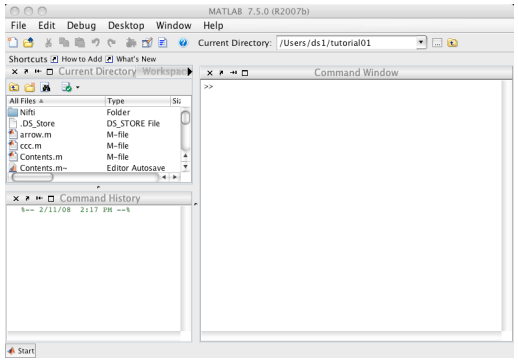
... you'll be fine.

Matlab

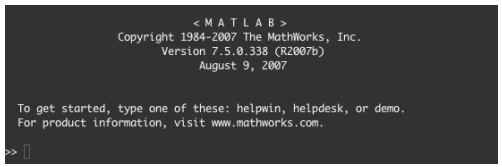


*if you have **any** spare time... borrow a book and do a tutorial!*

~ 30 licenses in Psychology computer room



desktop



command line [from terminal]

Matlab = life skill

"The successful candidate should have a PhD. ***Candidates with strong analytical skills,*** *and with research experience in visual neuroscience, cognitive neuroscience, computational methods, or functional MRI are encouraged to apply."*

"Applicants should have a background in MRI analysis techniques (FSL, SPM, ***Matlab*** *etc.), programming and statistics. Interest in clinical neuroscience and cognitive function would be appreciated..."*

"Candidates should hold (or expect) a Diploma or Masters degree in a relevant discipline (e.g. Psychology, Neuroscience, Physiology, biology, Computer Science). ***Programming experience with Matlab is a plus.***

Ads for Phd / Post-doc positions...

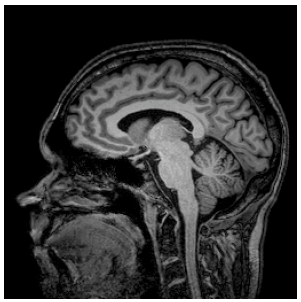
(Online) Resources

- please stop me if you are confused
- please take (some) notes
- hand-outs will be on course webpage (but my slides tend to have little text)
- *ditto:* links to Matlab information
- Huettel, Song & McCarthy (ch. 8-12)
- denis.schluppeck@nottingham.ac.uk (e-mail questions for '10 minute clinic')

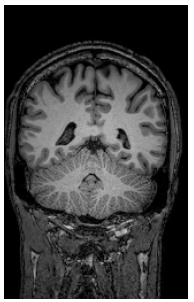
Glossary

- **1D, 2D, 3D, nD:** dimensionality
  line (1D), plane (2D), cube (3D), ...
- **voxel:** volume element, 3D version of a **pixel**
- **slice:** plane of *x* by *y* voxels (x, y often 2^n: 64, 128, 256)
- **volume:** made up of *z* slices (so $x \cdot y \cdot z$ voxels)
- **scan/run:** series of *t* volumes collected (~5-10 minutes)
- **session:** several scans for which one subject goes into the scanner

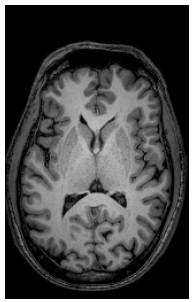
Orientations



sagittal



coronal

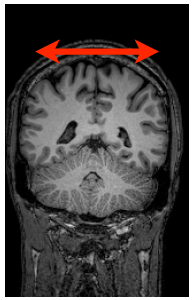


axial, horizontal, transverse

Orientations

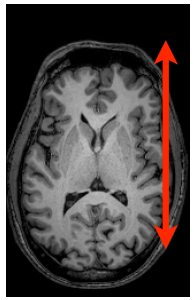
sagittal

foot-head
FH



coronal

right-left
RL

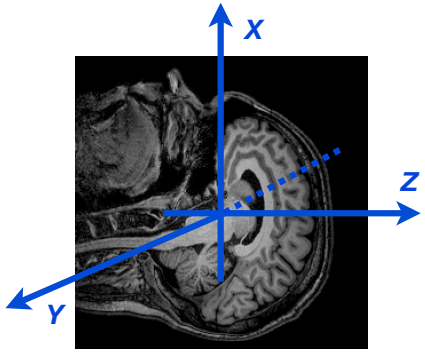


axial.
horizontal.
transverse

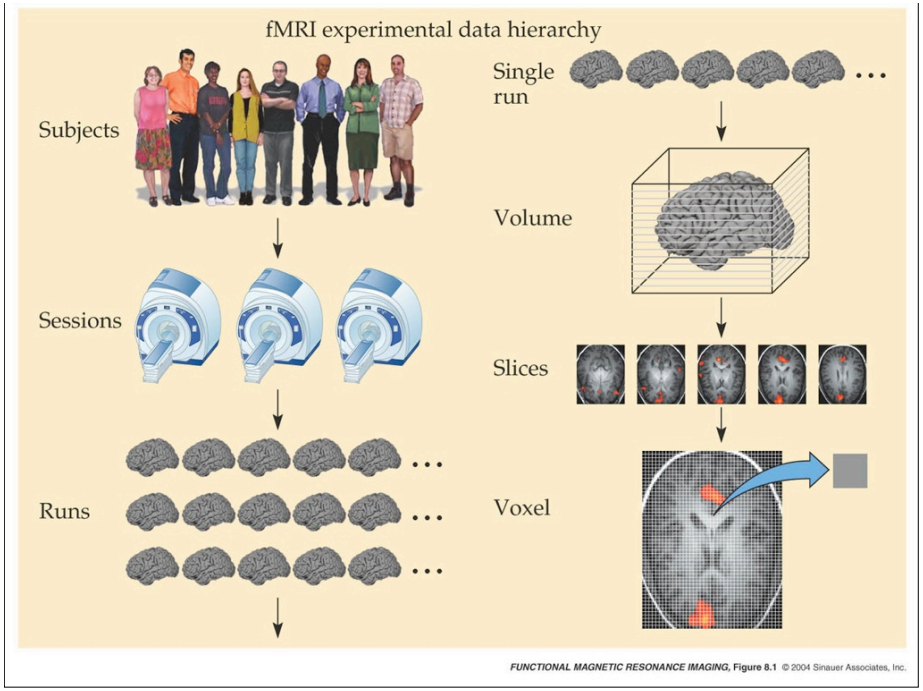
anterior-
posterior
AP

Orientations / scanner

feet

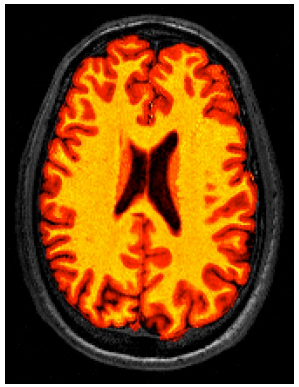


Subjects often go into the scanner:
head-first-supine *(HFS)*



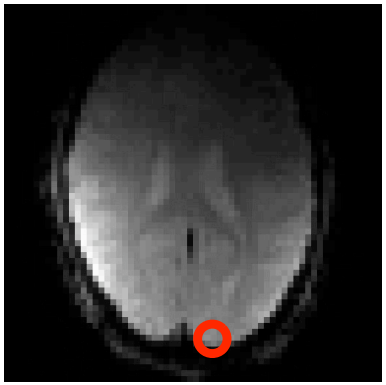
Example Images

Anatomy: 1·1·1mm^3



T1 MPRAGE (3T)
[minutes]

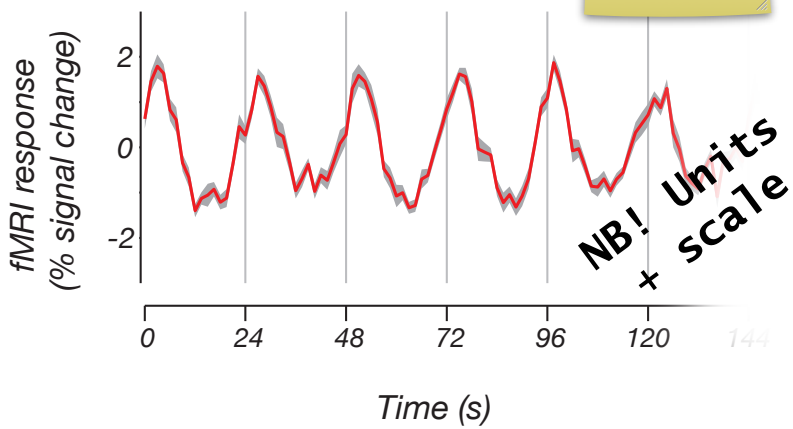
Functional: 3·3·3mm^3



T2 EPI (3T)*
[ms, s]

fMRI measures changes over ti

interesting temporal structure which we will discuss in much more detail later.



Size of fMRI response

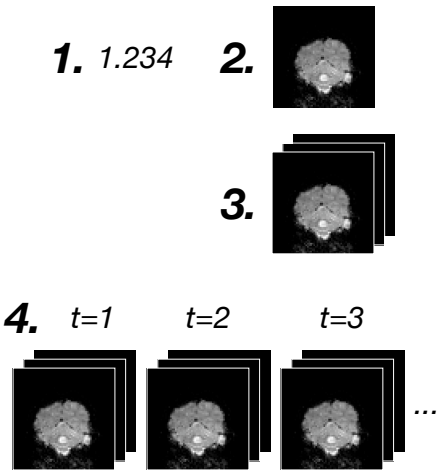
If a Caffè Latte costs £1.99 ...

... would you notice a 2% change in price?

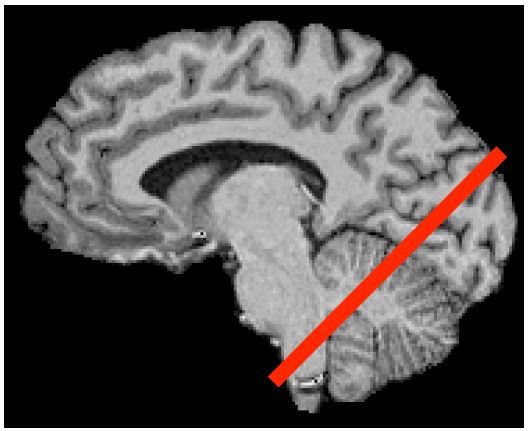
(see Lecture 4, Statistics)

Quick recap: data

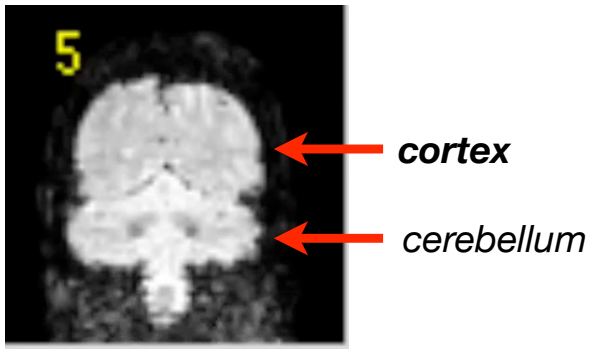
1. numbers (=pixel/voxel)
2. a bunch of numbers on a grid (=slice)
3. a collection of slices (=volume)
4. many volumes over time, acquired every TR (=timeseries)



Example: visual cortex



Example: visual cortex



one slice over 160 repeated measurements (every 1.5s)

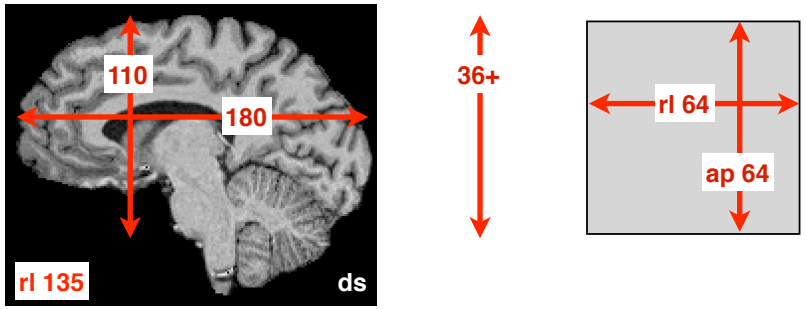
"There is no free lunch!"

- both, **spatial** resolution and **temporal** resolution, are limited
- often, experimenter has to trade off one against the other
- so, different choices for different applications...

What limits spatial resolution?

- hardware (the scanner)
- the subjects
  - peripheral nerve stimulation [PNS]
  - specific absorption rate [SAR] limits
  - time in scanner (>1.5h is not fun)
- signal-to-noise ratio (see lecture 2)
  - smaller voxels = proportionally more noise
  - head motion, physiology, ...

Example: Scanner limits

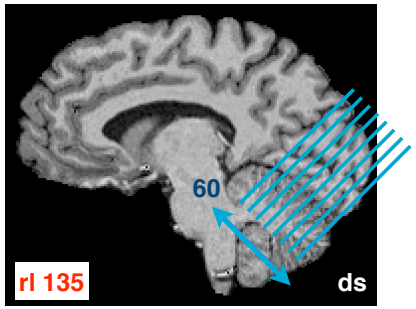


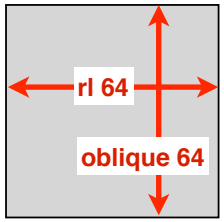
~brain dimensions (mm) ~# of slices ~# of voxels

64×3mm=**192mm**

❖ *our 3T scanner can do ~13slices/s for these settings with SENSE r=2 so min[TR] for 36 slices with 3mm voxels = ~3s*

One solution: partial coverage



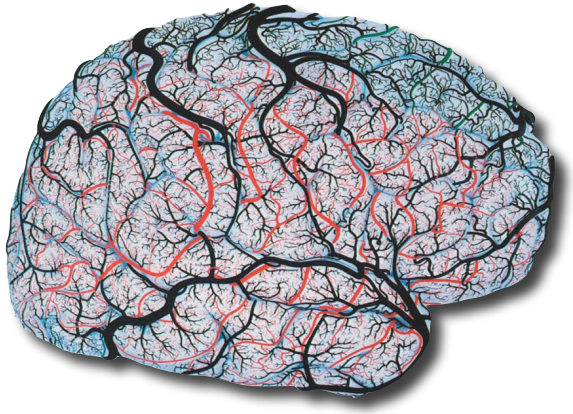


~dimensions (mm) ~# of slices ~# of voxels

64×3mm=**192mm**

❖ *~13slices/s, so can run with a TR of ~1.5s*

Why do we need (high) spatial resolution?



(f)MRI

optical techniques

e-phys

TABLE 8.1 Different Spatial Scales in the Human Brain

Structure	Scale
Brain	100 mm
Gyri	10 mm
Dominance column	1 mm
Neuron	0.01 mm
Synapse	0.001 mm
Ion channel	0.00001 mm

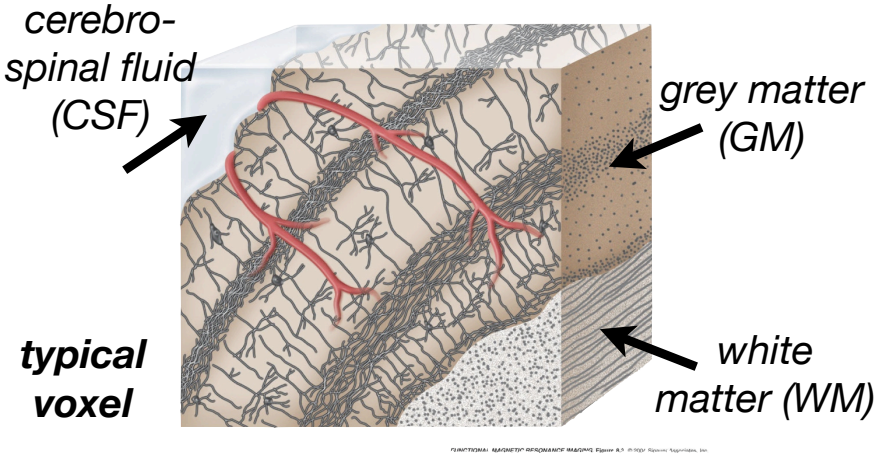
FUNCTIONAL MAGNETIC RESONANCE IMAGING, Table 8.1 © 2004 Sinauer Associates, Inc.

for fMRI, voxel sizes usually $(3\text{-}5\text{mm})^3$ but as small as $(1\text{mm})^3$

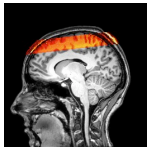
Why do we need (high) spatial resolution?

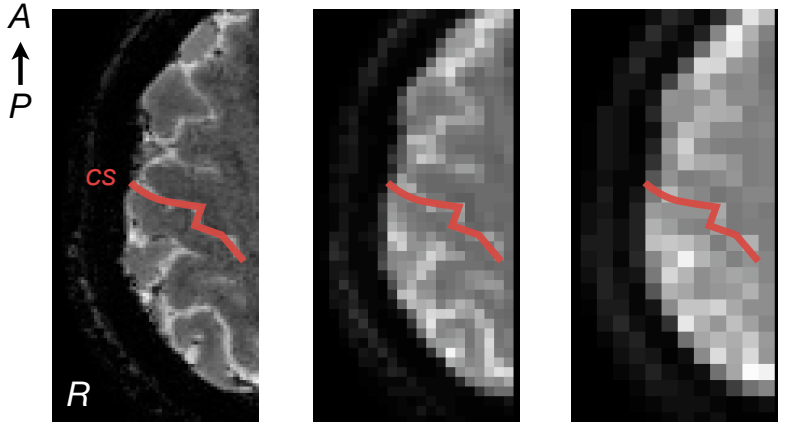
- brain structures of interest are ~mm in size, sometimes separated by ~cm; need appropriate **sampling** (see Sampling/Nyquist, lecture 2)
- smaller voxels: less mixing of grey matter, white matter, CSF, veins, ... reduced **partial voluming**

Why do we need (high) spatial resolution?



Spatial resolution



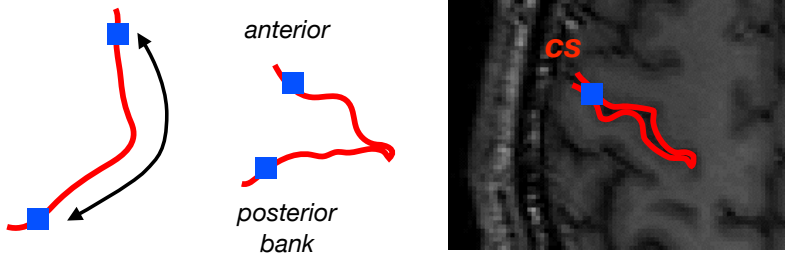


Volume: # of cells

- if packing density in grey matter of cortex is ~50,000 cells / mm^3

edge (mm)	*volume (mm^3)*	*#cells in pure GM*
1	1	50k
3	27	1.35M
5	125	6.25M

Volume: anatomical space



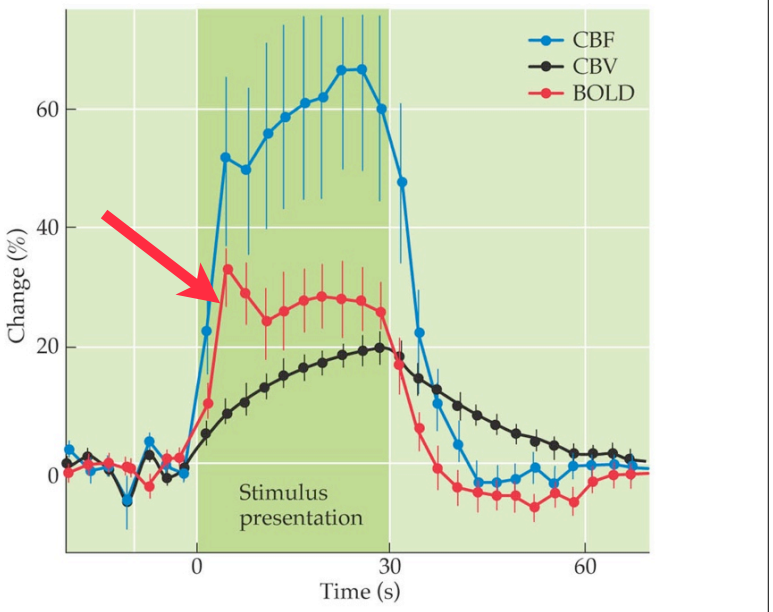
ε: ~cm ← *projection from x,y,z to vertices on surface* → *ε: ~mm*

Temporal resolution

- you ~~had~~ **will have** lectures about the blood-oxygen-level-dependent (BOLD) signal
- BOLD is **haemodynamic**, an indirect measure of neural activity (+ hotly debated)
- BOLD signal is blurred in space, and also in **time**

What limits temporal resolution?

- haemodynamics!
- hardware (the scanner) - not so much
- signal-to-noise ratio (see lecture 2)
  - for TR < 2.0s, can't use 90° flipangle
- the subjects
  - specific absorption rate [SAR] limits
  - time in scanner (>1.5h is not fun)
    with reduced SNR, need more repeats



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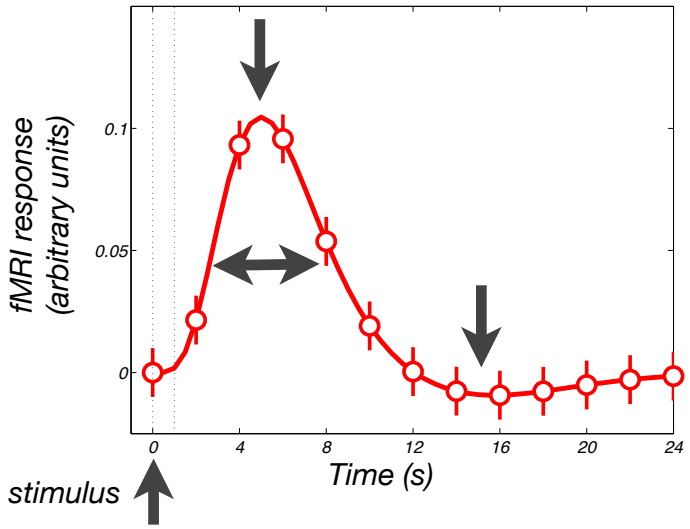
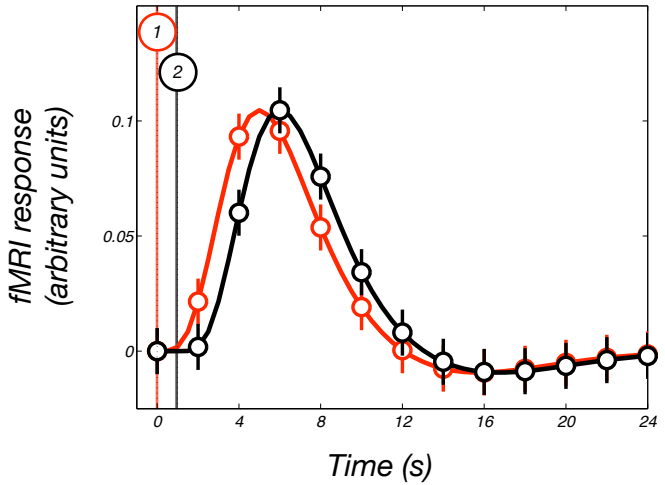
HRF

- the shape of the response to a brief impulse (e.g. visual stimulus) is called the haemodynamic response function (HRF)
- haemodynamic impulse response function (HIRF, HRF, IRF, ...)
- this is an important concept (see 2nd part of lecture)
- e.g. haemodynamic response to a 1s visual stimulus peaks several seconds later and is spread out

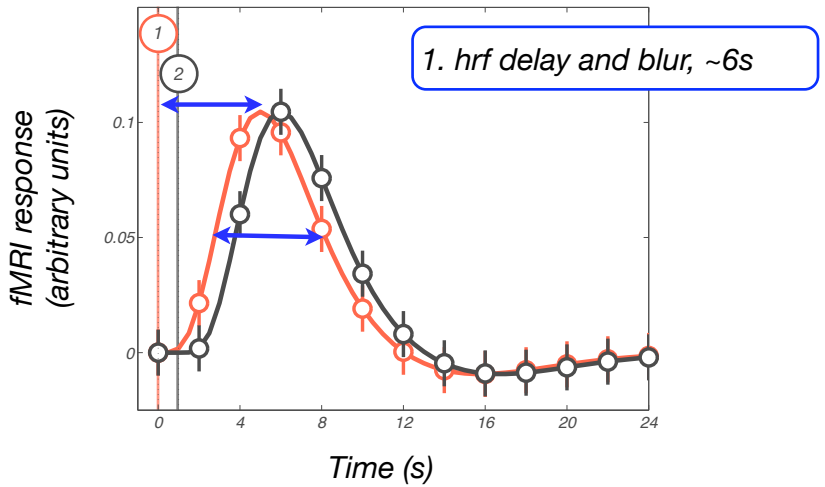
HRF



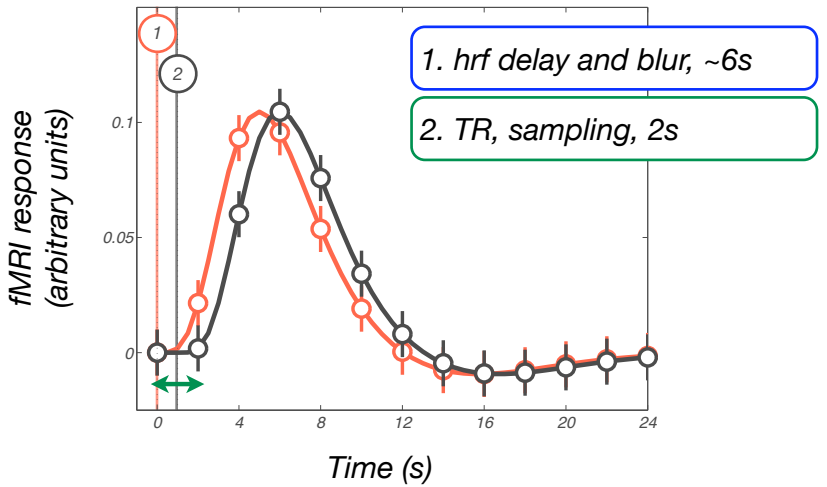
HRF & temporal precision



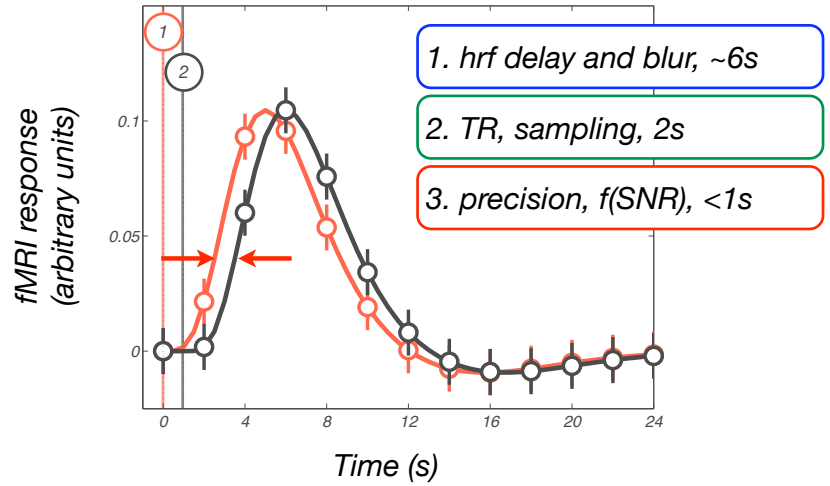
HRF & temporal precision



HRF & temporal precision

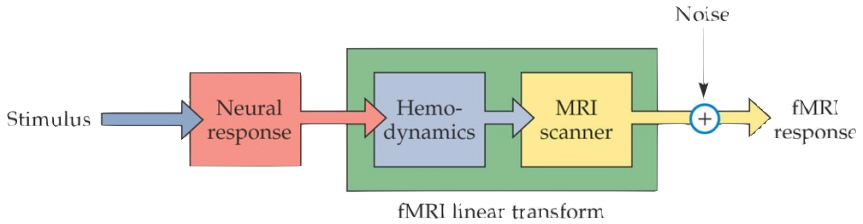


HRF & temporal precision



1b – Linear Systems, Convolution

fMRI response as a linear system



input *output*

Boynton et al (1996)

Linear system

- A linear system has two basic properties:
  1. **scaling** (homogeneity)
  2. **superposition**

engineers: linear system,
linear time-invariant (LTI) system

Linear system

Scaling

Superposition

Examples

multiply by a number ✔

$y = 3x$

Examples

$y = 3x$

$a \Rightarrow 3a$

$+b \Rightarrow 3b$

$3a+3b$

✔

$a+b \Rightarrow 3(a+b)$

Examples

squaring input

$y = x^2$

✗ no

Examples

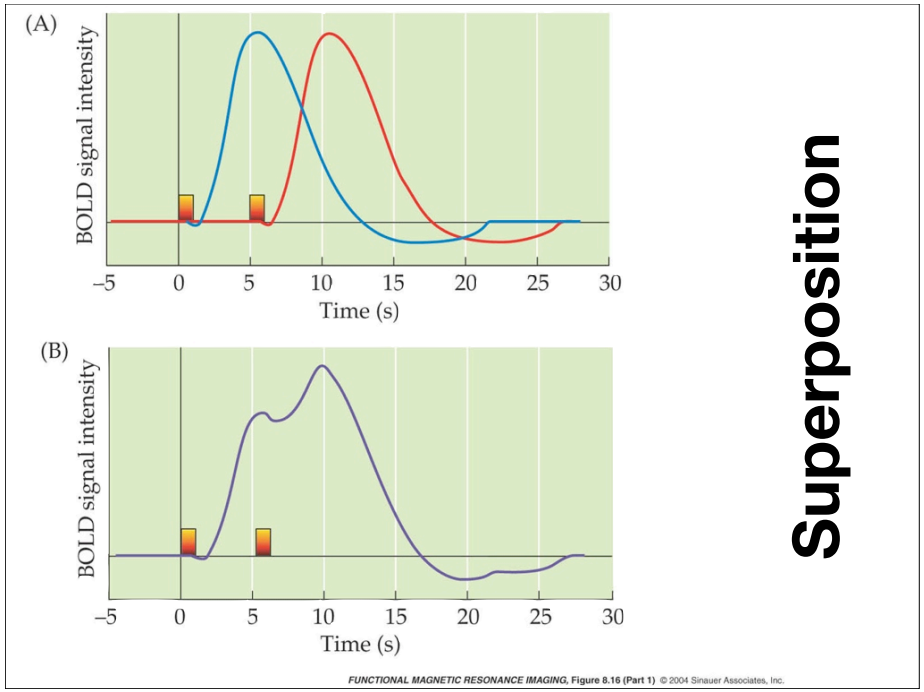
adding a number

$y = x+2.5$

✗ no

Linear system

1. If we a system is **linear**, then the impulse response function **fully** describes it
2. e.g. given the response to a brief stimulus (impulse), we can predict response to arbitrary inputs
3. mathematical operation of **convolution** is central to those predictions (lecture 2,4)



Superposition

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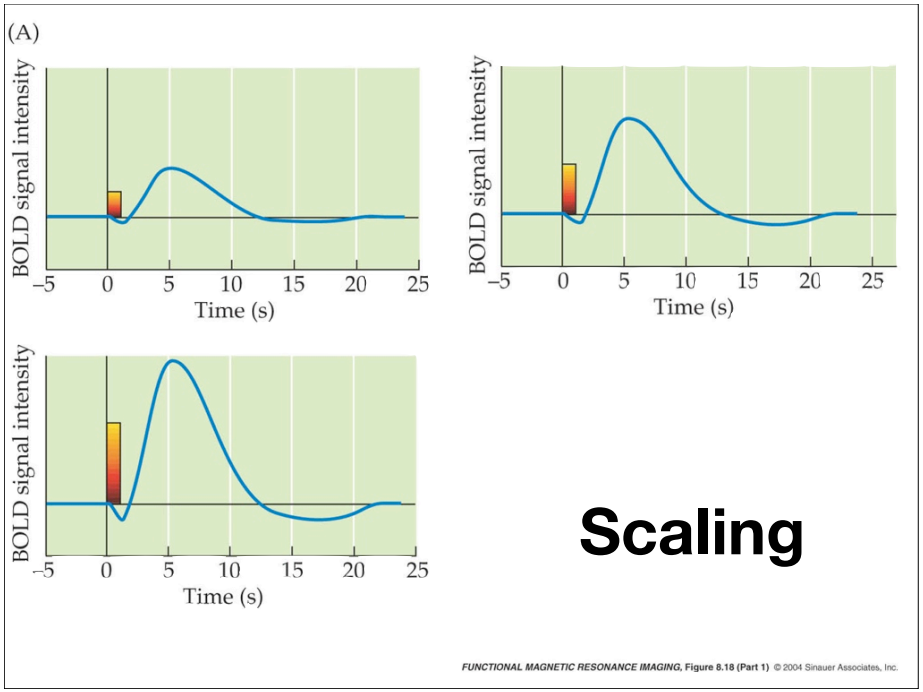

Scaling

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Summary

- new vocabulary
- **Matlab**
- what our fMRI data look like
- spatial resolution
- temporal resolution
- concept of HRF