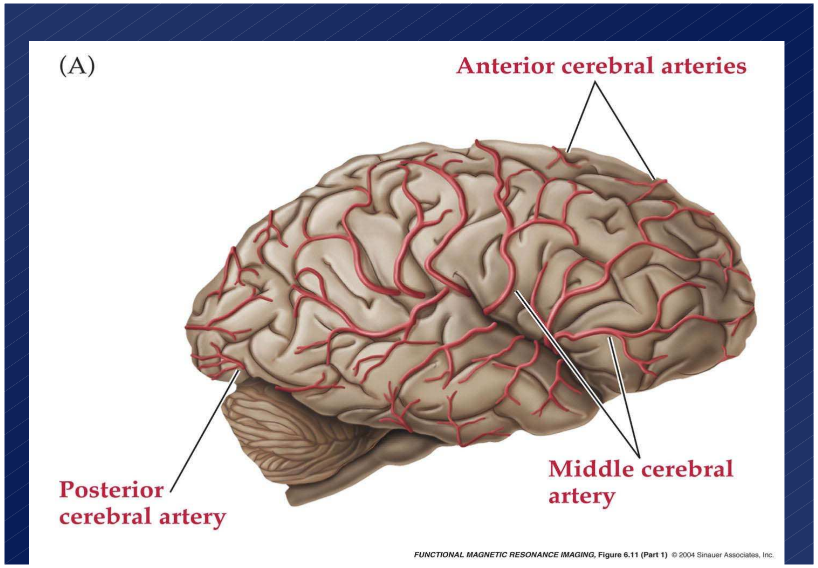
Medical Imaging
Magnetic Resonance Imaging, Functional Imaging Methods
(Outline of Lecture 5)

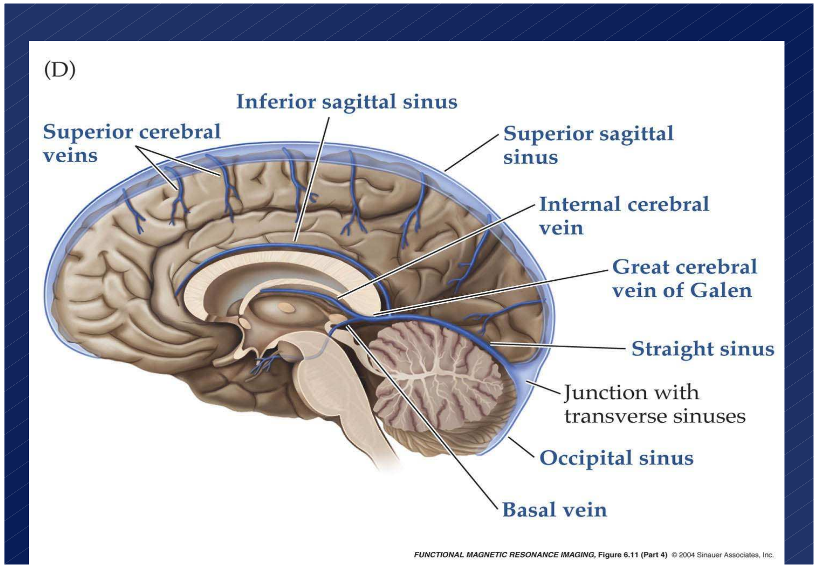
Functional MRI

Goal: Identification of brain areas involved in specific information processing tasks like e.g. speech, motion, vision

A. Basic Principles

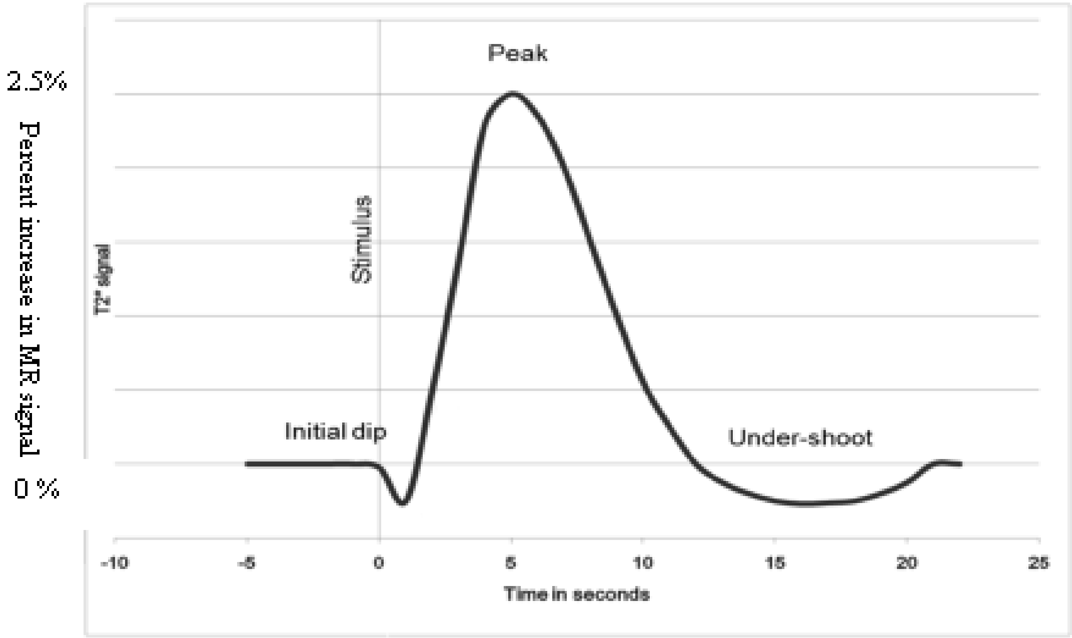
- Oxygen transport in the blood by haemoglobin (protein) which contains Fe
- Deoxyhaemoglobin – the form of haemoglobin without bound oxygen is paramagnetic
- Oxyhaemoglobin – the form of haemoglobin with bound oxygen is diamagnetic.
- Local neural activity ⇒ increase in blood flow and and proportion of oxy-/deoxyhaemoglobin. (This mechanism is not yet well understood)
- Resulting increase of T_2 relaxation time ⇒ BOLD-effect (Blood Oxygen Level Dependency)





Functional MRI

Haemodynamic response function (HRF)
response of the system as reflected by the MR signal to a brief, intense period of neural stimulation



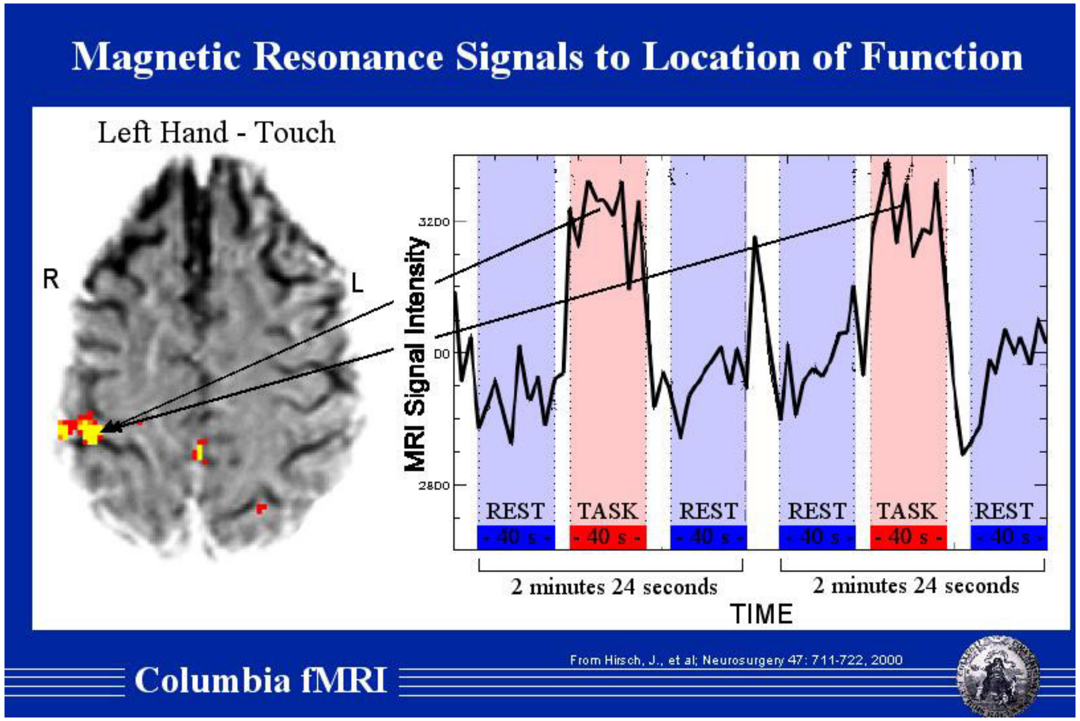
However in reality:

- Real HRF deviates strongly from the idealised form.
- HRF depends on the position - type of neurons, capillary bed, etc.
- HRF depends on the activation history.
- Signal-to-noise ratio is very small.

Functional MRI

B. Voxel-wise activity measurement

- Repeatedly apply MRI measurement with/without activity
- Time resolution > 1 sec, spatial resolution > 0.5 mm
- Apply registration if necessary.
- Record the time series of measured signal for each voxel



For each voxel: Determine whether the corresponding neurons where active/inactive in the trial.

Functional MRI

(1) Make an assumption about the activity course for neurons involved/not involved in processing: $s_a(t)$, $s_i(t)$, $t = 0, 1, 2, \ldots T$

(2) Model the relation between s and the MRI measurement

$$x_a(t) = \beta y(t) + z(t, \theta) + n(t), \quad x_i(t) = z(t, \theta) + n(t)$$

where:

- $n(t)$ identically distributed independent noise
- $z(t, \theta)$ slowly varying shift depending on some parameters θ
- $y(t)$ ideal response for boxcar-shaped activity

(3) Given the measured signal $x(t)$, determine the unknown parameters β, θ:

$$\sum_{t=0}^{T} [x(t) - \beta y(t) + z(t, \theta)]^2 \to \min_{\beta, \theta}$$

(4) Use the estimated β to decide whether the neurons in the voxel were active/inactive in the trial.

Functional MRI

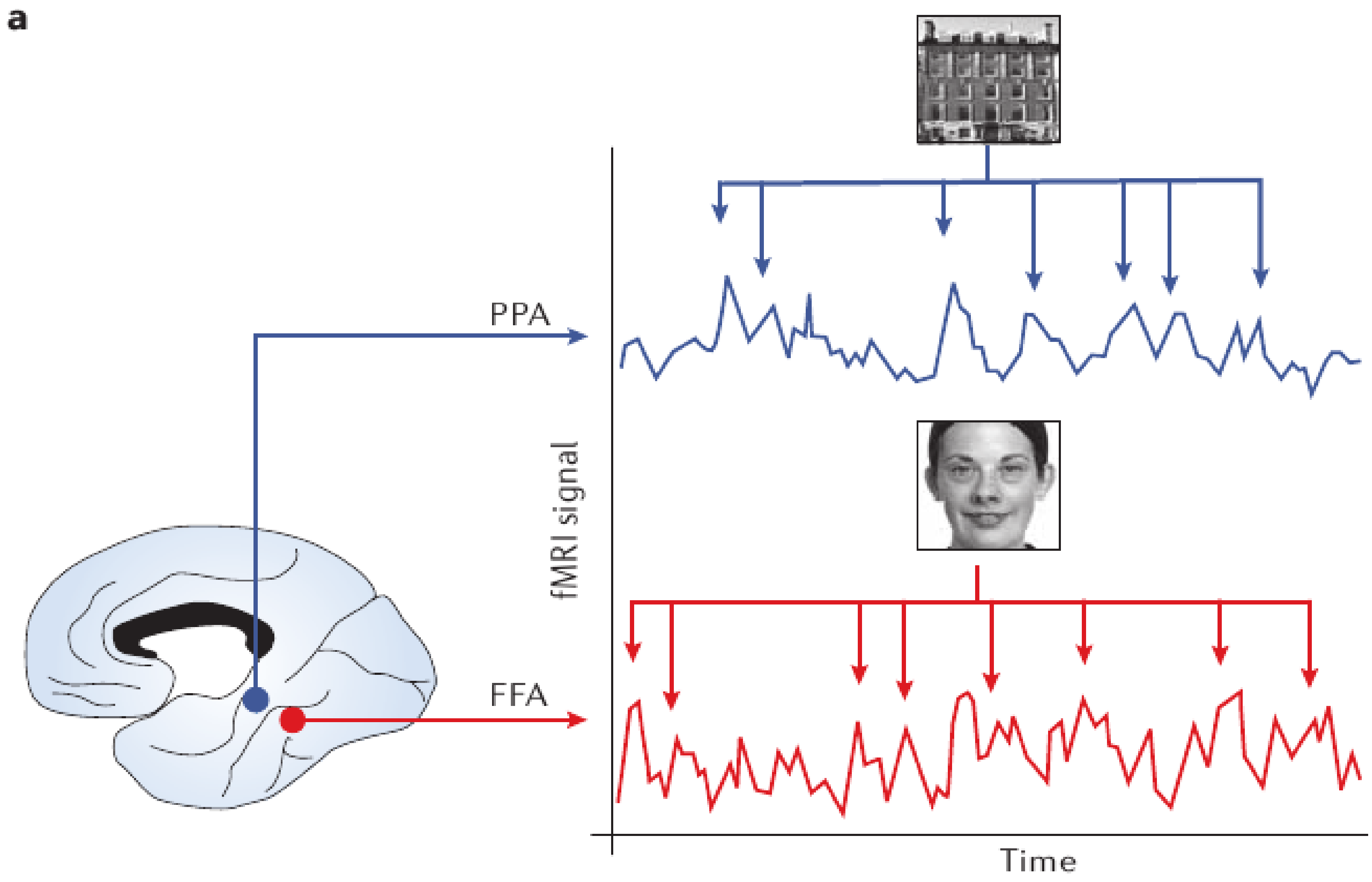
a) If the relation $s(t) - x(t)$ is known for a particular voxel: apply the outlined regression.

b) If both, $s(t)$ and $x(t)$ are known for a particular voxel: model and estimate the relation between them.

In reality neither $s(t)$ nor the relation $s(t) \Leftrightarrow x(t)$ are known.

Answer: apply a) and b) iteratively until convergence (e.g. for groups of adjacent voxels).

Functional MRI



During periods of face imagery (red arrows), signals are elevated in the fusiform face area whereas during the imagery of buildings (blue arrows), signals are elevated in the parahippocampal place area

Functional MRI

C. Recognising spatial activity patterns

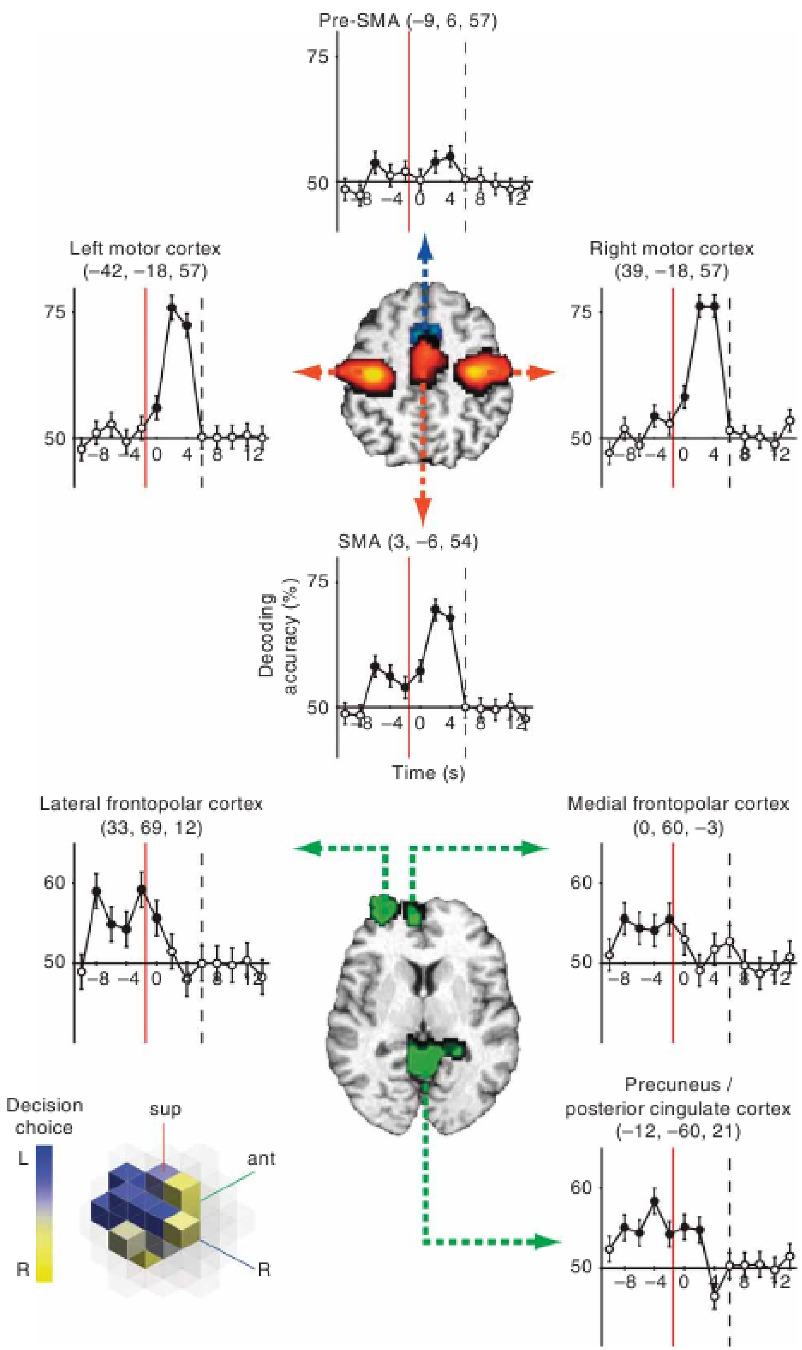
So far activity of each voxel was analysed independently. However mental states, object perception, motor actions, intentions etc. might by coded in **spatial activity patterns**.

- Ask subjects to make a decision (e.g. out of two possible) followed by a corresponding action.
- Capture fMRI images during this process.
- Try to identify brain regions whose activity pattern allows to predict the specific outcome of the choice.

For each small brain region V like e.g. a cube of voxels and for each time onset t_0:

- Consider the measured signal $x(\vec{r}, t_0)$, $\vec{r} \in V$ as a feature vector $\vec{x}$ and the known decision $y = 0, 1$.
- Having this information $(\vec{x}_i, y_i)$, $i = 1, 2, \ldots, \ell$ for ℓ trials, try to learn a linear classifier or a support vector machine to correctly predict the outcome.
- Identify brain regions and time onsets, for which the learned classifier predicts best.

Functional MRI



- J.-D. Haynes et.al., Unconscious determinants of free decisions in the human brain, Nature Neuroscience, 2008
- Subjects were asked to relax while fixating on the center of the screen where a stream of letters was presented.
- At some point, when they felt the urge to do so, they were to freely decide between one of two buttons, operated by the left and right index ngers, and press it immediately.
- In parallel, they should remember the letter presented when their motor decision was consciously made.
- After subjects pressed their freely chosen response button, a ‘response mapping’ screen with four choices appeared. The subjects indicated when they had made their motor decision by selecting the corresponding letter with a second button press.

Functional MRI

D. Neurosurgery Planning