Introduction

Brain Imaging

Tomas Knapen

Welcome to this course!

Who are we?

Tomas Knapen
Course Coordinator

Assistant Professor
Cognitive Psychology

Spinoza Centre for
Neuroimaging

Matthias Nau
Course coordinator

Assistant Professor
Cognitive Psychology

Contact

Ask questions after lectures or on Canvas!

No email: 

What to expect

12 Lectures:
Real-life interactions are invaluable for learning and engaging with the material, so lectures will be face-to-face.

3 Practicals:
Hands-on practicals will be provided on Google Colab (e.g., data analysis).
You can do them online or face-to-face with us in the dedicated time slots.

2 Journal clubs:
In small groups, you will read research articles, which we will discuss together in a dedicated face-to-face.

What will you learn?

Functional Magnetic Resonance Imaging (fMRI)

Conceptual knowledge

- What does fMRI measure, and how does it measure it?
- What research questions can it address?
- How do you design an experiment?
- How do you interpret fMRI results?

Practical know-how

- Working with (f)MRI data
- Analyze fMRI data
- Advances analyses

Image: amberusa.com

Course structure

What determines your grade?

Exam – End of the course (60%)

- Multiple-choice & open questions
- Content: Lectures, practicals, journal club
- Selected YouTube modules Wager & Lunquist

Quizzes – End of each modules (25%)

Participation in Perusall reading & journal club (15%)

Image: amberusa.com

Perusall reading

What determines your grade?

Perusall automatically scores your participation based on engagement time, comments, reactions...

First reading starts today!

Perspective

Functional neuroimaging as a catalyst for integrated neuroscience

https://doi.org/10.1038/s41586-023-06670-9

Emily S. Finn[1], Russell A. Poldrack[2] & James M. Shine[3]

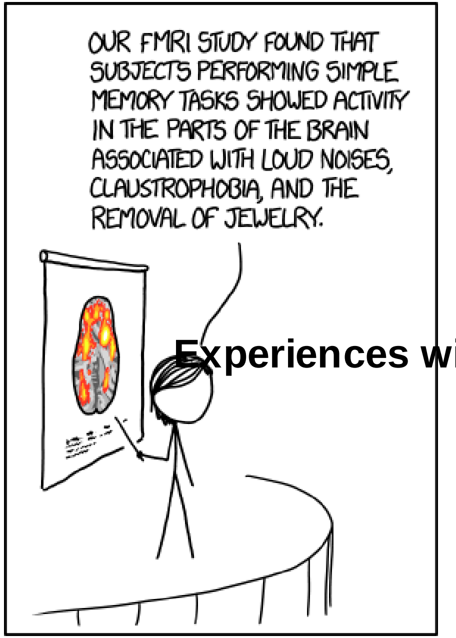
Received: 16 March 2023

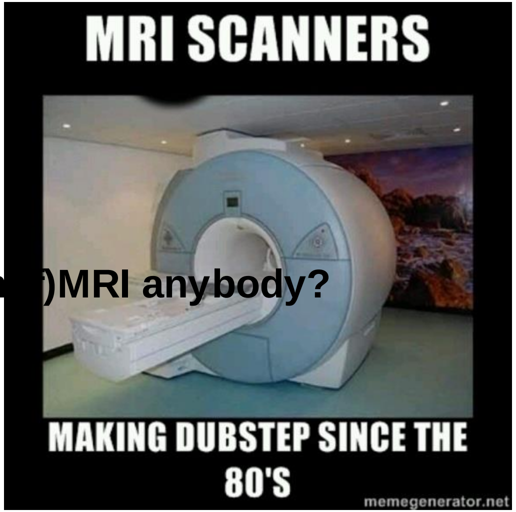
The following weighting is used:

Comment content	Opening assignment	Reading, watching, or listening to the end	Active engagement time	Getting responses	Upvoting	Quizzes
The content of the comments students post, automatically scored by Perusall's quality algorithm.	Breaking up work on the assignment into multiple sittings.	Reading the entire document, watching the entire video, or listening to the entire podcast.	Time spent actively engaging with the assignment.	Writing comments that elicit responses from other students.	Writing comments that are upvoted by other students, and upvoting other students' comments.	Responding to quiz questions that are part of an assignment.
50 %	10 %	20 %	10 %	20 %	20 %	0 %
Options	Options	Options	Options	Options	Options	Options

Students earn full credit on this metric by submitting 2 high-quality comments.

Experiences with (f)MRI anybody?





MRI scanners are loud and uncomfortable.
You can’t move, and your doing often boring tasks for a long time.

Why!?

Why fMRI?

fMRI allows studying the human brain in action

Non-invasive measurement of brain activity

Appealing balance between:

- Temporal resolution: Seconds
- Spatial resolution: Millimeter
- Coverage: Whole-brain

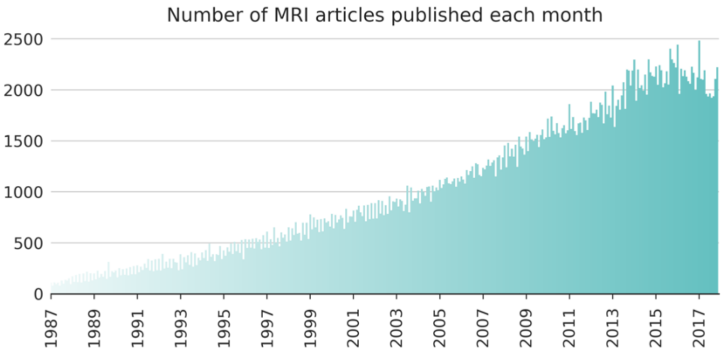
MRIs are **available** in many hospitals

Imaging analysis **skills are a sought after** also in other disciplines

Highest-end technology that is **continuously evolving** (work stays interesting!)

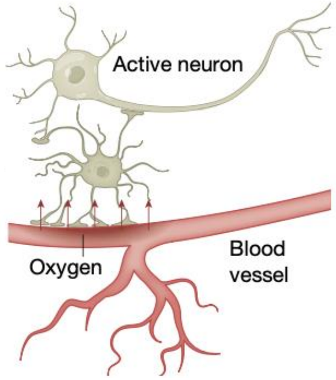
Inherently interdisciplinary field (You will meet SO many fun and interesting people!)

Brain imaging has exploded over the 30 years!



Retinotopy viewer: https://gallantlab.org/viewer-retinotopy-demo/

Why not fMRI: Common criticisms



Indirect (blood flow related) measure of neural activity

- Hemodynamic coupling is well established, and at least it measures everything, not ‘just’ the effect of neuronal spikes (e.g., 4x more glia cells than neurons in the cortex)

Limited resolution (e.g., no single cells, no action potentials...)

- Constant improvements, and who decided what the relevant scale is for understanding the brain?

Constrained set of experiments (e.g., head motion not possible)

- Many beautiful experiments feasible, every technique has constraints, data can be combined with other techniques

MRI signal is **noisy** (e.g., often low signal-to-noise ratios)

- Contant improvements, fMRI tools are being developed that help other techniques, someone’s noise is someone’s signal

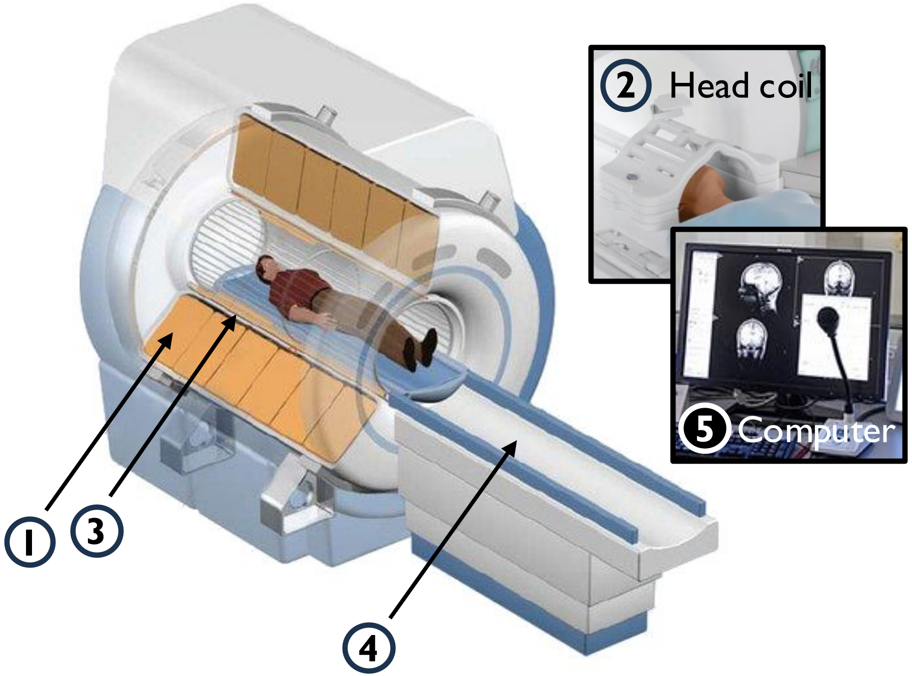
Analytical challenges (e.g., autocorrelations...)

- Not unique to fMRI, task design can counteract, the field has matured a lot over the past 30+ years

The MRI scanner

Image:
amberusa.com

The MRI scanner



Main components

1) **Main magnet**
Creates a strong magnetic field
(7 Tesla = 140.000x earth's magnetic field)

2) **Radiofrequency (RF) coil**
Transmits & receives radio frequency waves

3) **Gradient coils**
Create additional magnetic fields whose strength varies along XYZ dimensions (important for localizating the signal!)

4) **Patient table**
Moves the patient in and out

5) **Computer system**
Controls the scanner from another room

The MRI scanner

Magnetic field strength

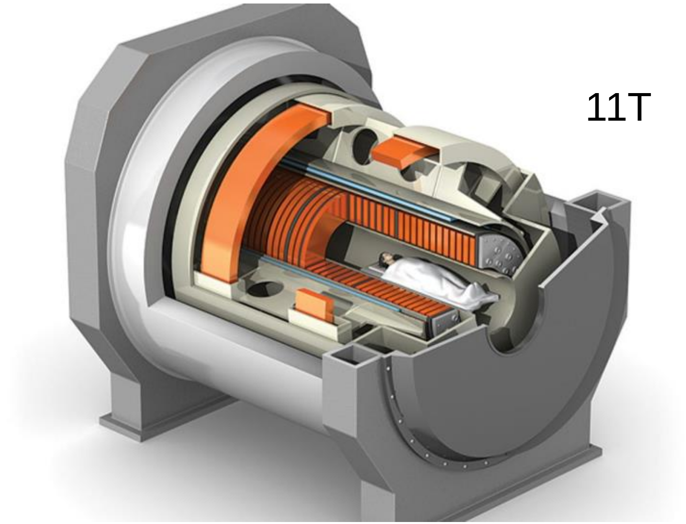
- Measured in Tesla (T)
- 1T = 20.000 x Earth magnetic field
- Typical hospital scanner: 1.5-3T
- Research scanners: 3-11T
- Higher field strength = stronger signal

The MRI scanner creates many different types of **images of living tissue** like the brain **non-invasively**

Different images are created by running different programs called **MRI sequences**

1.5T

7T



11T

The MRI scanner

Careful! The main magnetic field is always on!

'There was a patient on the table and this trainee brought the non-MRI-safe-wheelchair in'
Fox news, Sept 2024

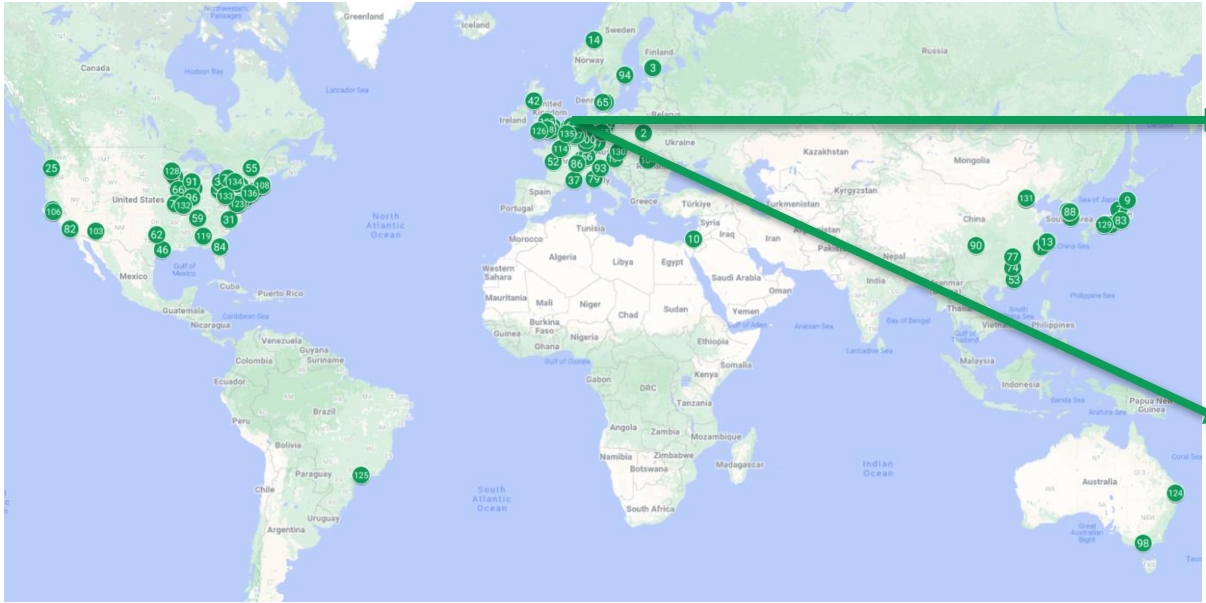
'A nurse was injured in an MRI accident'
Fox news, Oct 2023

'Lawyer Dies After Shot By His Own Concealed Gun Triggered By MRI'
Forbers, Feb 2023

MRI is generally safe, but remember: Never bring magnetic objects into the scanner room!

The MRI scanner

There are currently around 140 Ultra-high field MRI scanners in the world



Each dot is a >=7T MRI, https://layerfmri.com/2018/01/04/high-field-mri-scanners/

Spinoza Centre

for Neuroimaging

Amsterdam (7T)

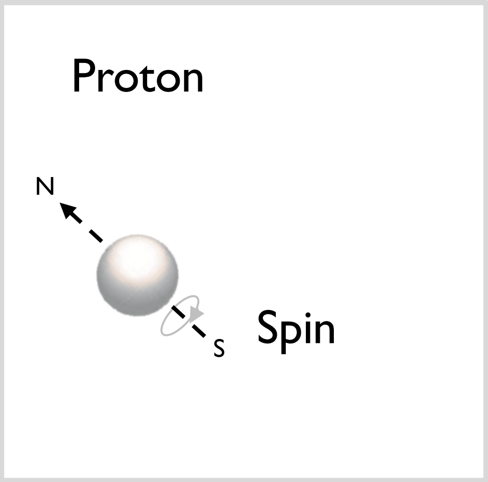
New National MRI Facility

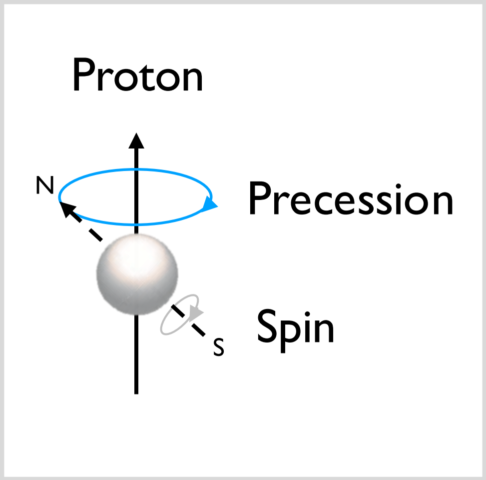
Currently being built in

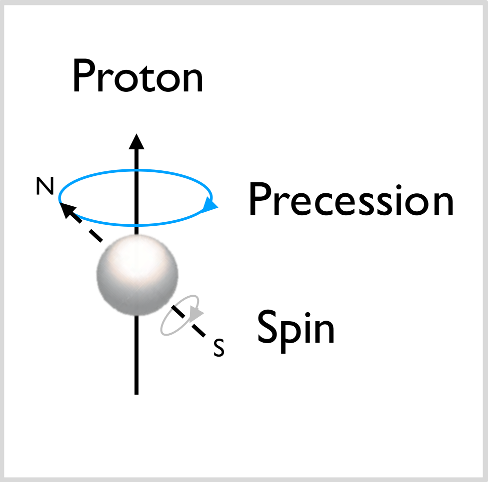
Nijmegen (14T)

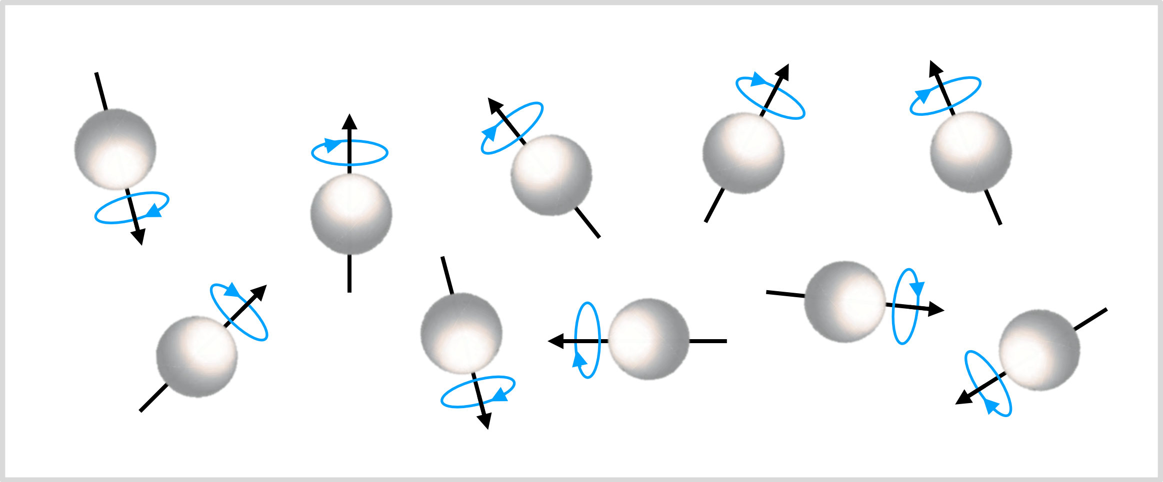
MR-physics and data acquisition

Image:
amberusa.com


Proton
N
S
Spin


Proton
N
Precession
Spin
S

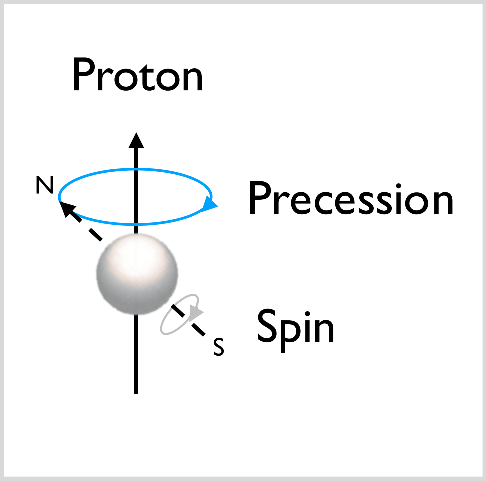


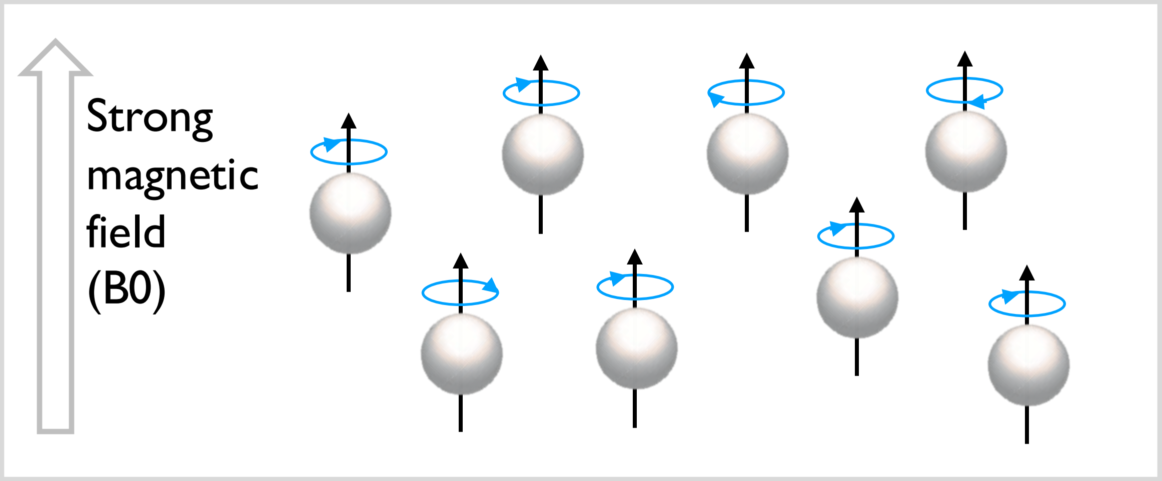


No net-magnetization

Random axis

Random phase

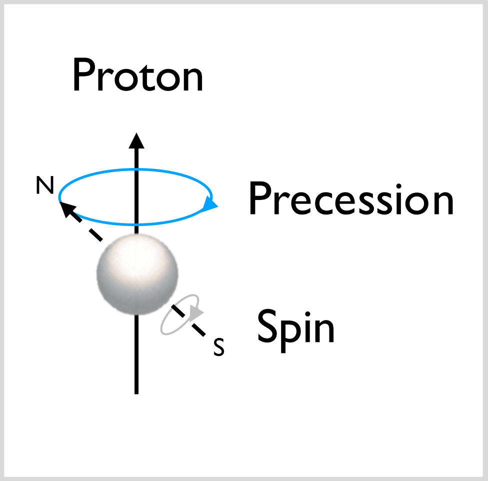


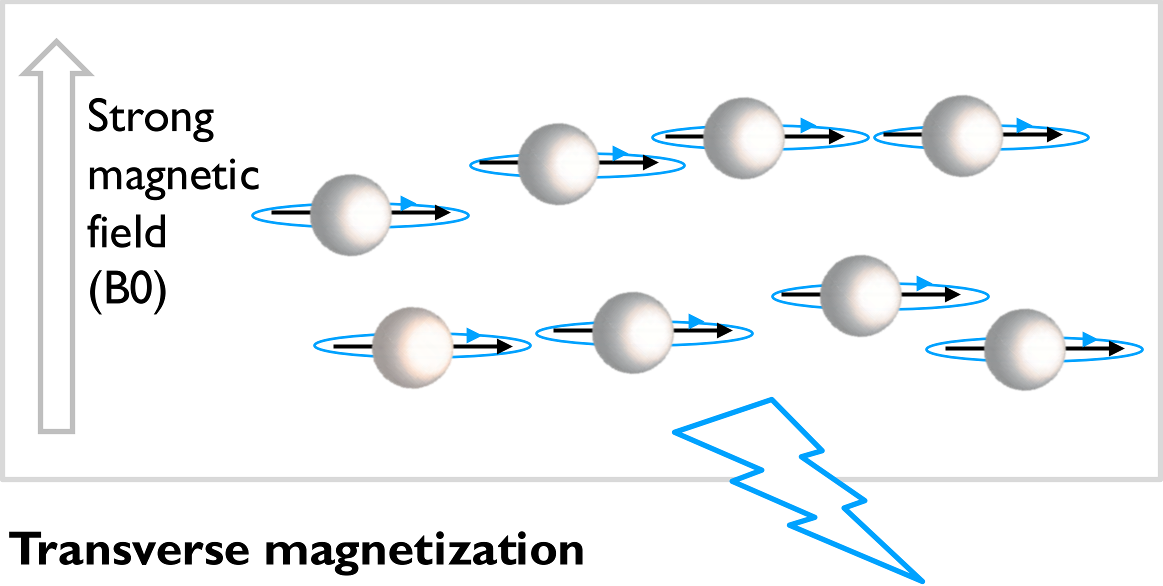


Longitudinal magnetization

Axis aligned to B0

Random phase





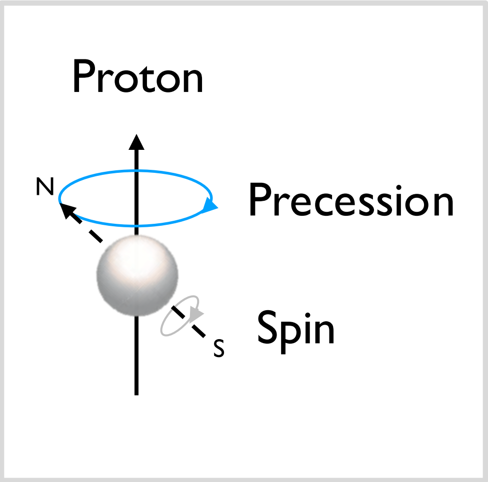
Protons **resonate** if the RF-pulse frequency matches their precession frequency (i.e., they take on energy).

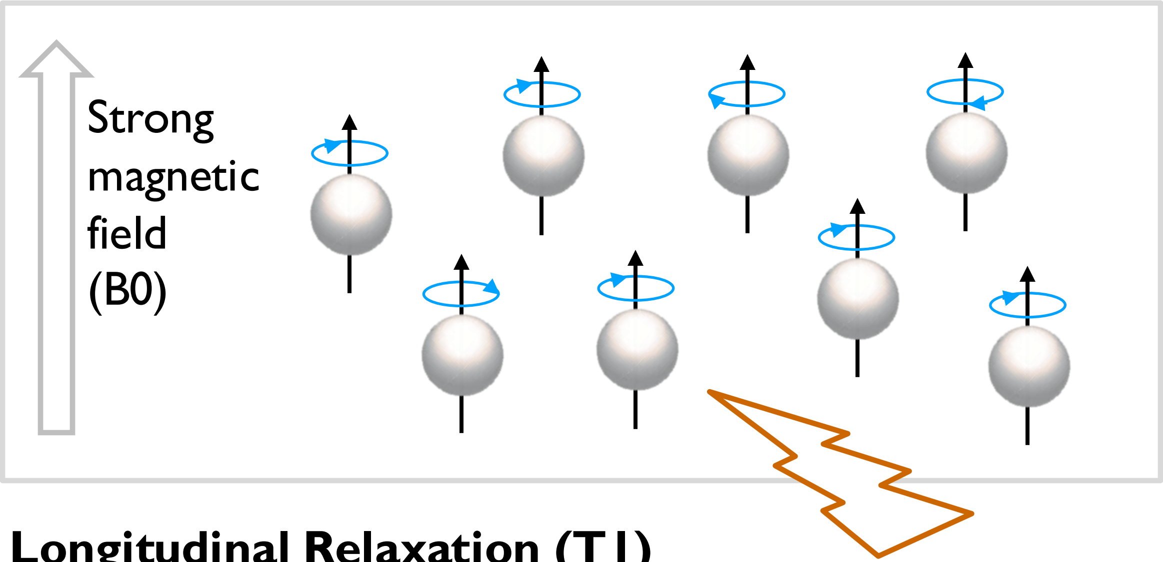
Transverse magnetization

Axis flipped orthogonal to B0

Protons now phase aligned

Radiofrequency (RF) pulse





After RF-pulse ceases, **protons emit energy** in the form of RF waves that induce currents in **receiver coils** (That's the MRI signal!)

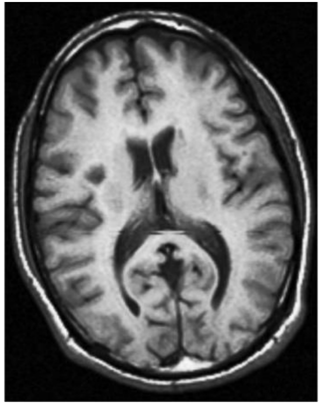
Longitudinal Relaxation (T1)
Axis flips back into B0 direction

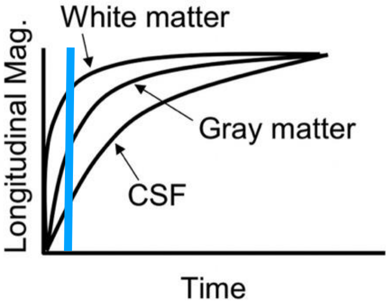
Energy release

Transverse Relaxation (T2)
Phase coherence gets lost

More on MR-physics in Lecture 10

T1-weighted image



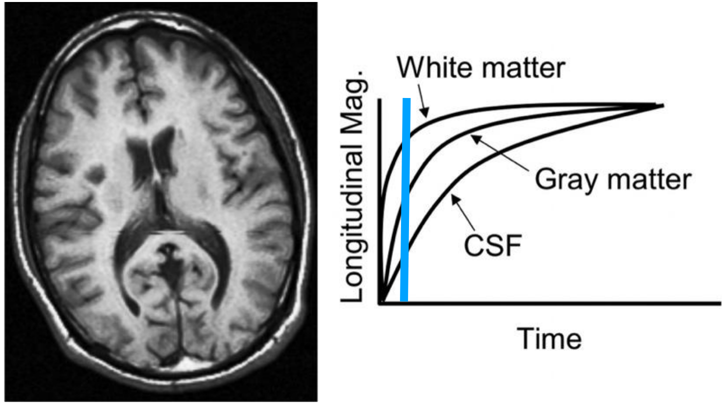


Structural images

Higher resolution (~1mm at 3T),
high contrast, fewer artifacts

Pooley (2005)

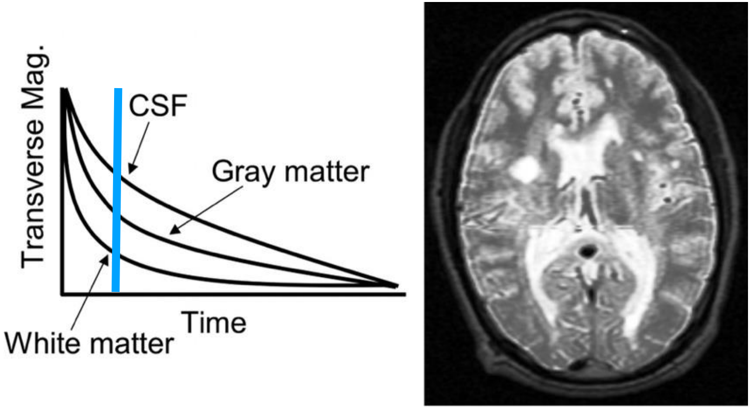
T1-weighted image



⇨ Structural images

Higher resolution (~1mm at 3T),
high contrast, fewer artifacts

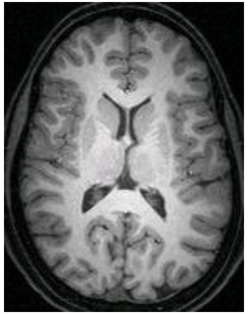
T2-weighted image



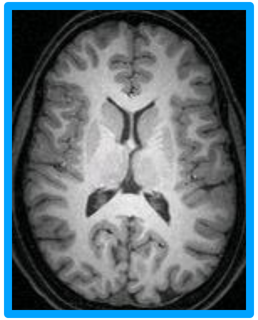
⇨ Functional images

Lower resolution (~2mm at 3T),
susceptible to blood oxygenation (**T2***)

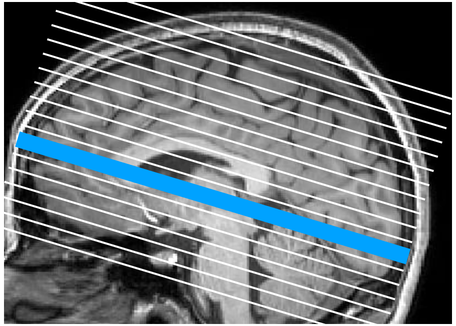
Pooley (2005)



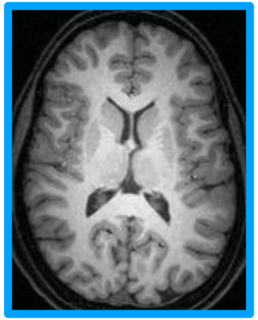
Slice



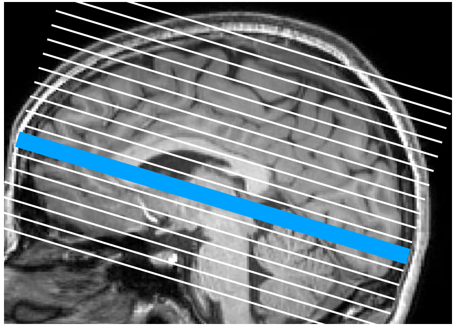
Slice



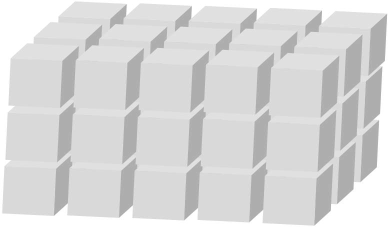
Volume



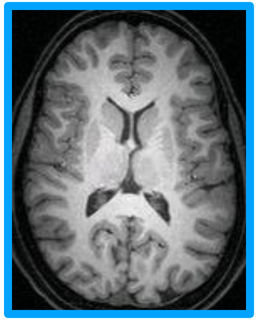
Slice



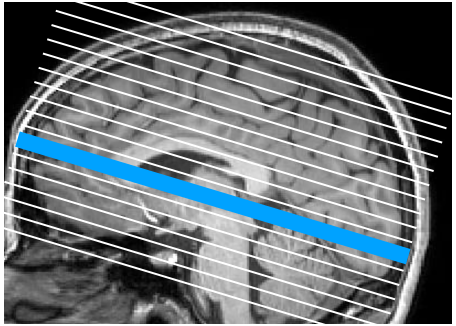
Volume



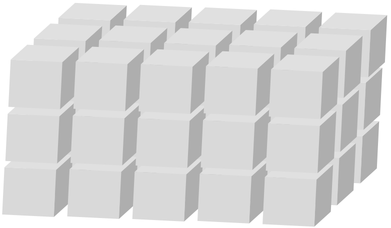
Voxels



Slice

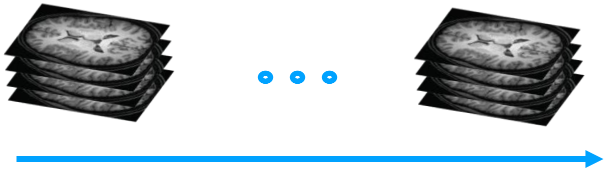


Volume

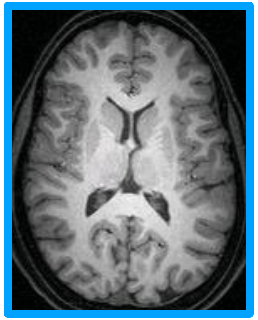


Voxels

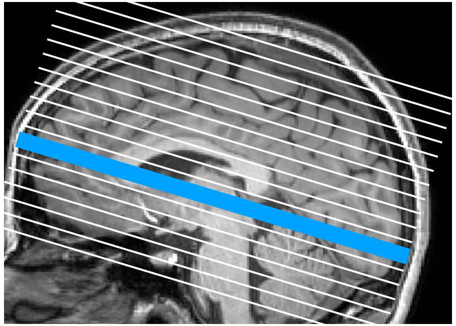
Scanning



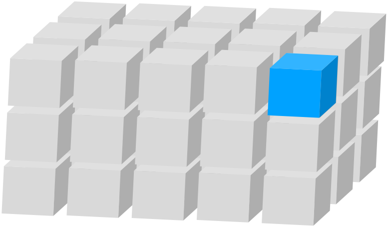
Time



Slice

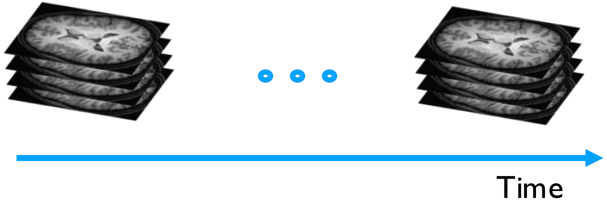


Volume

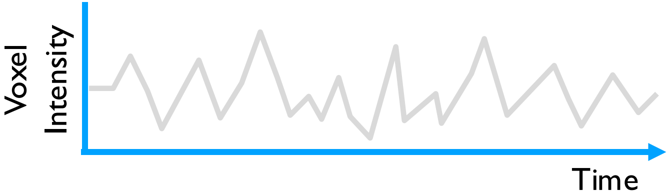


Voxels

Scanning



Data = Voxel intensities over time*



*Time between images = Repetition time (TR)

Preprocessing

Image:
amberusa.com

Motion correction

Problem: Head movements shift voxels

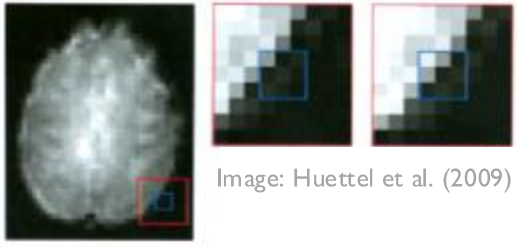
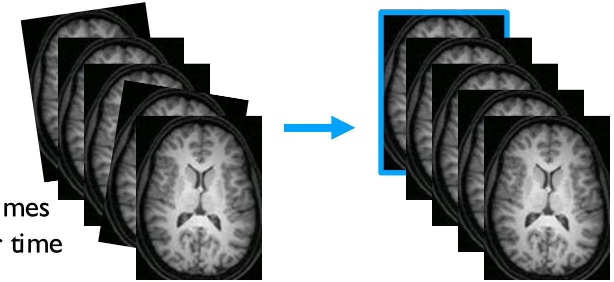


Image: Huettel et al. (2009)

Solution: Realignment



Images are rotated & moved until they align

Motion correction

Problem: Head movements shift voxels

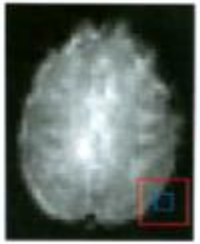
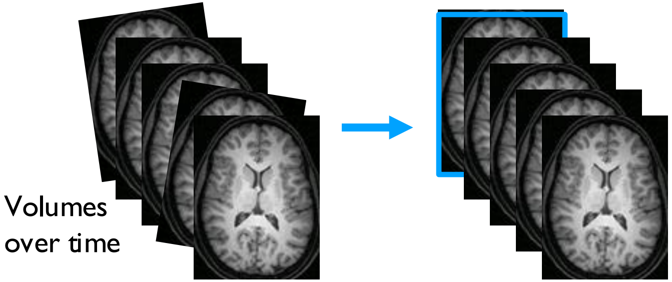


Image: Huettel et al. (2009)

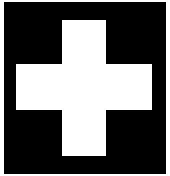
Solution: Realignment



Images are rotated & moved until they align

Unwarping

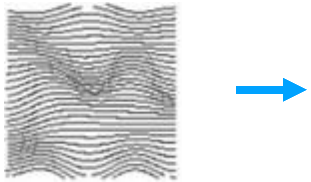
Problem: Recorded image is often distorted



True

Recorded

Solution: Map and correct magnetic field distortions



e.g. B0-field mapping

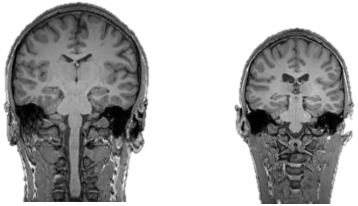
Unwarped

Images are corrected for warping

Images: Davis & Loh, UCL-slides (2011)

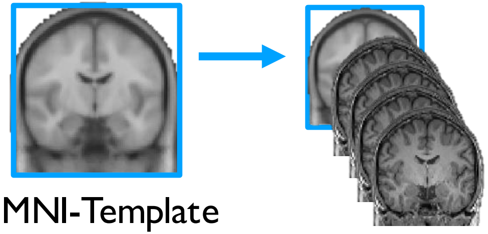
Normalization

Problem: Anatomical differences between subjects, coordinates are not comparable



Subject 1 Subject 2

Solution: Convert images into common space



e.g. MNI-Template

Warping all images of all participants such that they align with the same template brain

Overview:

*Additional standard steps we did not talk about yet

1) **Motion correction**
2) **Unwarping**
3) Slice time correction*
4) Coregistration*
5) **Normalization**
6) Spatial Smoothing*
7) High-pass filtering*

More on Preprocessing in Lecture 10 and the Practicals

Images: Fiford & Kia (2014), lecture slides

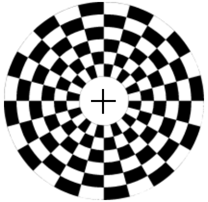
Data Analysis

Image: amberusa.com

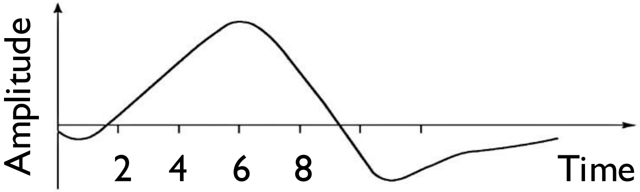
Blood Oxygenation Level Dependent (BOLD) Signal

MRI

Stimulus



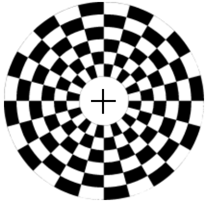
Hemodynamic response function (HRF)



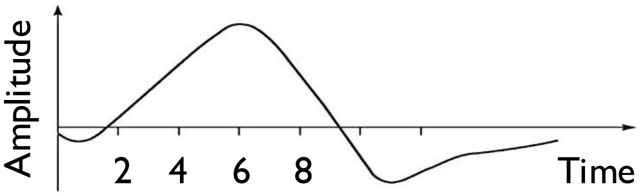
Blood Oxygenation Level Dependent (BOLD) Signal

MRI

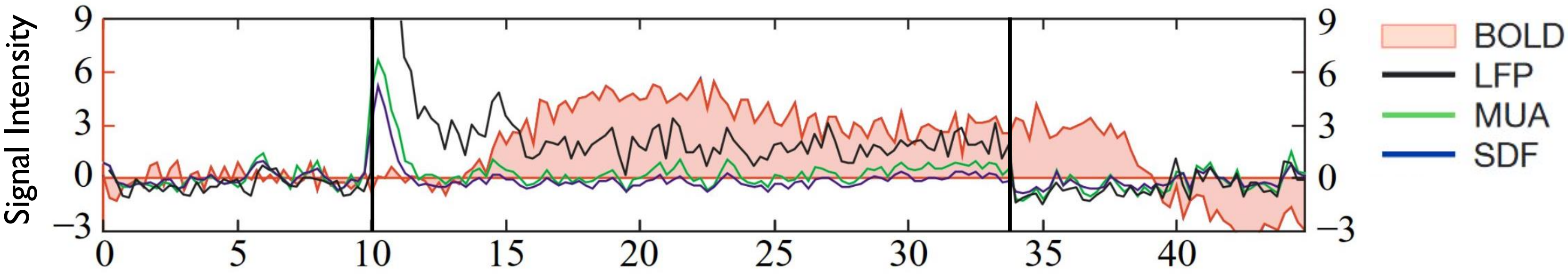
Stimulus



Hemodynamic response function (HRF)



Neurophysiological underpinnings



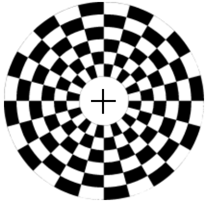
Time

Logothetis et al. (2001, 2008)

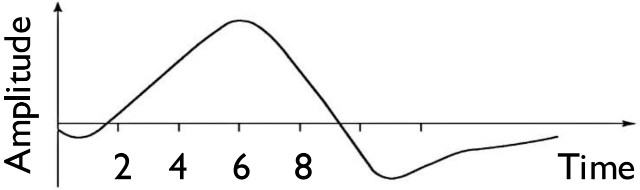
Blood Oxygenation Level Dependent (BOLD) Signal

MRI

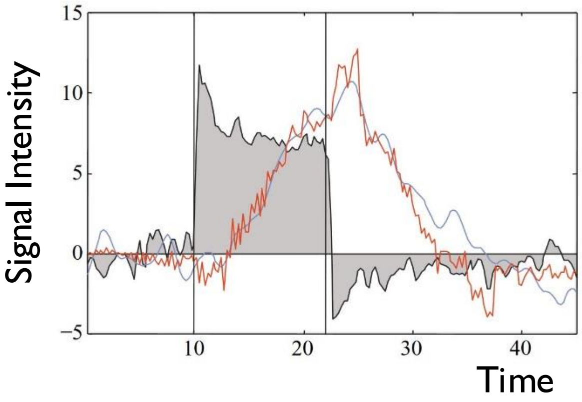
Stimulus



Hemodynamic response function (HRF)



Neurophysiological underpinnings



Local field potential (LFP)

LFP convolved with HRF

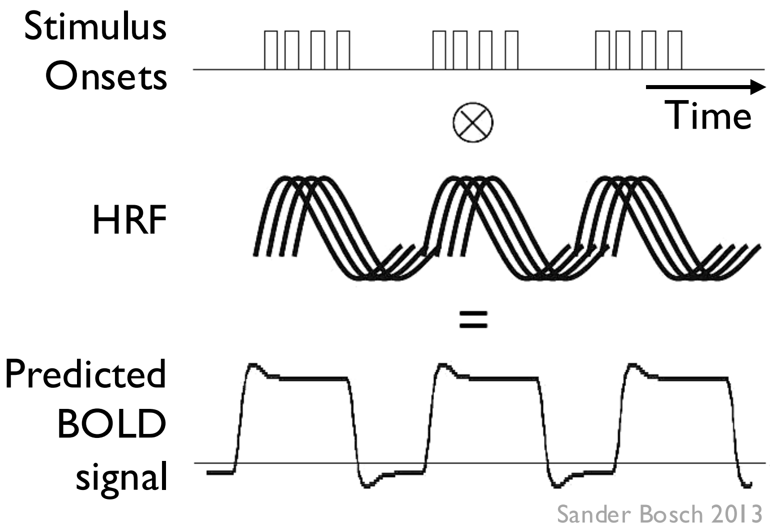
Observed BOLD

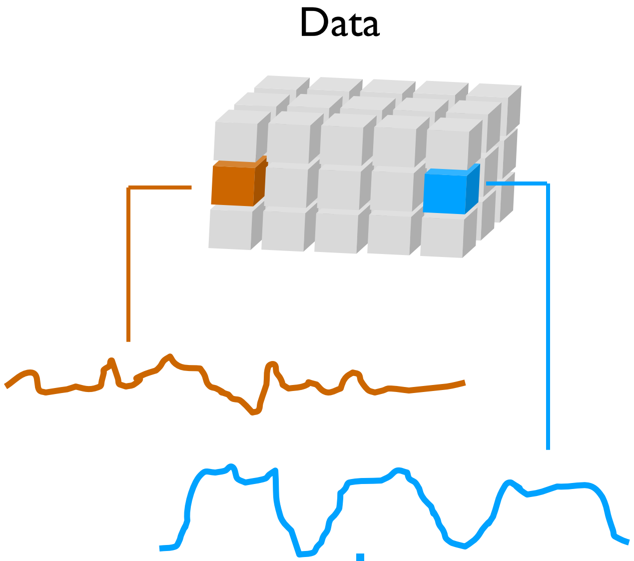
More on Physiology in Lectures 3-5

More on Experiments in Lecture 2

Logothetis et al. (2001, 2008)

Basic analysis

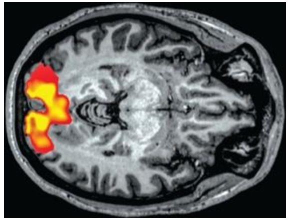




How well does prediction match the data?

More on analyses in Lectures 7-10

General Linear Model (GLM)



Hot colors show voxels whose time series could be well predicted based on the experiment

Key terms to remember

- Field strength (Tesla)
- Proton spin

  Precession
- Nuclear resonance
- B0 magnetic field
- Longitudinal magnetization
- Transverse magnetization
- Radiofrequency pulse
- T1-weighted (structural) images
- T2-weighted (functional) images
- Voxel
- Repetition time
- Preprocessing
- Motion correction
- Unwarping
- Normalization
- Hemodynamic response function
- BOLD signal
- General linear model

Image: amberusa.com

Thanks! See you all on Friday!

"...the single most critical piece of equipment is still the researcher's own brain. […] What is badly needed now, with all these scanners whirring away, is an understanding of exactly what we are observing, and seeing, and measuring, and wondering about."

Endel Tulving*, interview in Cognitive Neuroscience*
2002, Gazzaniga, Ivry & Mangun, Eds., NY: Norton, p. 323