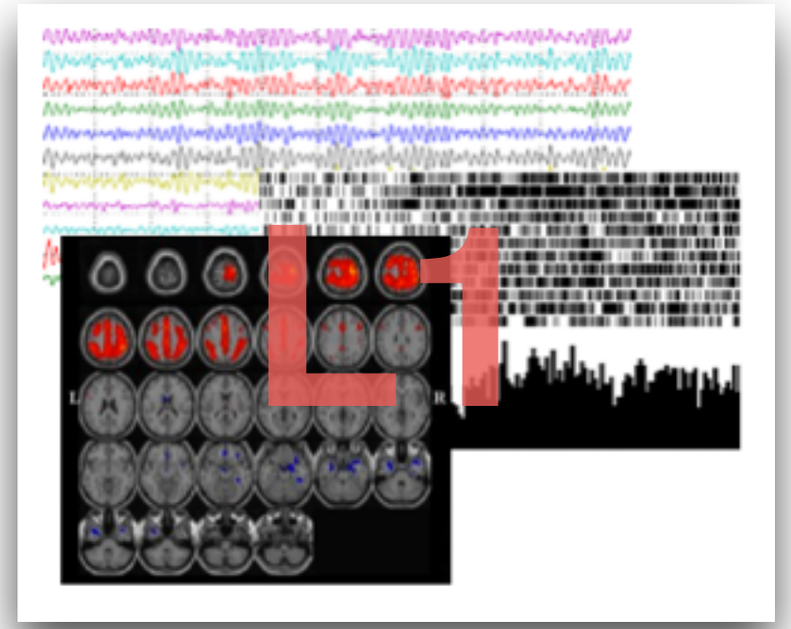
Machine Learning on Neuroimaging Data

Lecture 1: Neuroimaging Techniques

Ilya Kuzovkin

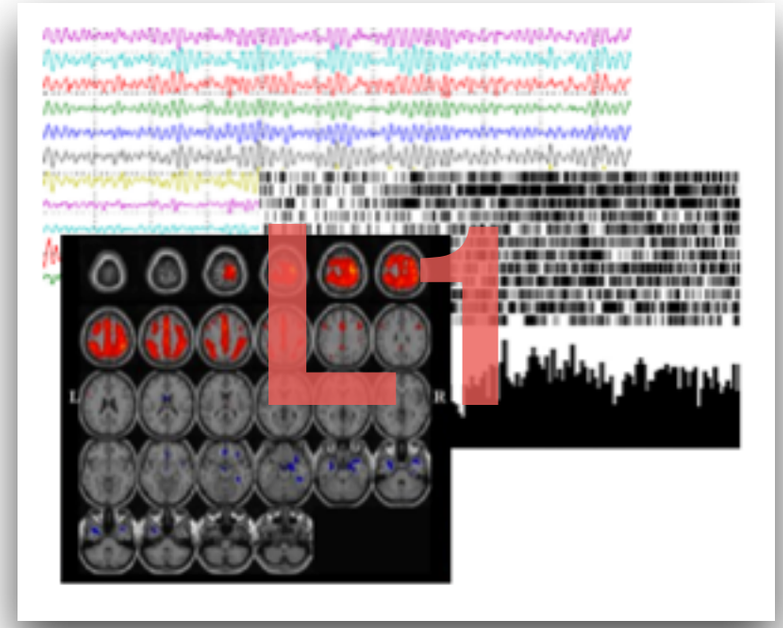
AACIMP, August 2014

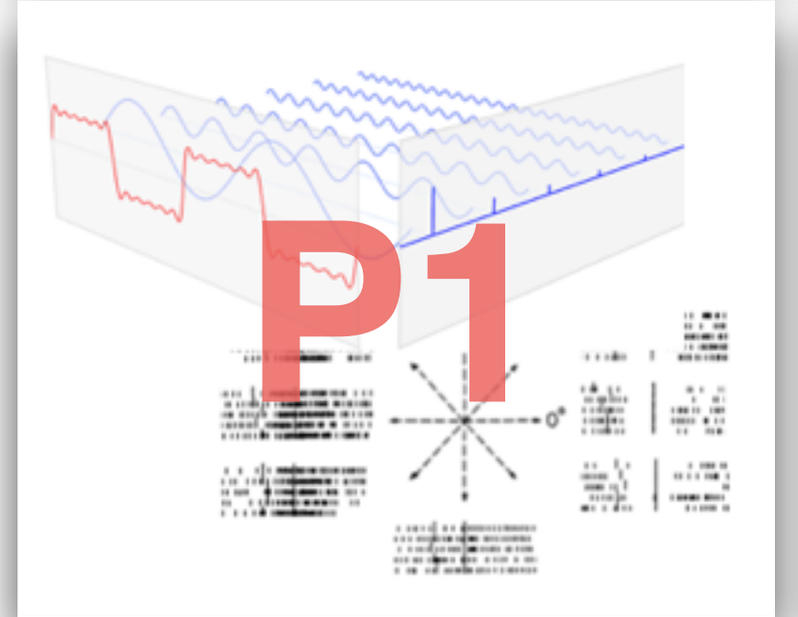
The course

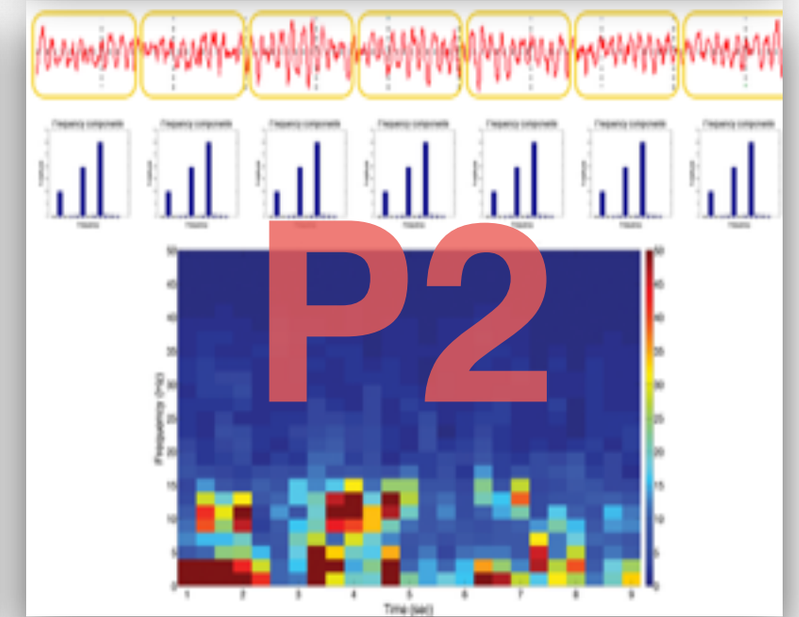


Neuroimaging Data

THE COURSE

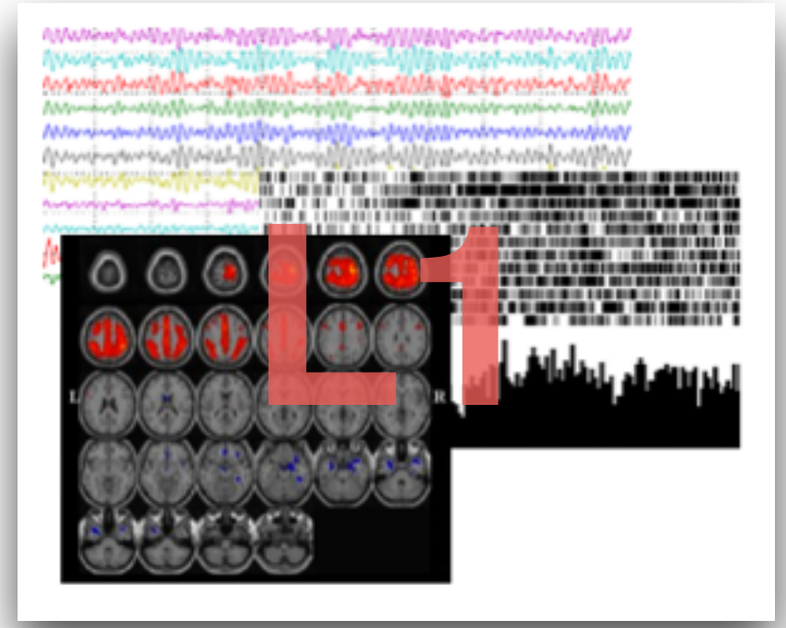


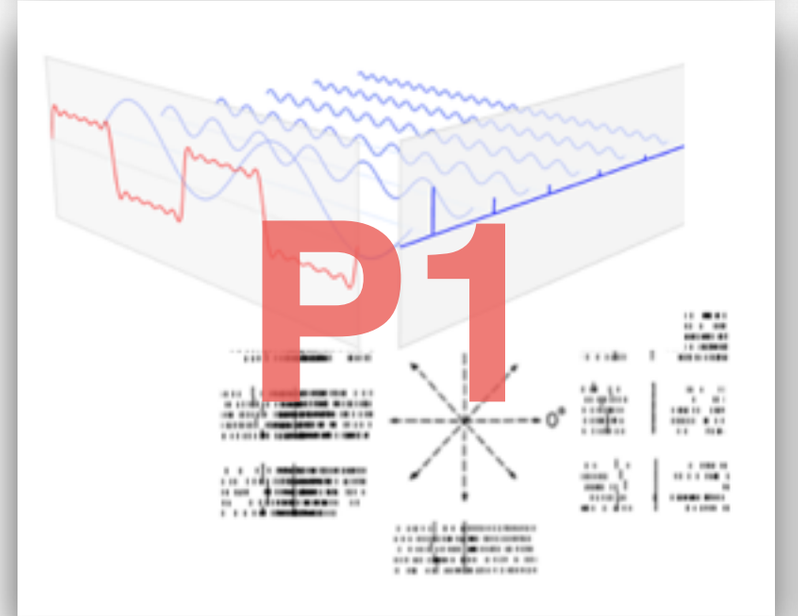


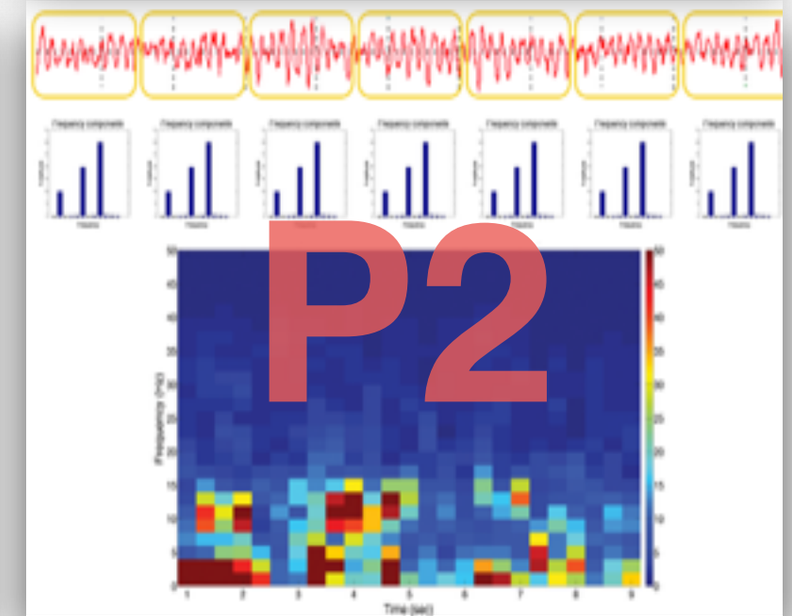


NEUROIMAGING DATA + MACHINE LEARNING

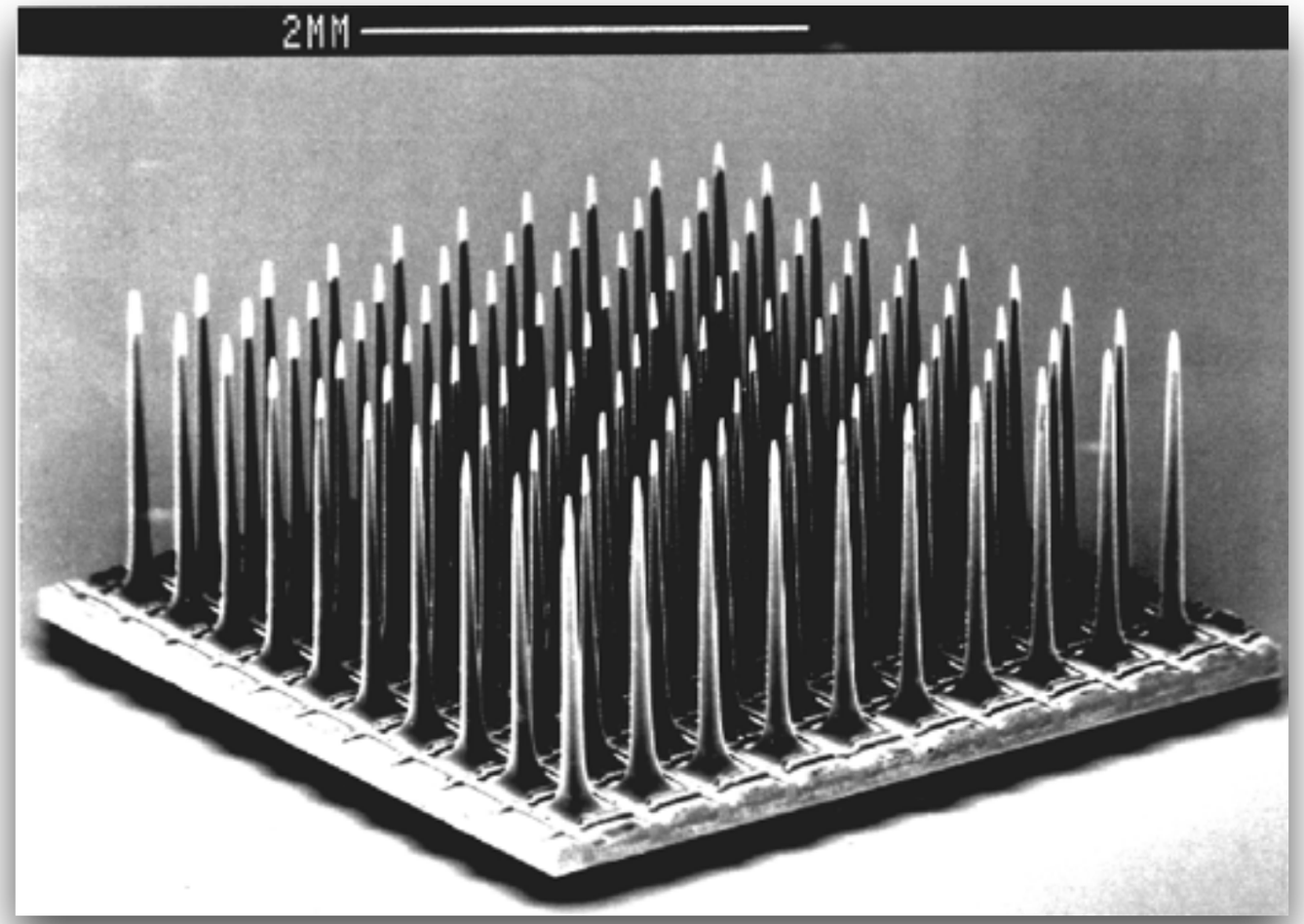
THE COURSE





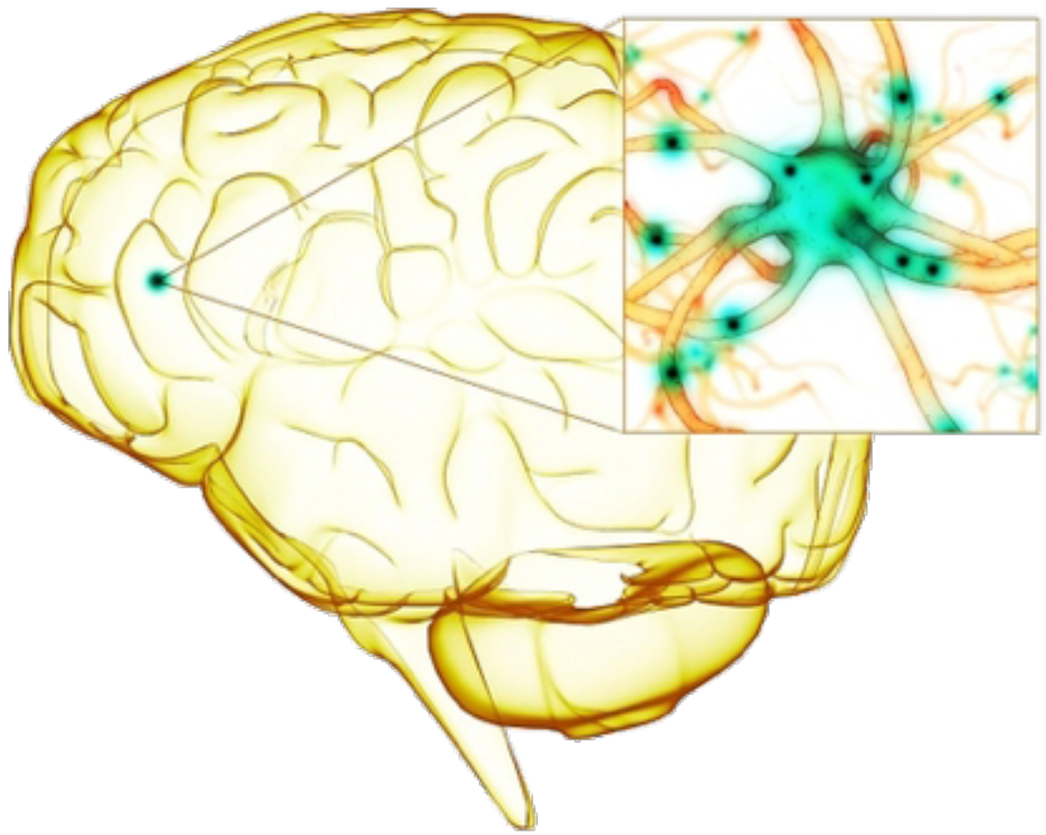


NEUROIMAGING DATA + MACHINE LEARNING = BRAIN-COMPUTER INTERFACE



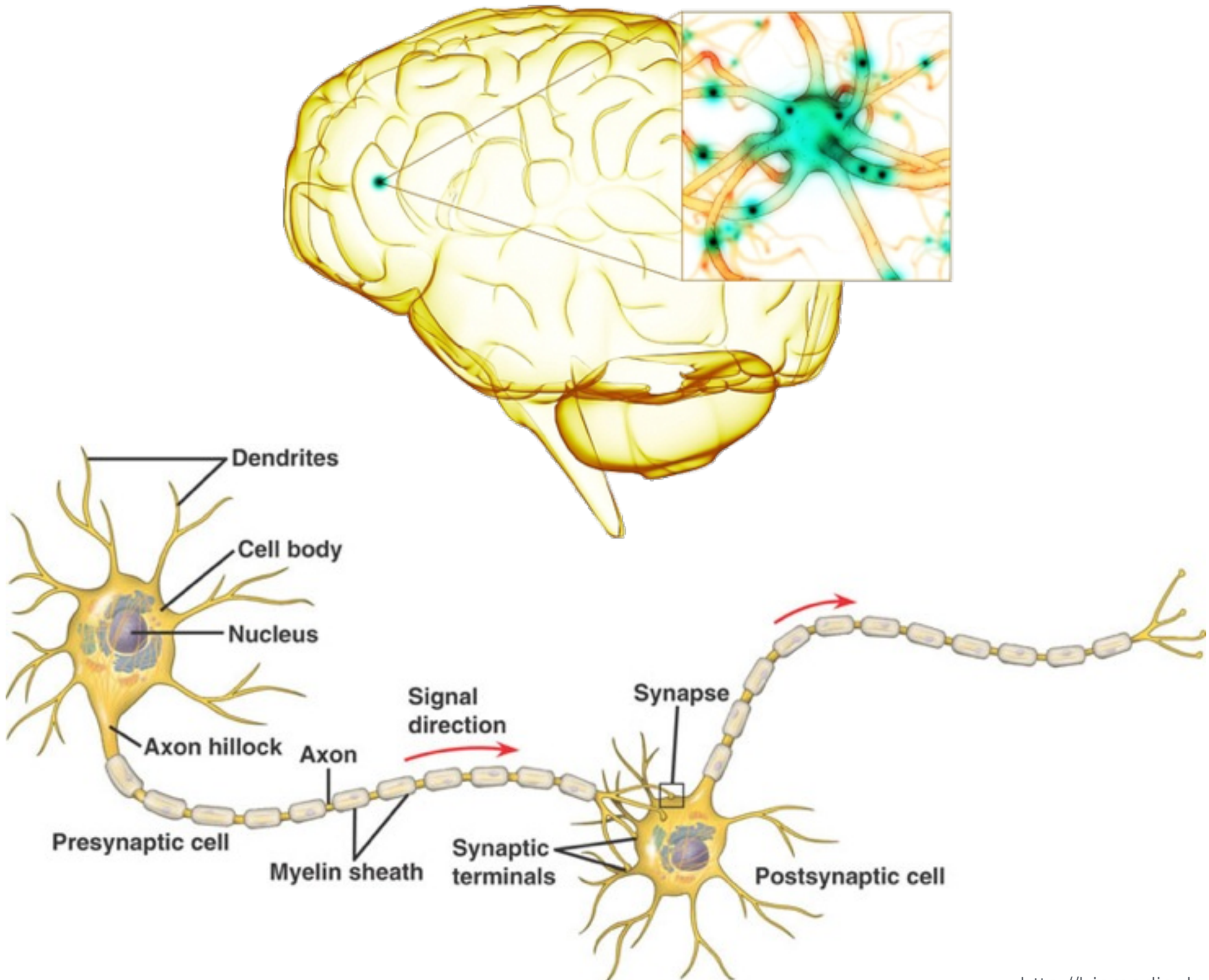
PART I
INTRACORTICAL

Neurons



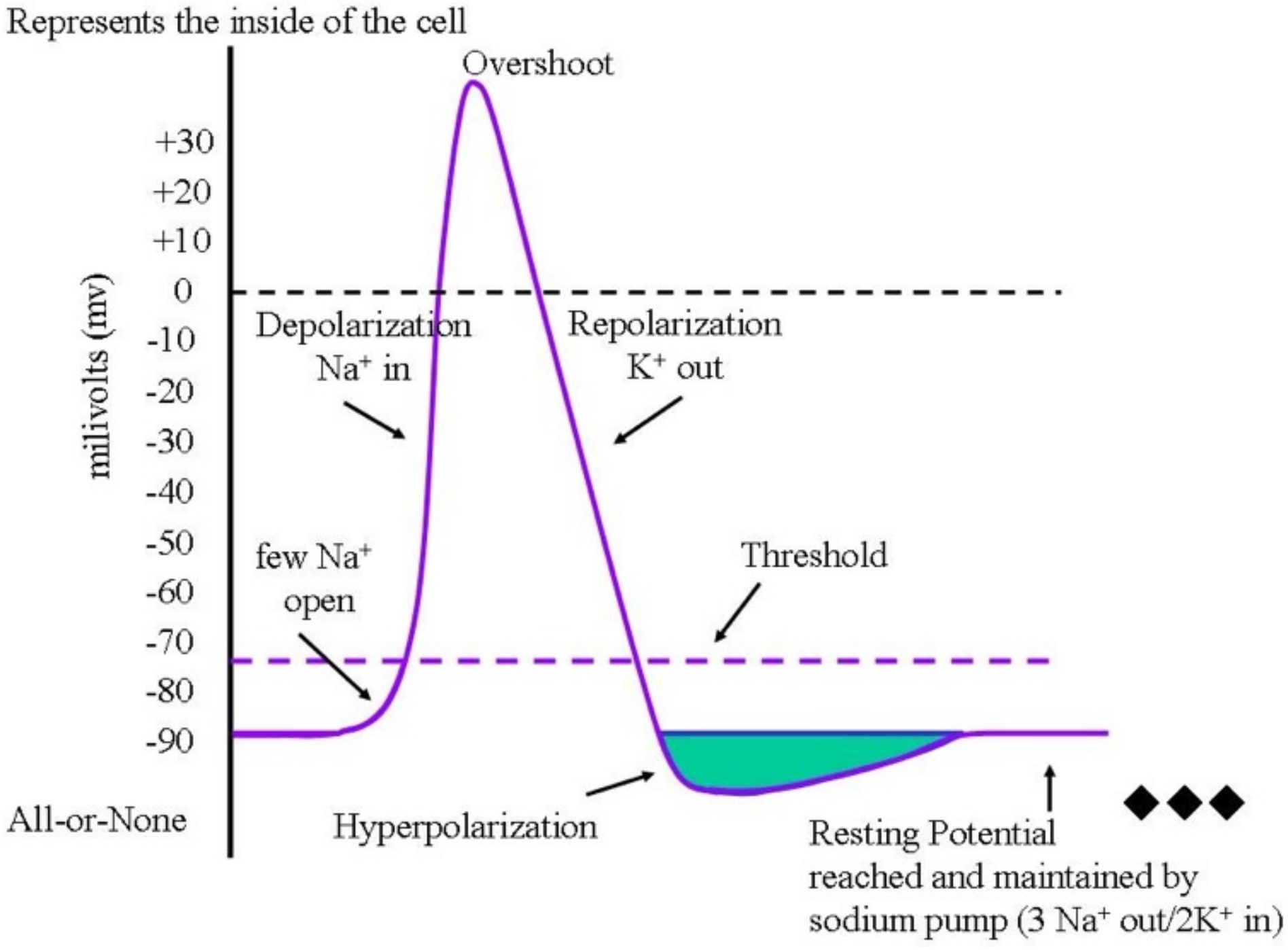
http://biomedicalengineering.yolasite.com

Neurons



http://biomedicalengineering.yolasite.com

SPIKE



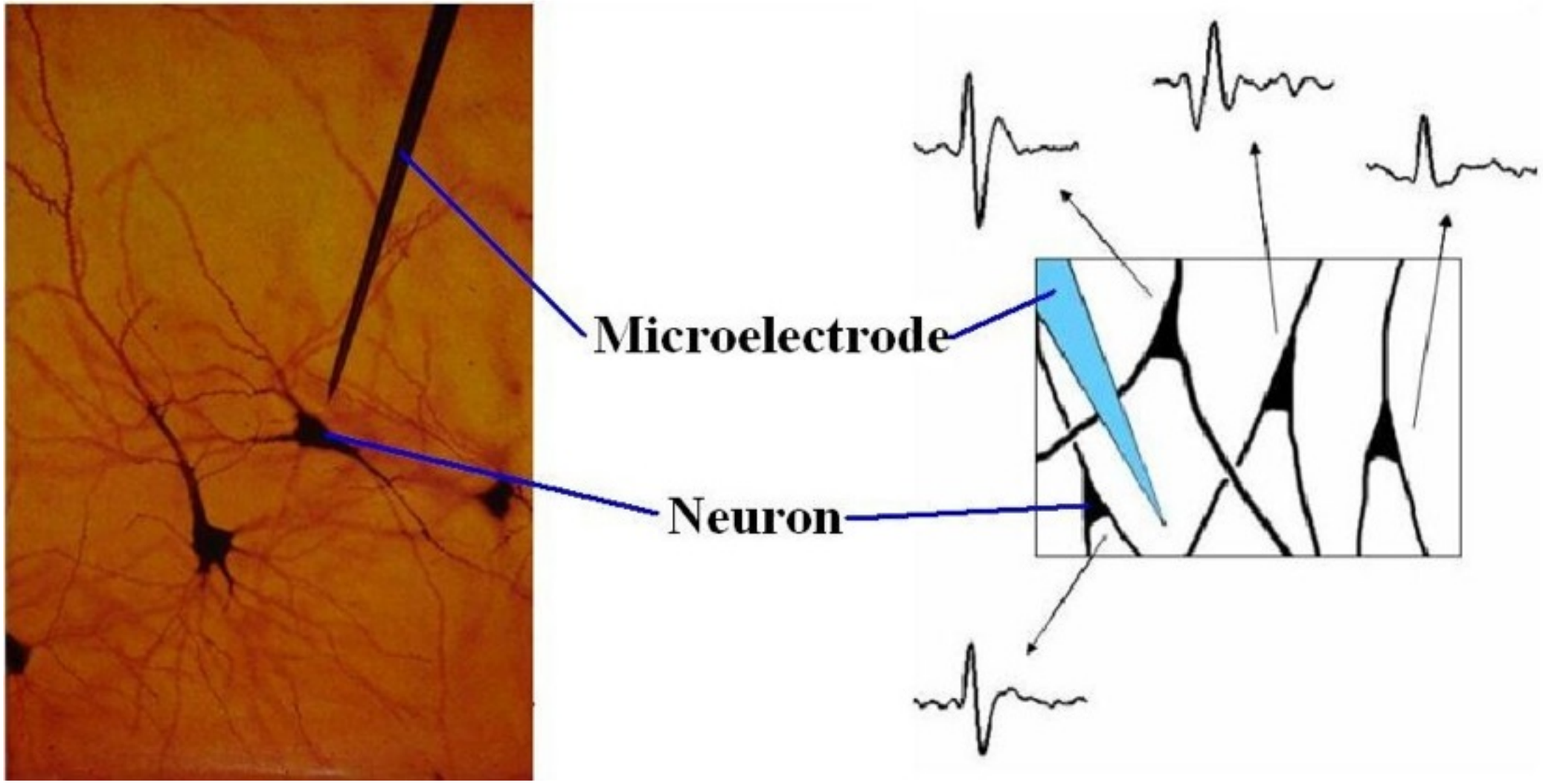
http://faculty.tcc.edu/mmitchell/142/ap-graph1.jpg

SPIKE

How can voltage be negative?

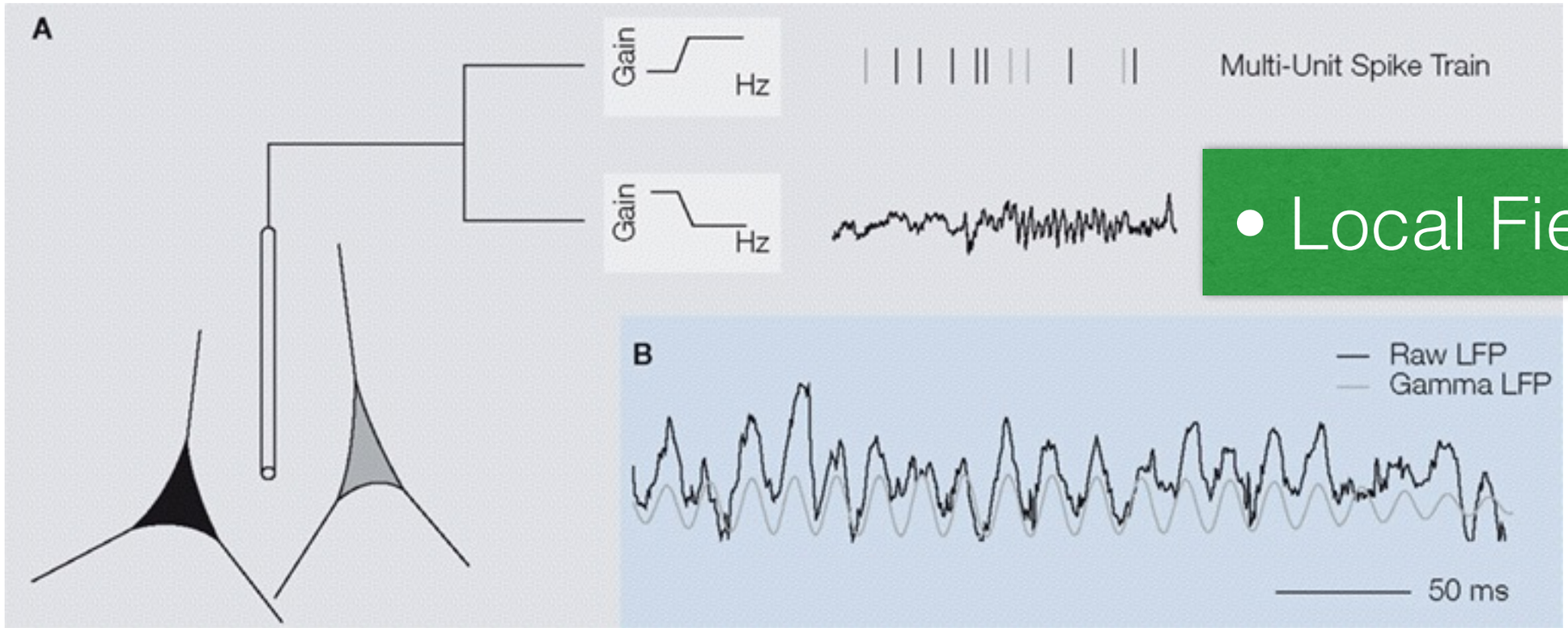
http://faculty.tcc.edu/mmitchell/142/ap-graph1.jpg

ELECTRODES



http://newton.umsl.edu/tsytsarev_files/neuron_electrode.JPG

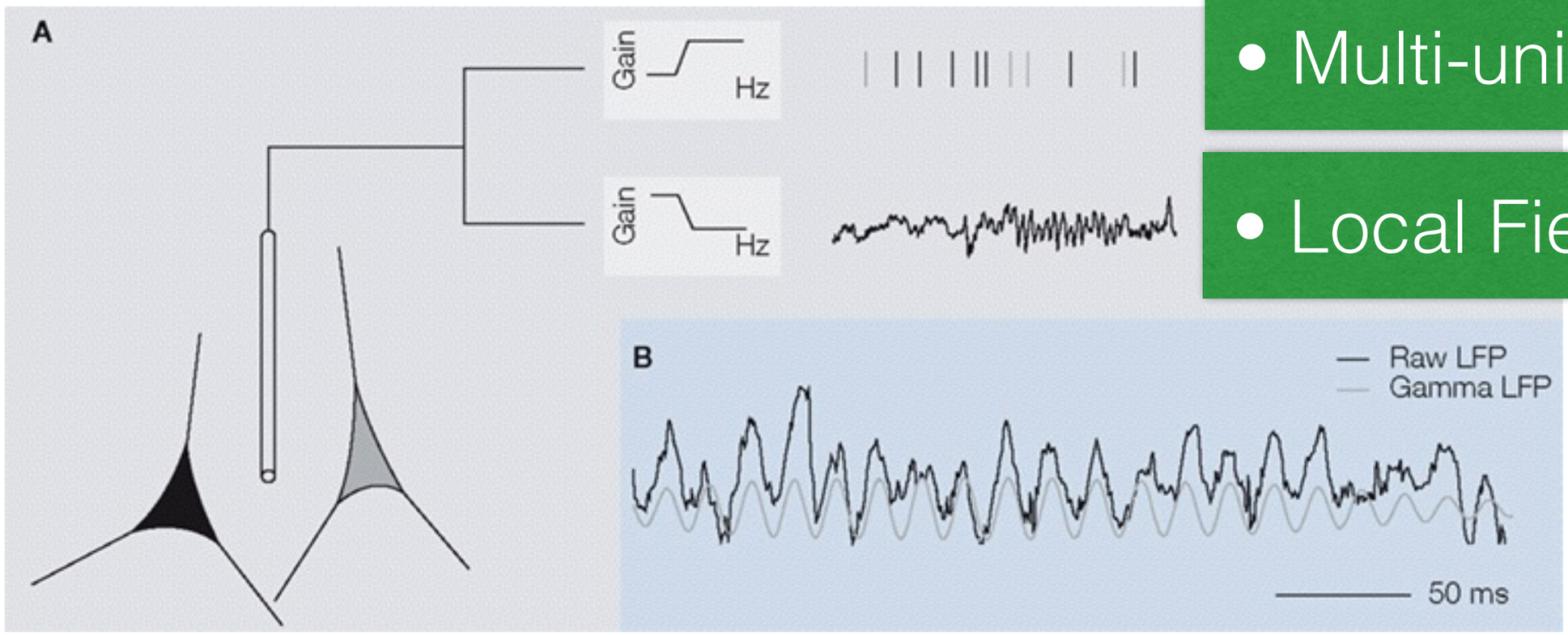
THE SIGNAL



- Local Field Potential

http://www.frontiersin.org/files/Articles/414/fnins-02-037/image_m/fnins-02-037-g001.jpg
http://lifesciences.ieee.org/images/stories/life-sciences/2012-01-spike-01_l.png

THE SIGNAL



- Multi-unit spikes
- Local Field Potential

http://www.frontiersin.org/files/Articles/414/fnins-02-037/image_m/fnins-02-037-g001.jpg
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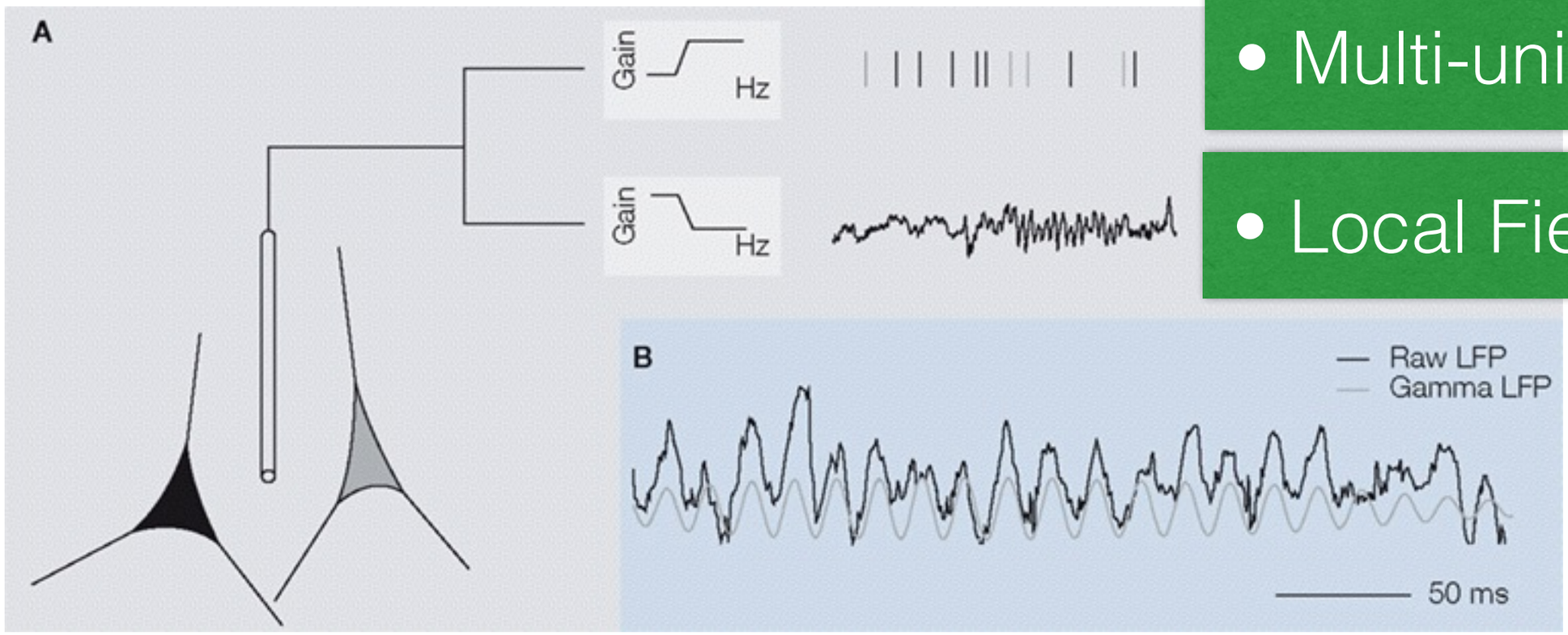
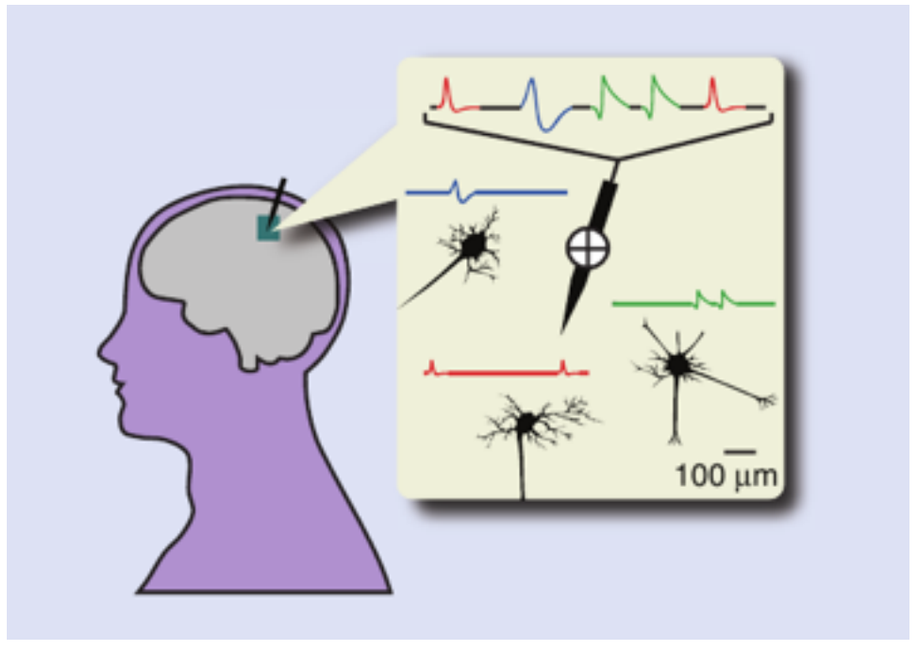
THE SIGNAL



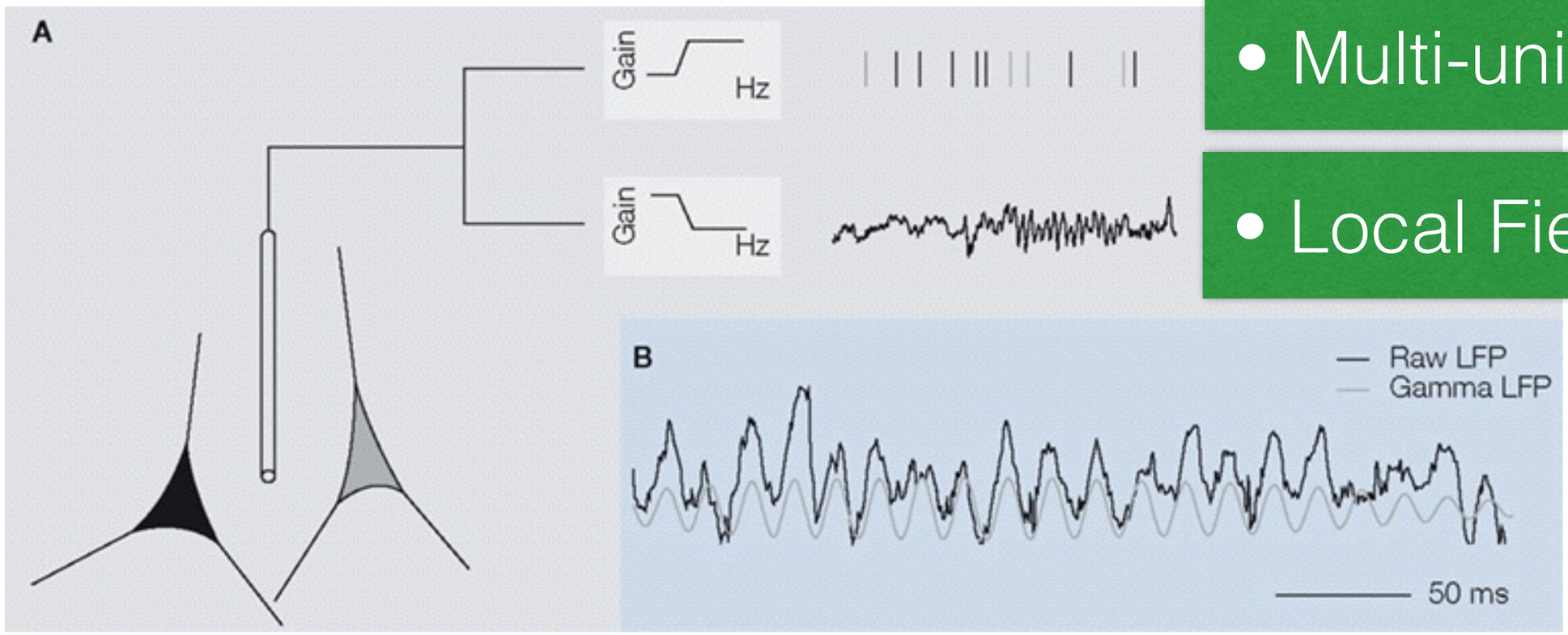
- Multi-unit spikes
- Local Field Potential



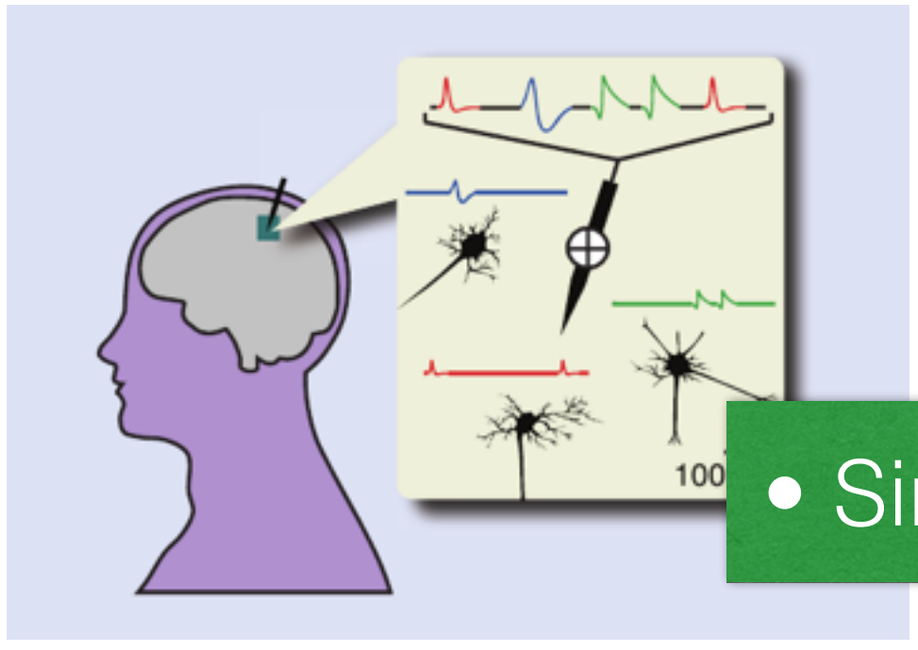
Spike sorting

http://www.frontiersin.org/files/Articles/414/fnins-02-037/image_m/fnins-02-037-g001.jpg
http://lifesciences.ieee.org/images/stories/life-sciences/2012-01-spike-01_l.png

THE SIGNAL



- Multi-unit spikes
- Local Field Potential



Spike sorting

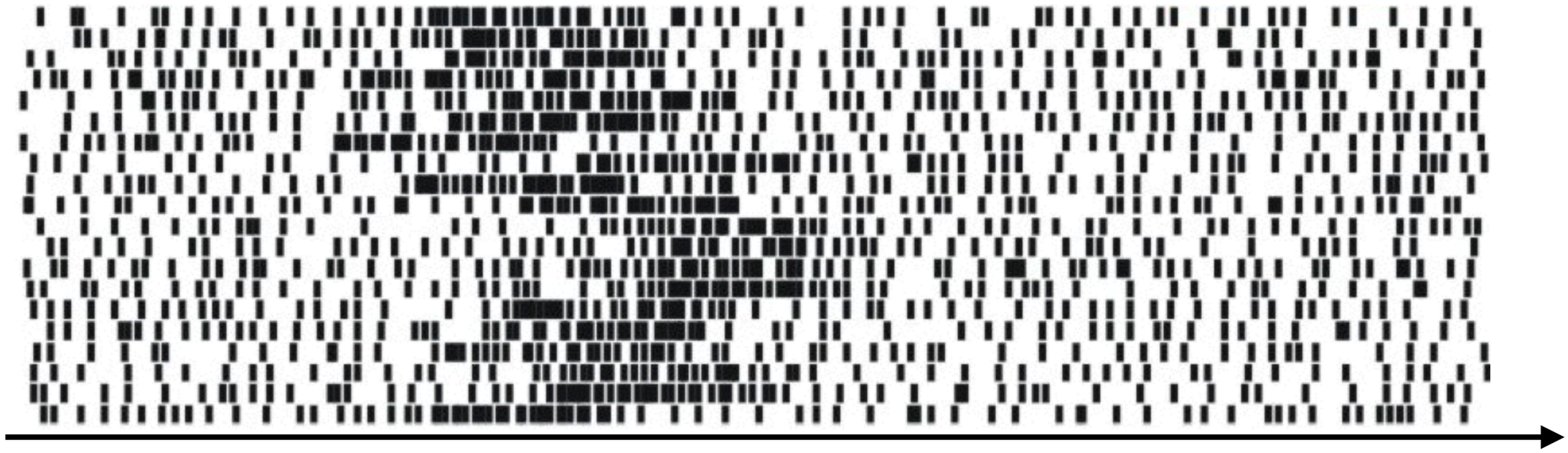
- Single-unit spikes

http://www.frontiersin.org/files/Articles/414/fnins-02-037/image_m/fnins-02-037-g001.jpg
http://lifesciences.ieee.org/images/stories/life-sciences/2012-01-spike-01_l.png

For each measured **neuron** we record the **time** moments when it **spiked**

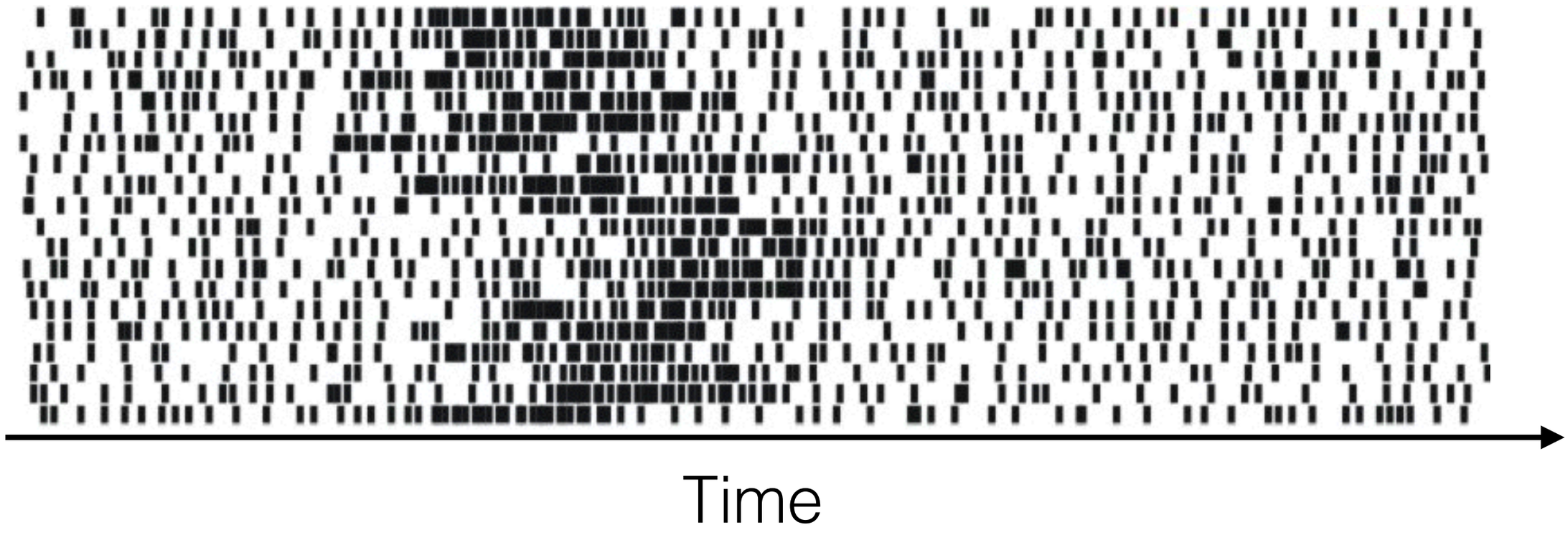
Raster plot

Raster plot

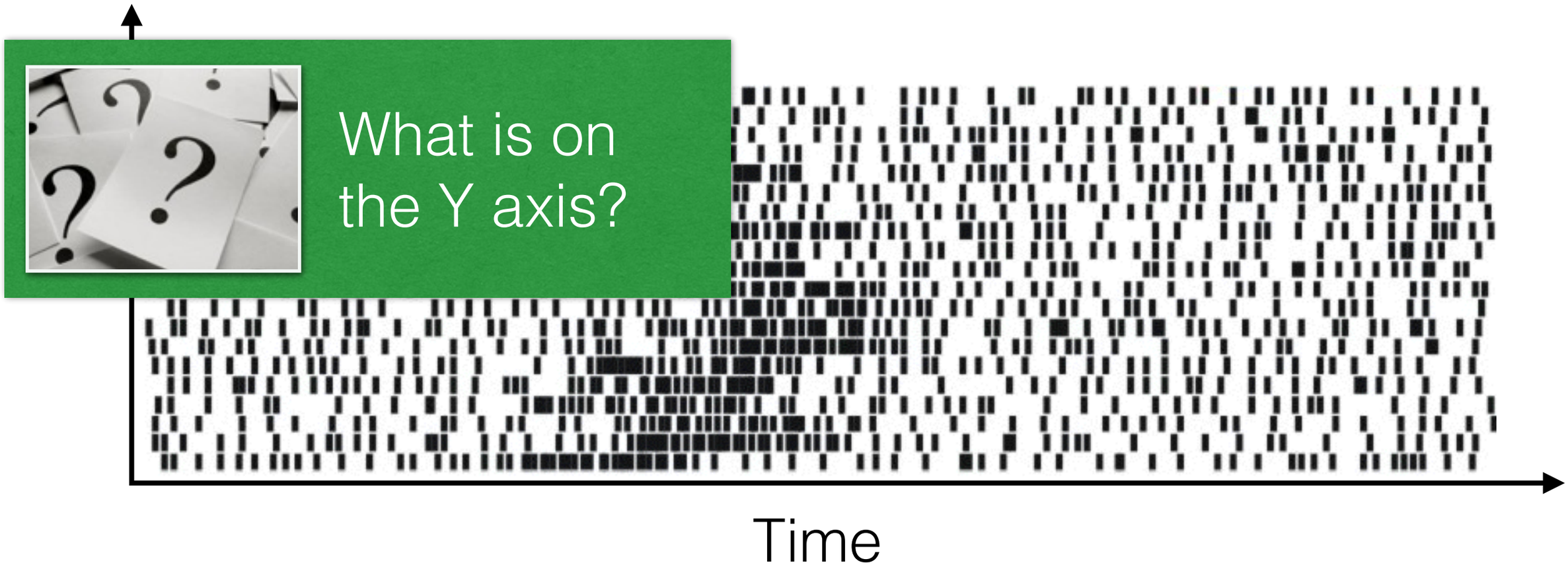


What is on the X axis?

Raster plot

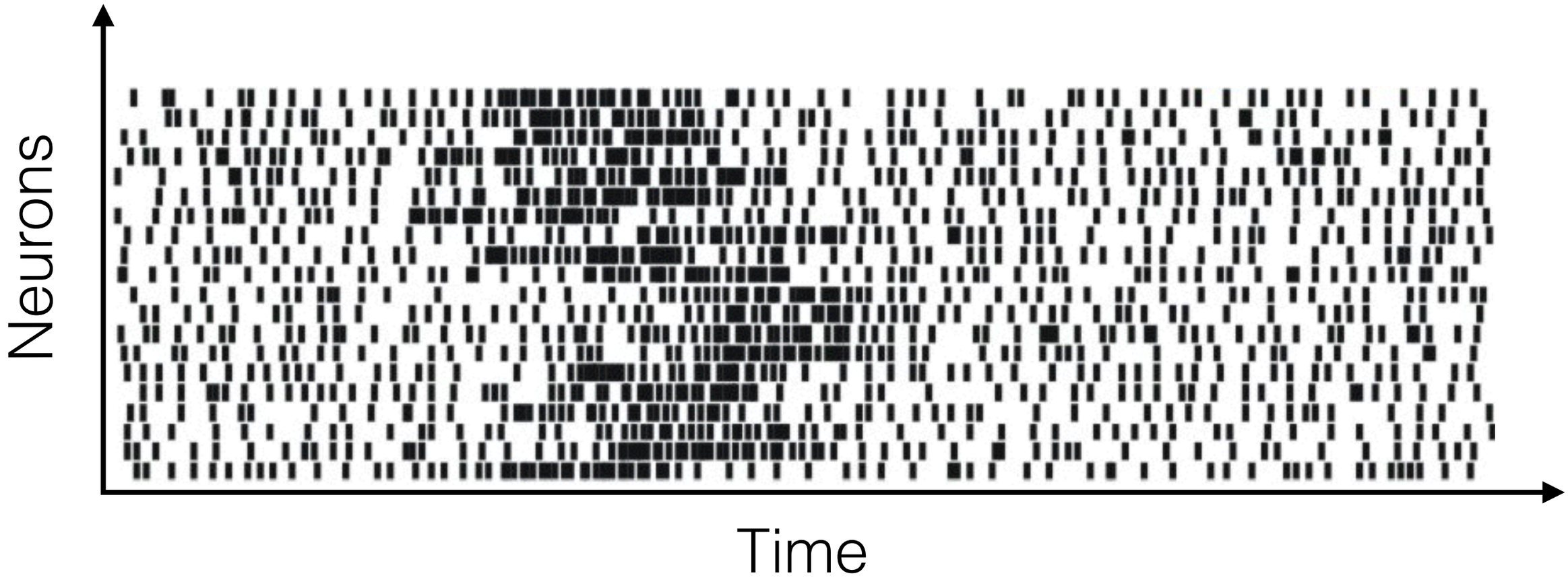


Raster plot

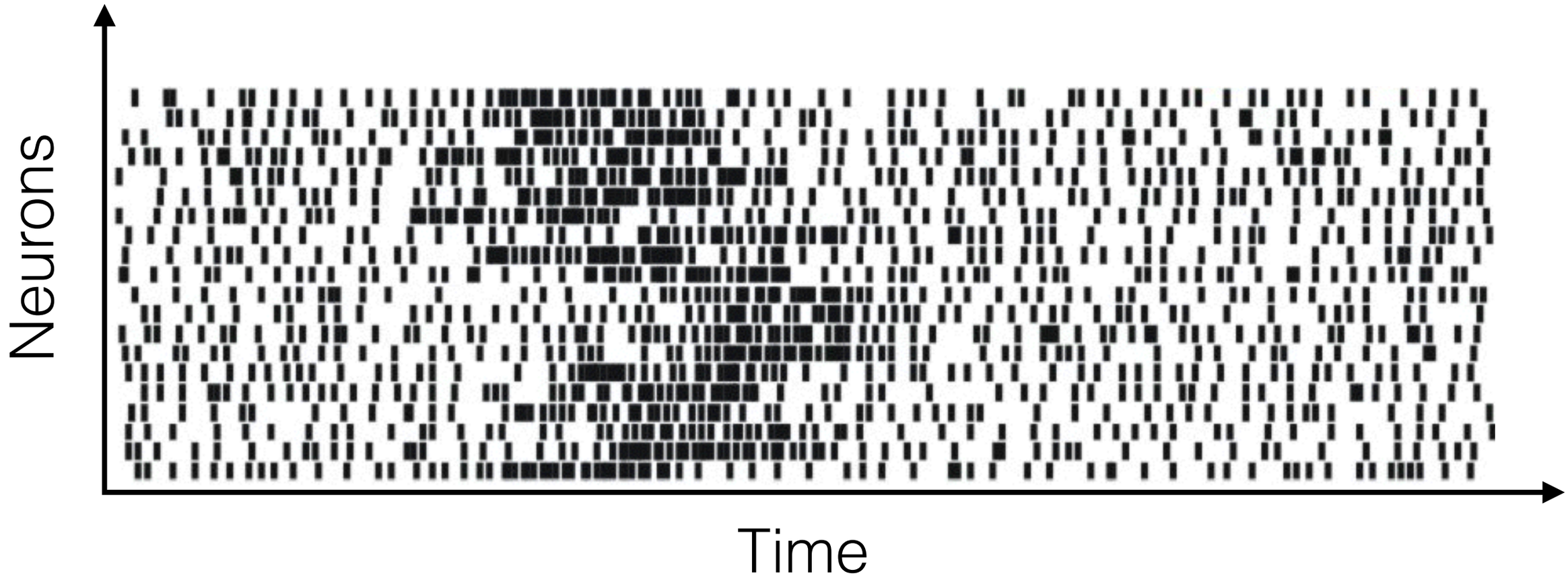


What is on the Y axis?

Raster plot



RASTER PLOT



PSTH

Post-Stimulus Time Histogram

PSTH

Post-Stimulus Time Histogram

PSTH

Post-Stimulus Time Histogram

PSTH

Post-Stimulus Time Histogram

PSTH

Post-Stimulus Time Histogram

Neurons \ Trials

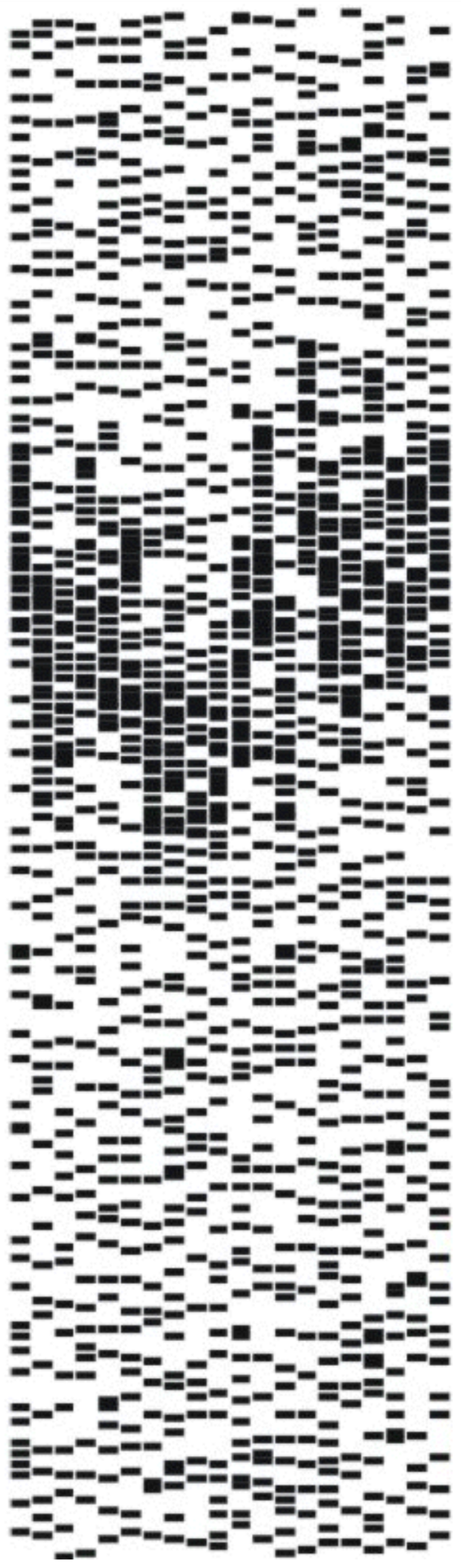
31 spikes 100 ms

34 spikes 100 ms

27 spikes 100 ms

218 spikes

33 spikes 100 ms



Post-Stimulus Time Histogram

PSTH

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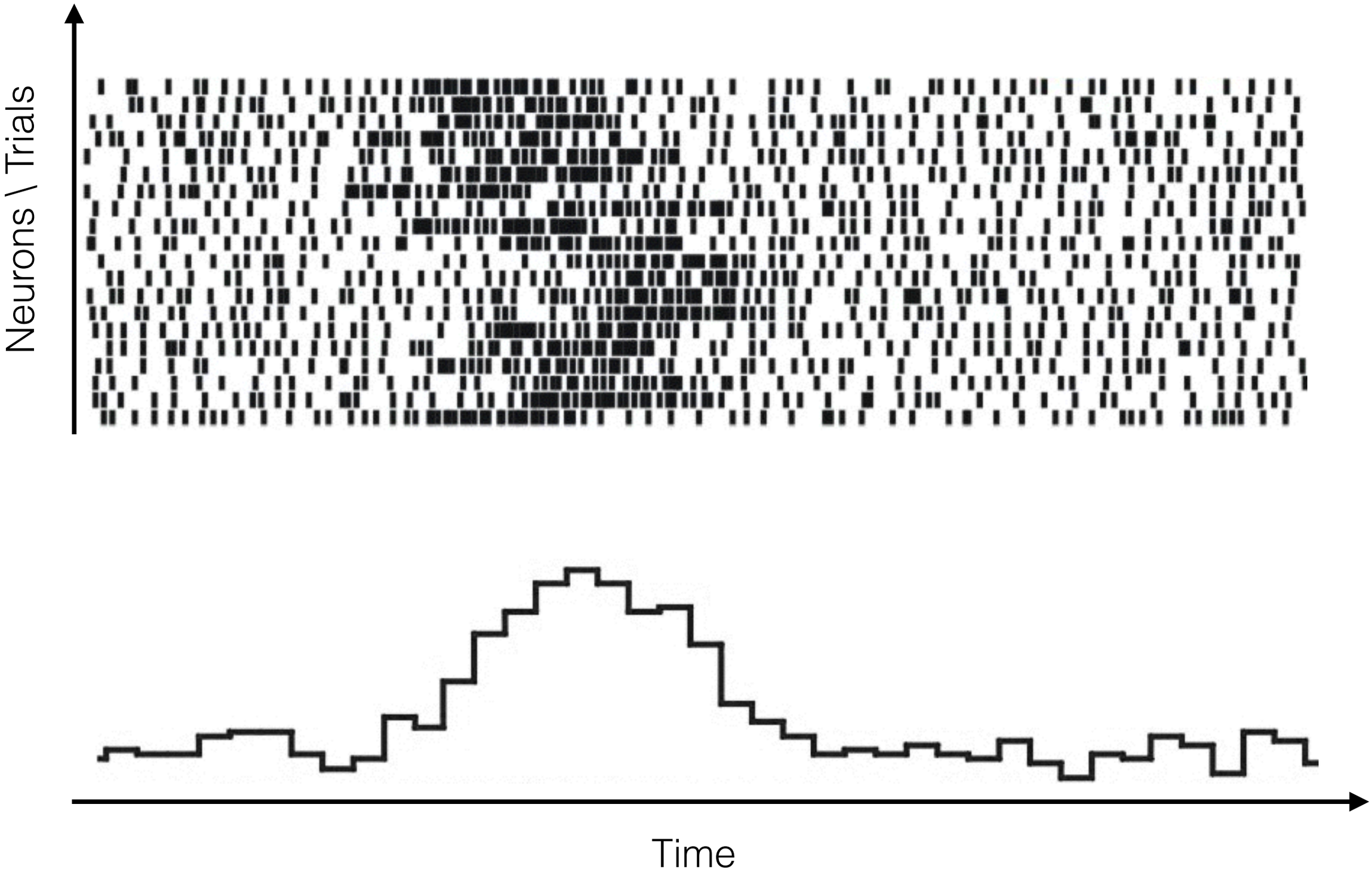
Post-Stimulus Time Histogram



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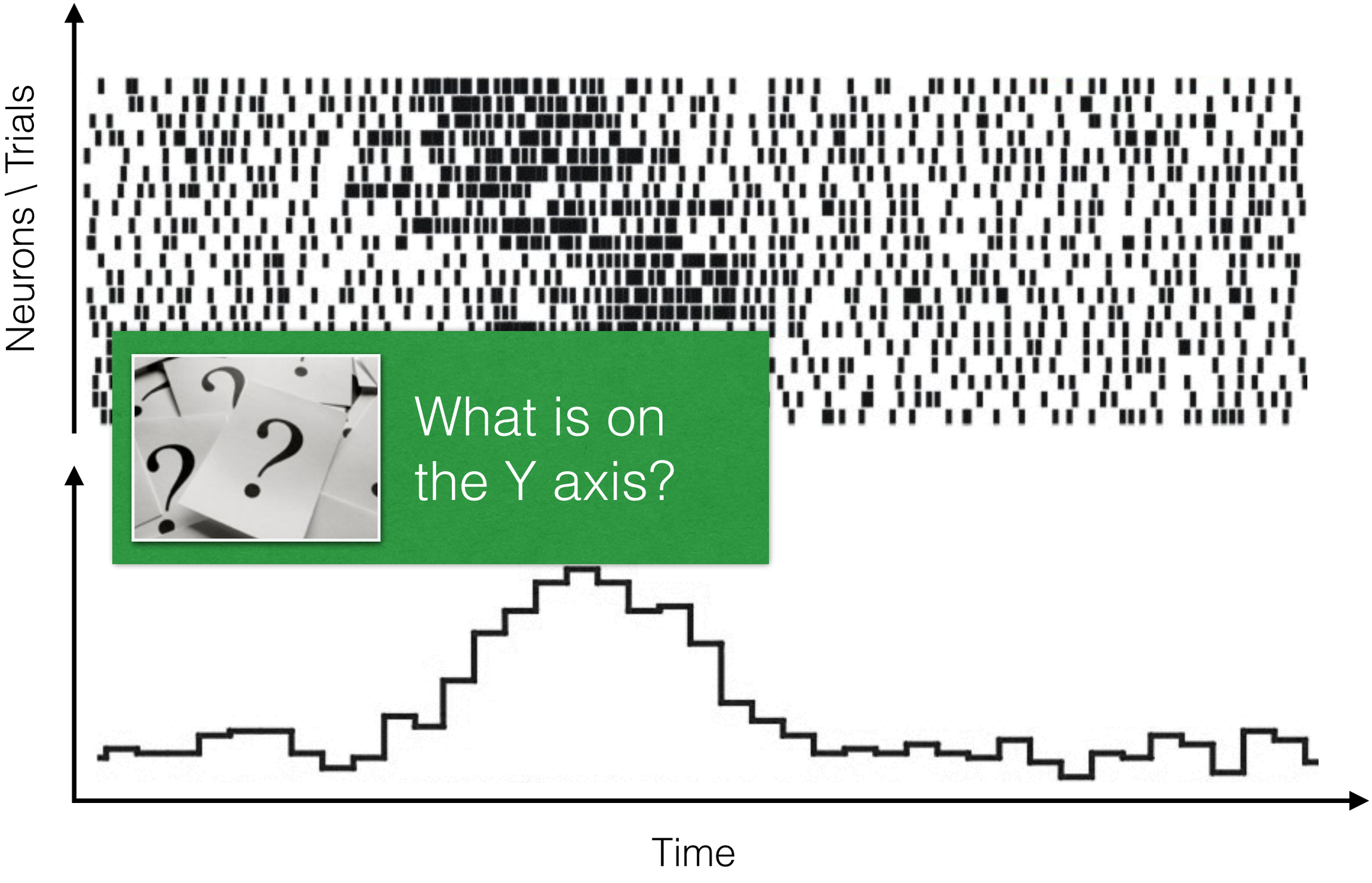

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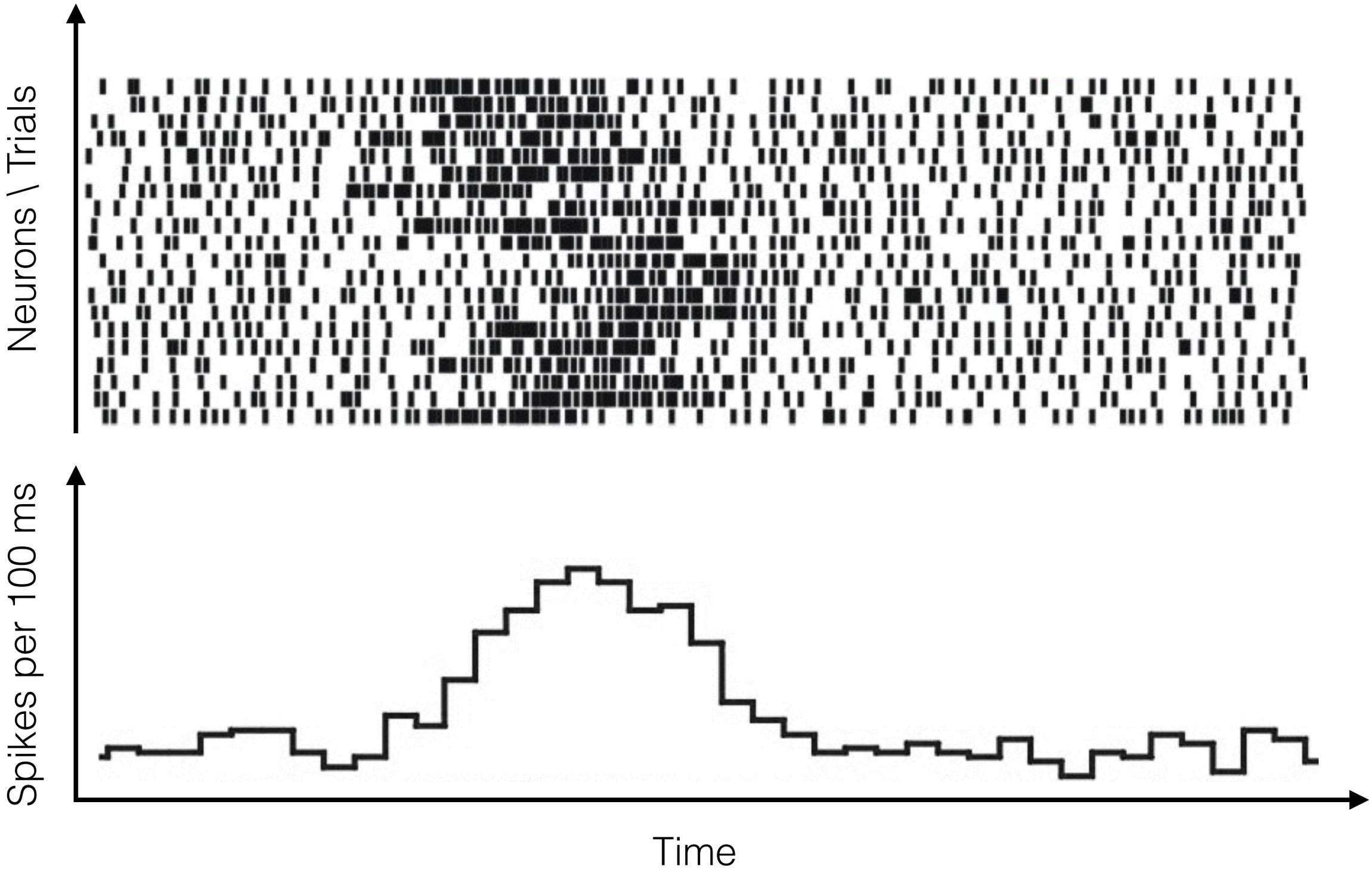

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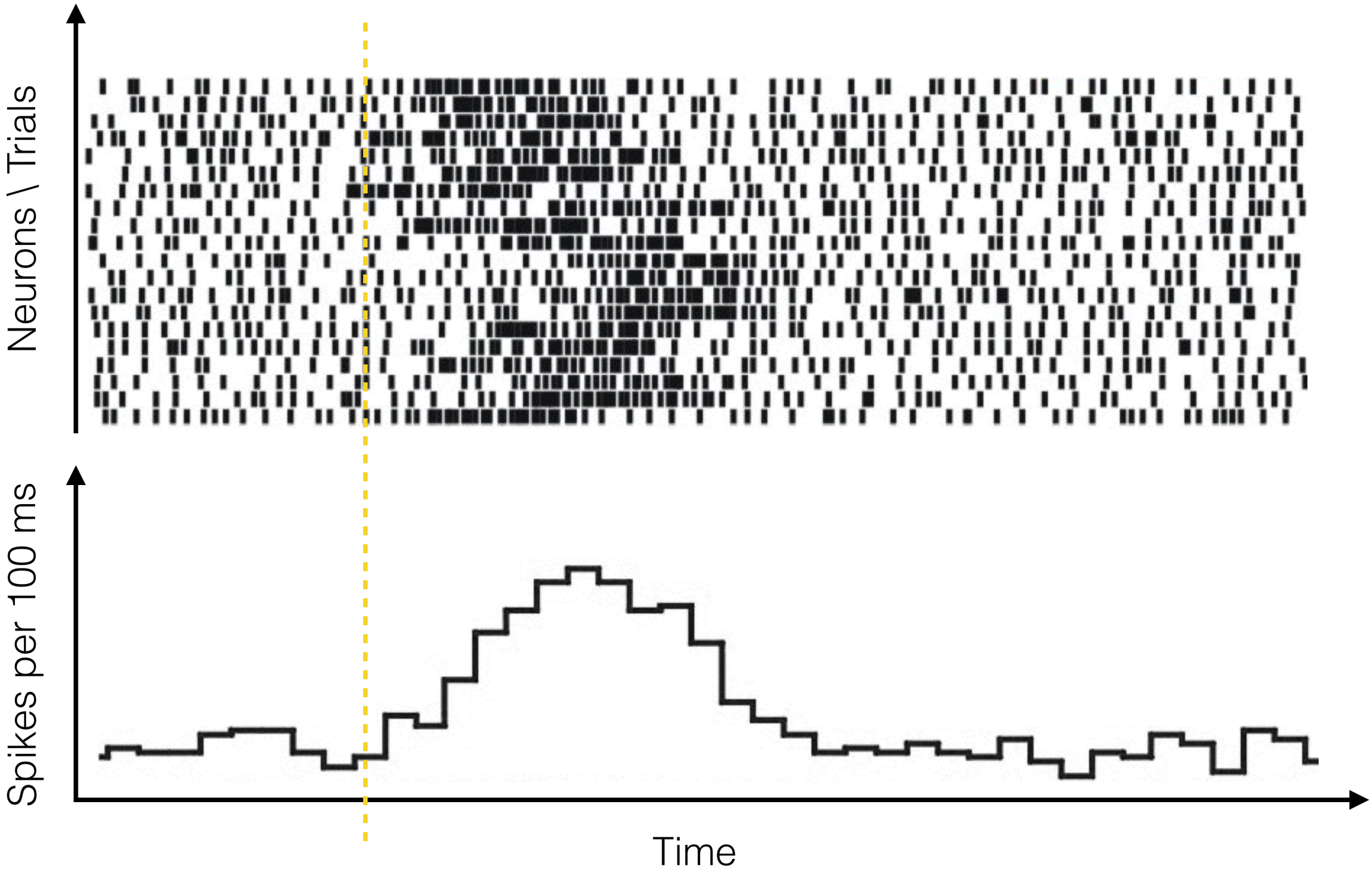
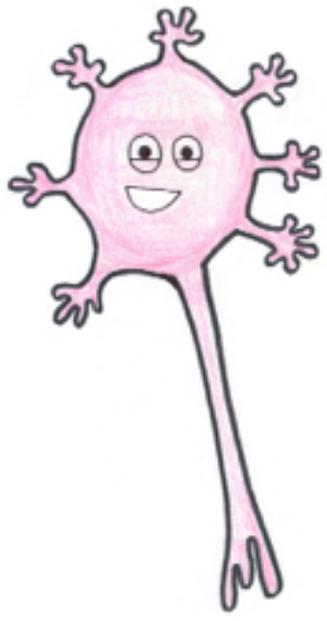
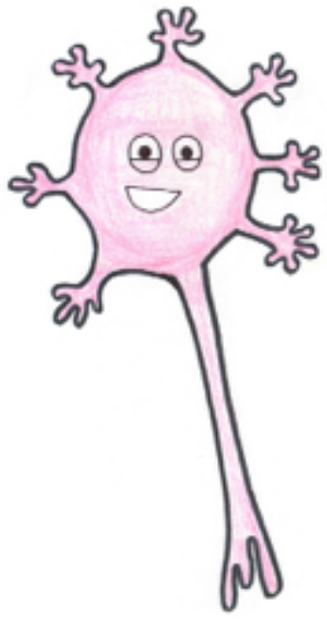


Tuning curve



http://www.beatricebiologist.com/2012/11/types-of-cells.html

Tuning curve



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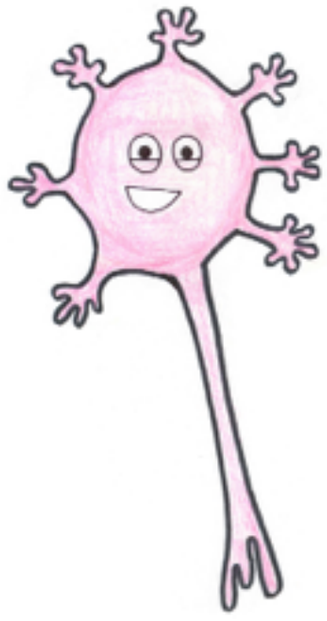

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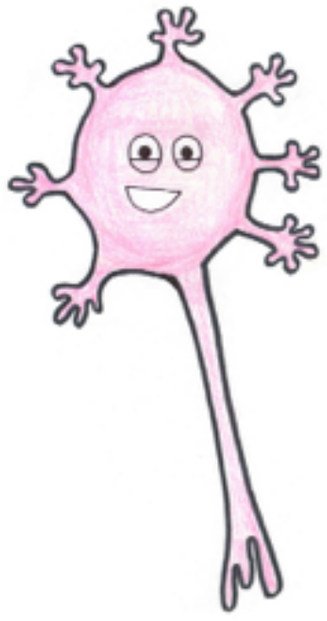
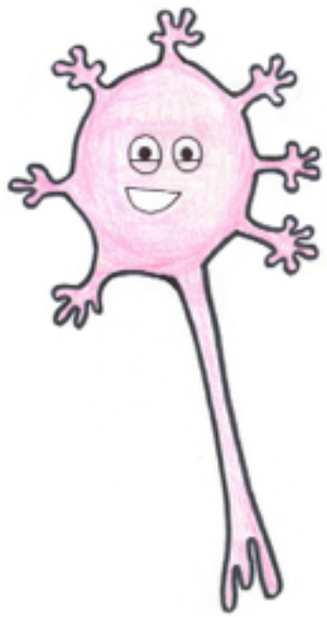
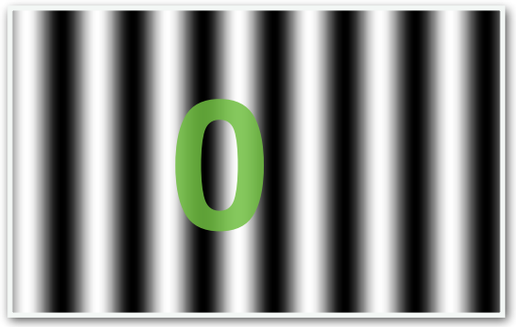


40 spikes per second (40 Hz)

http://www.beatricebiologist.com/2012/11/types-of-cells.html

Tuning curve





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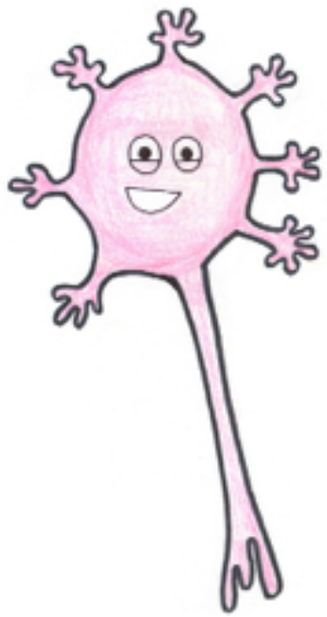

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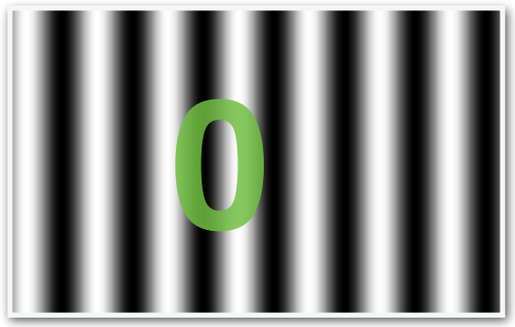
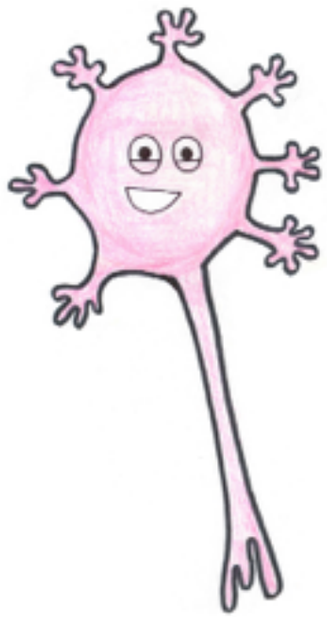


7 spikes per second (7 Hz)

http://www.beatricebiologist.com/2012/11/types-of-cells.html

TUNING CURVE



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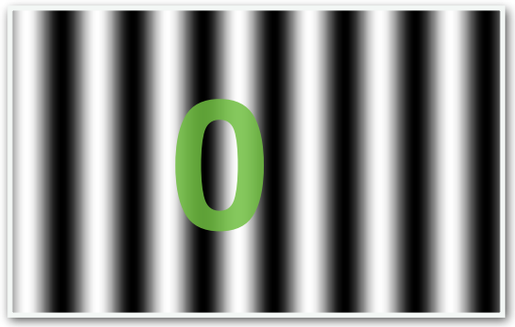

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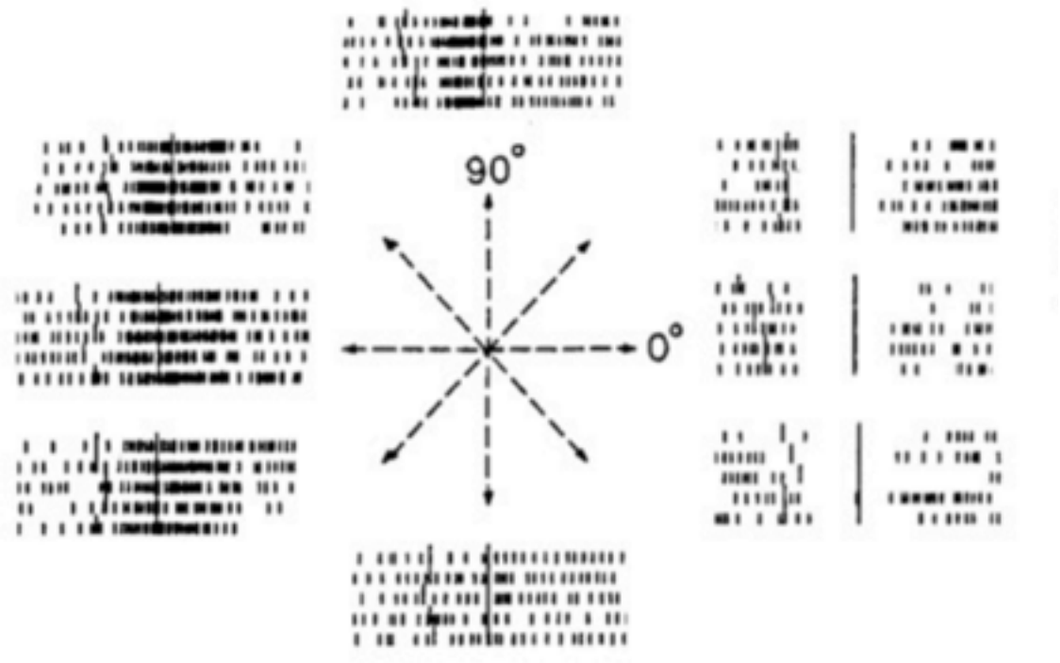

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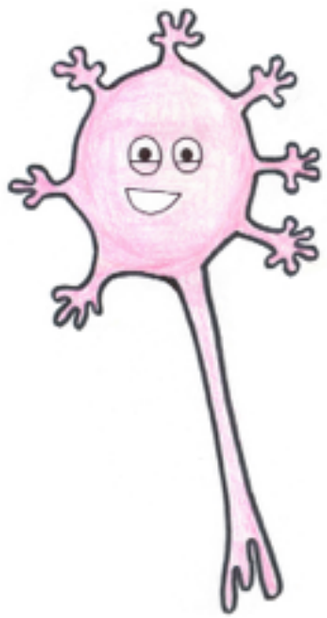
Tuning curve



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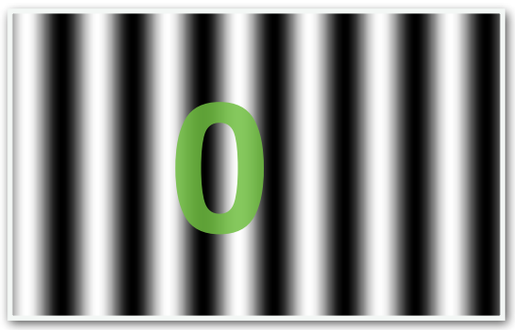

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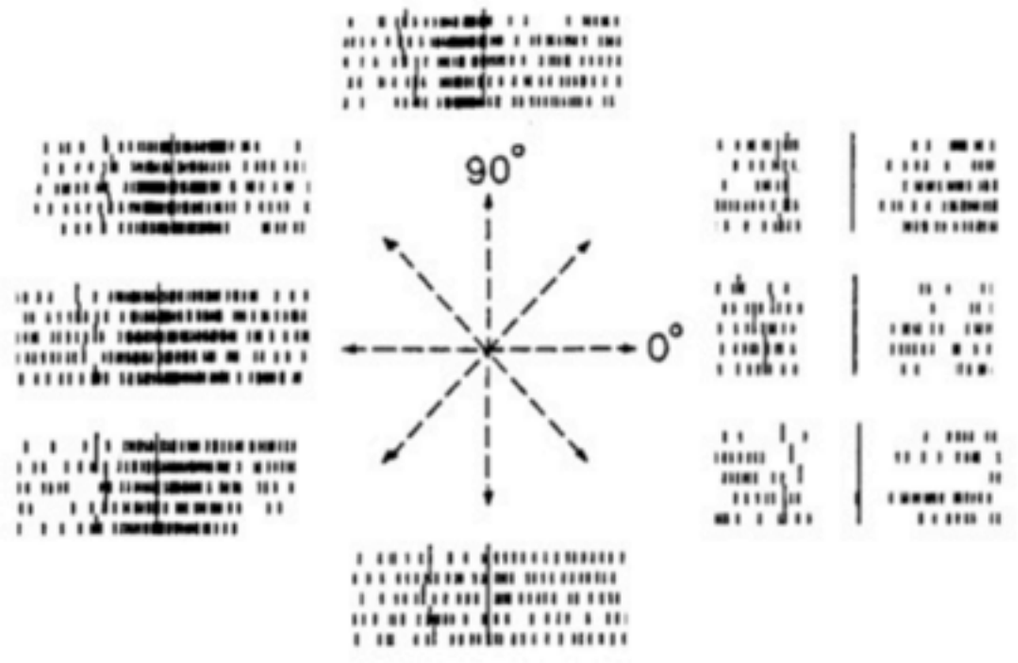

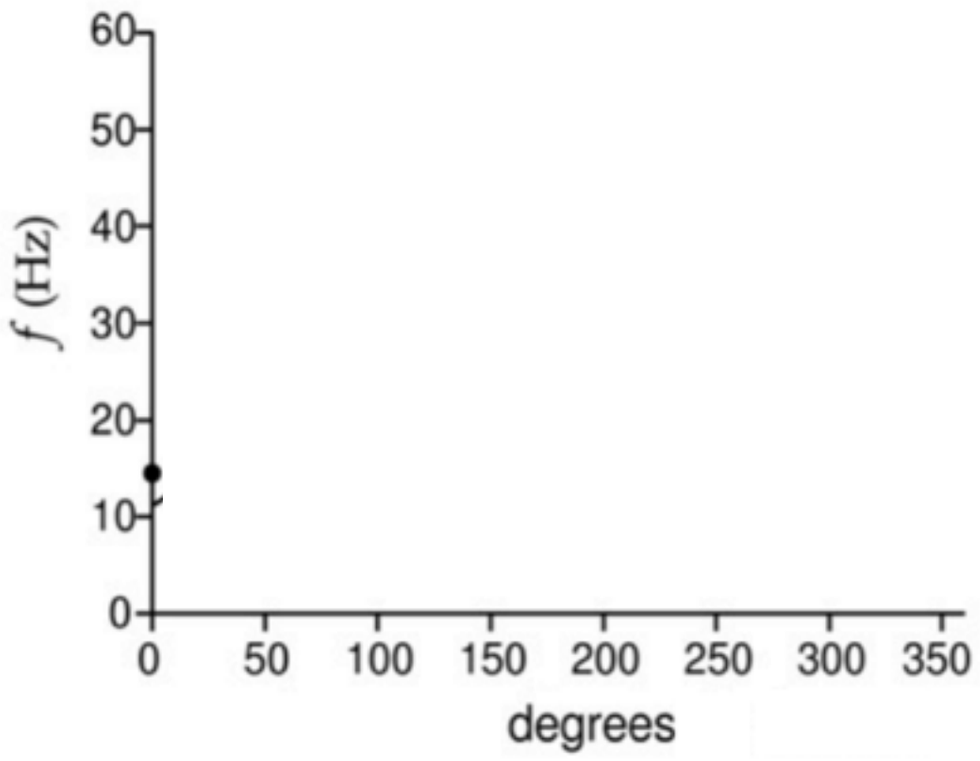

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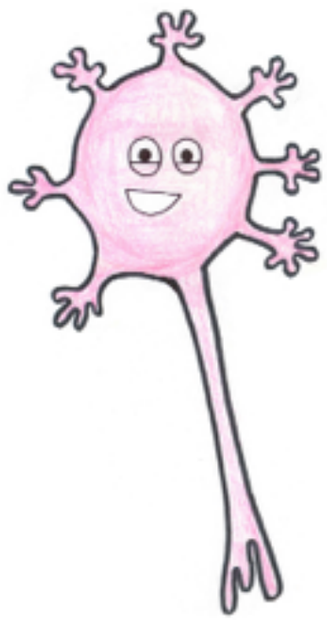
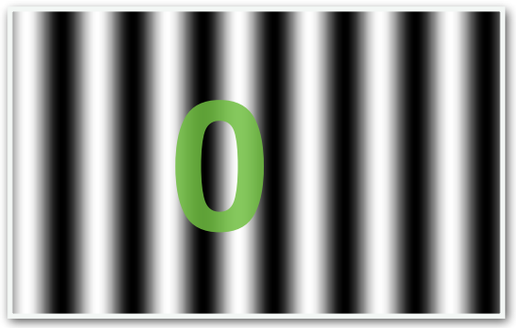
TUNING CURVE

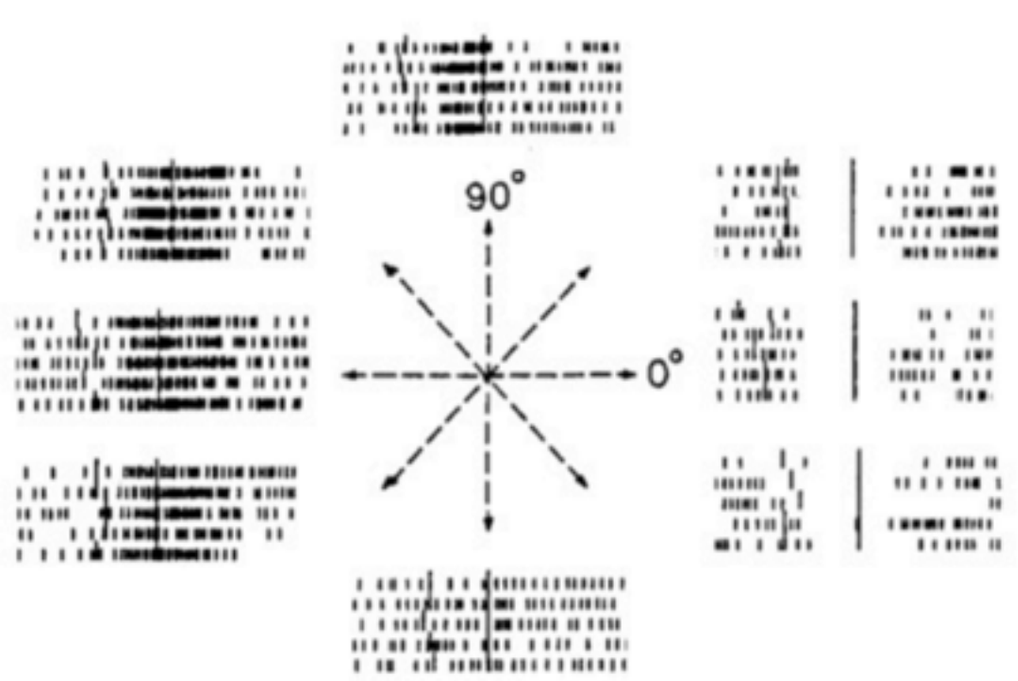


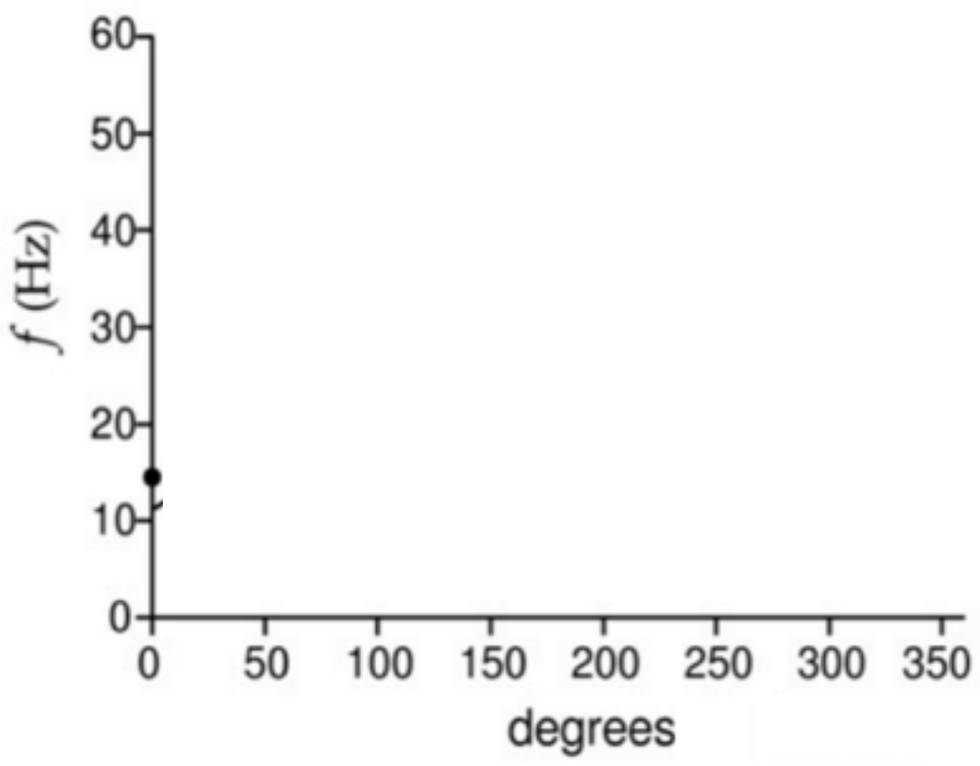


40 spikes per second (40 Hz)

7 sp

What do you expect to see on this plot?





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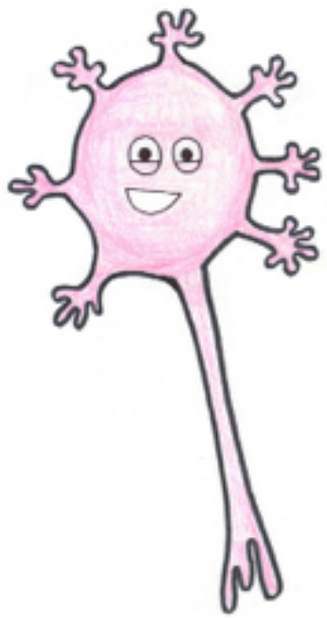
Tuning curve



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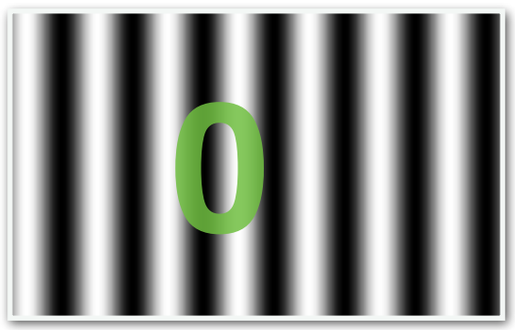

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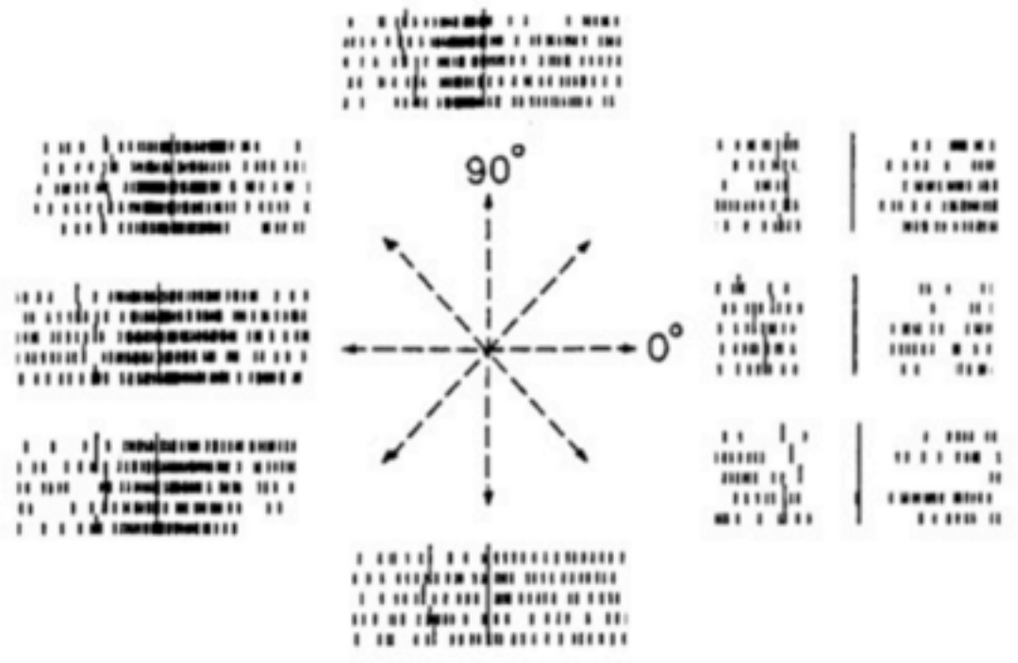

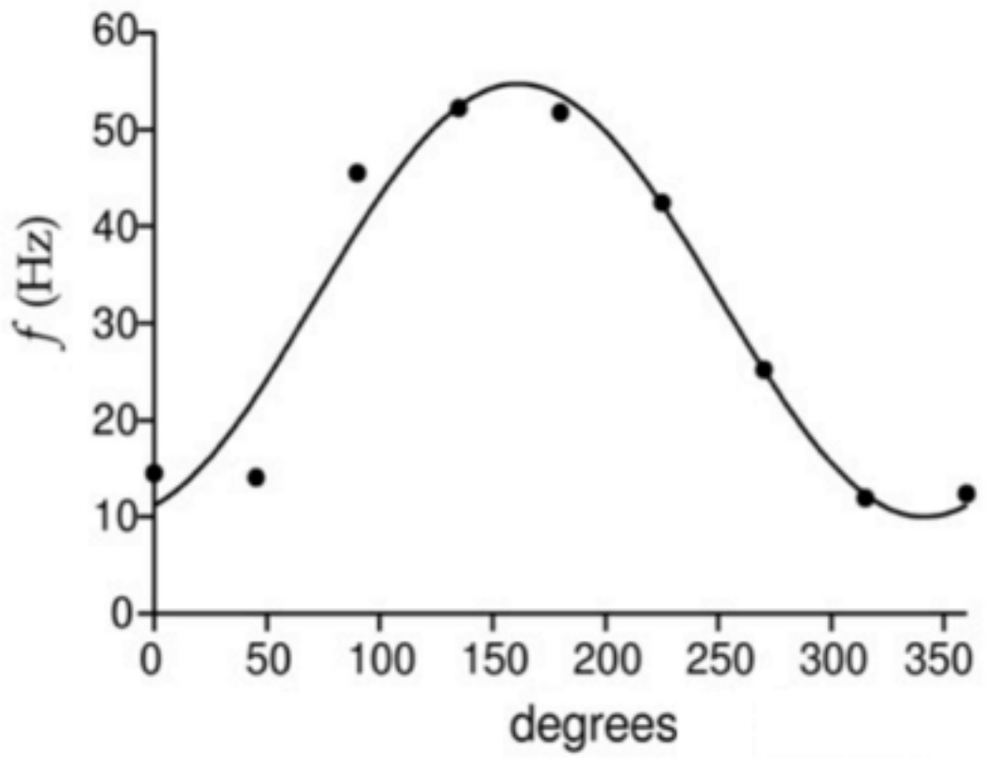

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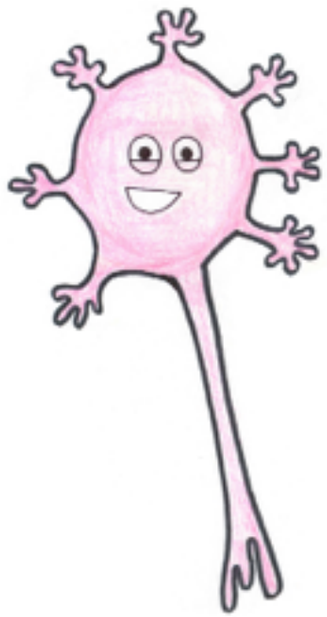

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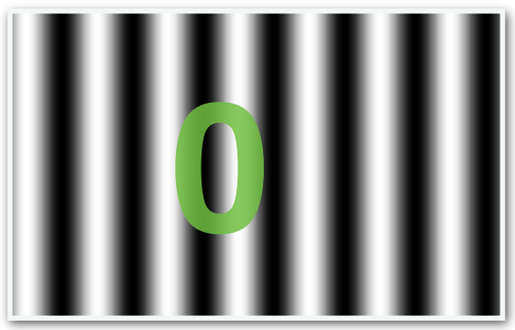
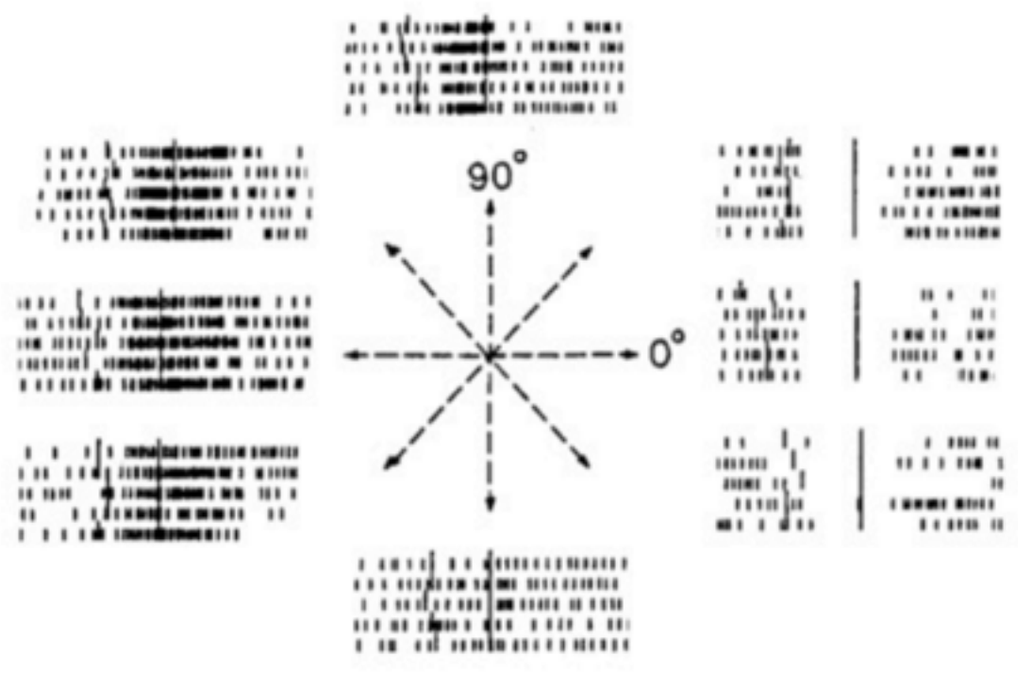
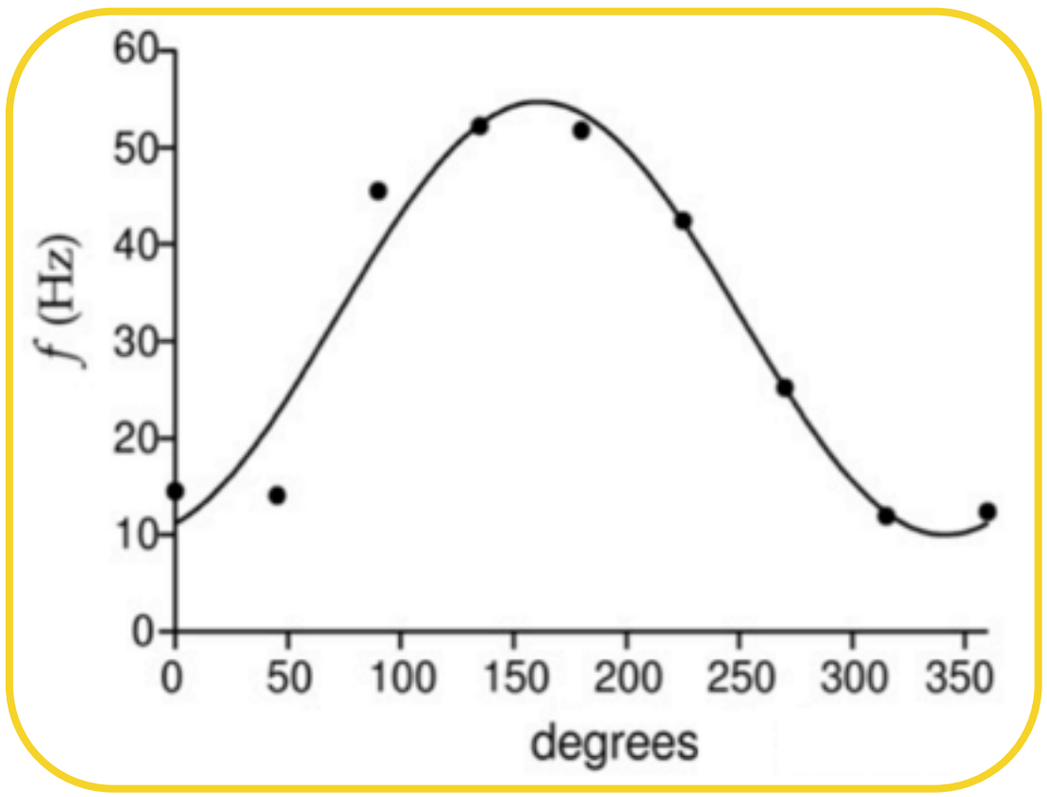


7 spikes per second (7 Hz)





http://www.beatricebiologist.com/2012/11/types-of-cells.html

SUMMARY

- High spatial resolution (up to single neuron)
- High temporal resolution

SUMMARY

- High spatial resolution (up to single neuron)
- High temporal resolution

What does “spatial resolution” mean?

SUMMARY

- High spatial resolution (up to single neuron)
- High temporal resolution

What does "temporal resolution" mean?

SUMMARY

- High spatial resolution (up to single neuron)
- High temporal resolution

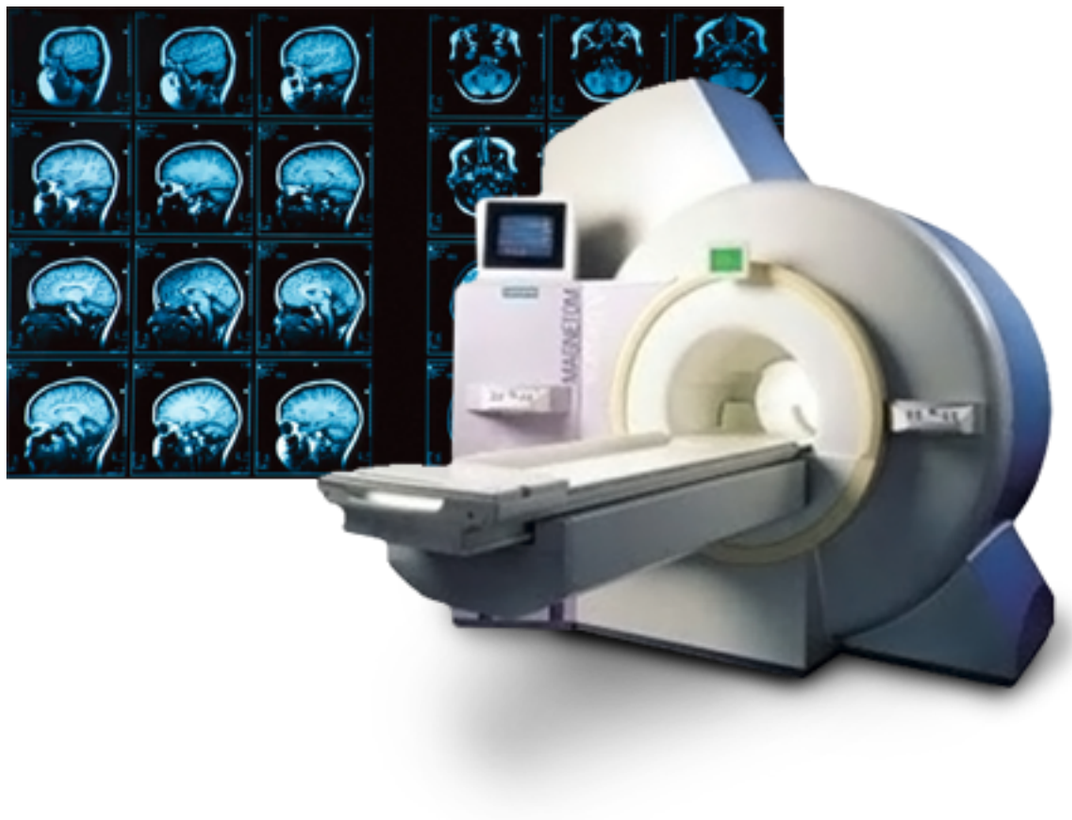
- Requires surgery
- Localized

SUMMARY

- High spatial resolution (up to single neuron)
- High temporal resolution

- Requires surgery
- Localized

Very informative and **precise**, but not applicable to general audience due to **surgery**.



PART II
FMRI

http://www.csulb.edu/~cwallis/482/fmri/fmri.h3.gif
http://neuro.mediasauce.com/images/fmri_machine.png

Nuclear Magnetic Resonance

Physical phenomenon

Nuclear Magnetic Resonance

Physical phenomenon in which **nucleus** of an atom

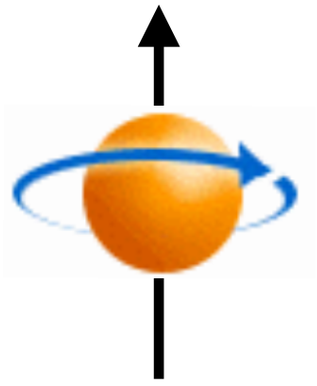
Nuclear Magnetic Resonance

Physical phenomenon in which **nucleus** of an atom can **absorb or reemit** **electromagnetic** radiation

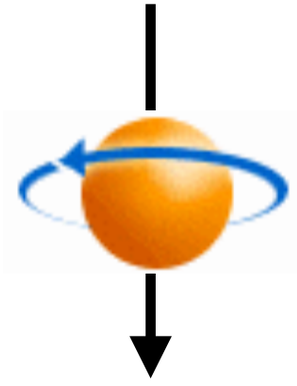
Nuclear Magnetic Resonance

Physical phenomenon in which **nucleus** of an atom can **absorb or reemit** **electromagnetic** radiation if placed in a **magnetic field.**

Spin



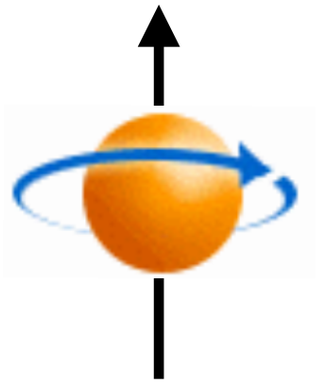
Spin-UP
+1/2



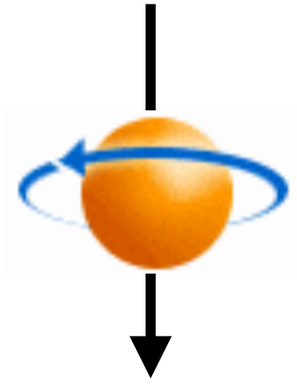
Spin-DOWN
-1/2

http://www.markusehrenfried.de/science/physics/hermes/whatisspin.html

Spin



Spin-UP
+1/2

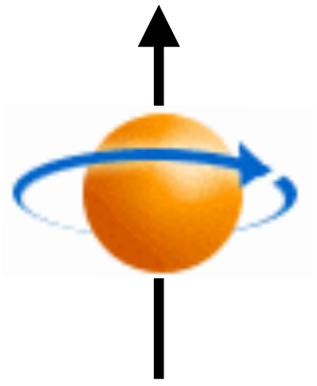


Spin-DOWN
-1/2

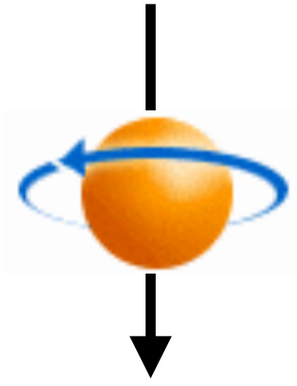
Nothing actually *spins* in there. No analogy in classical mechanics.

http://www.markusehrenfried.de/science/physics/hermes/whatisspin.html

Spin



Spin-UP
+1/2



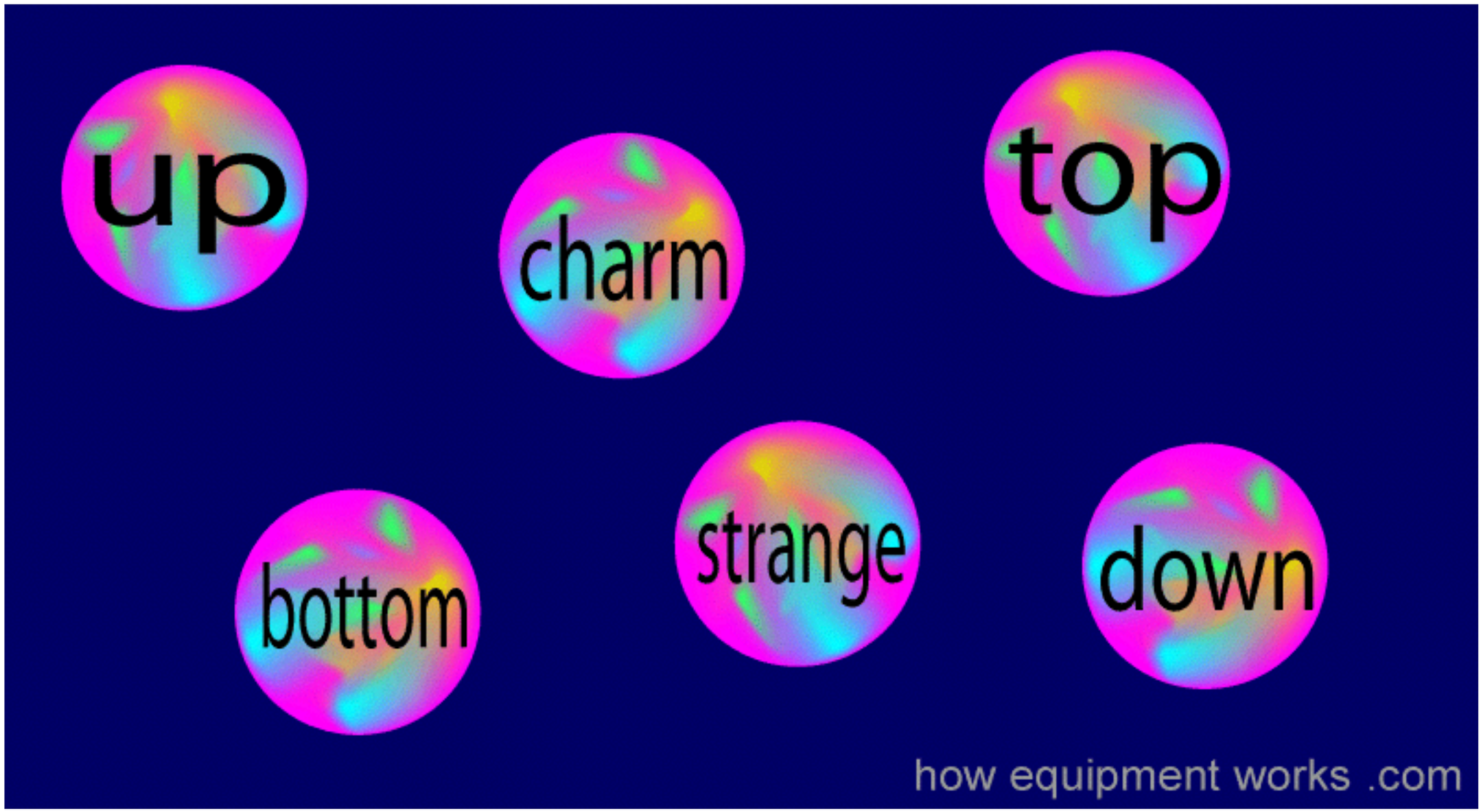
Spin-DOWN
-1/2

Nothing actually *spins* in there. No analogy in classical mechanics.

But why call it *spin* then?

http://www.markusehrenfried.de/science/physics/hermes/whatisspin.html

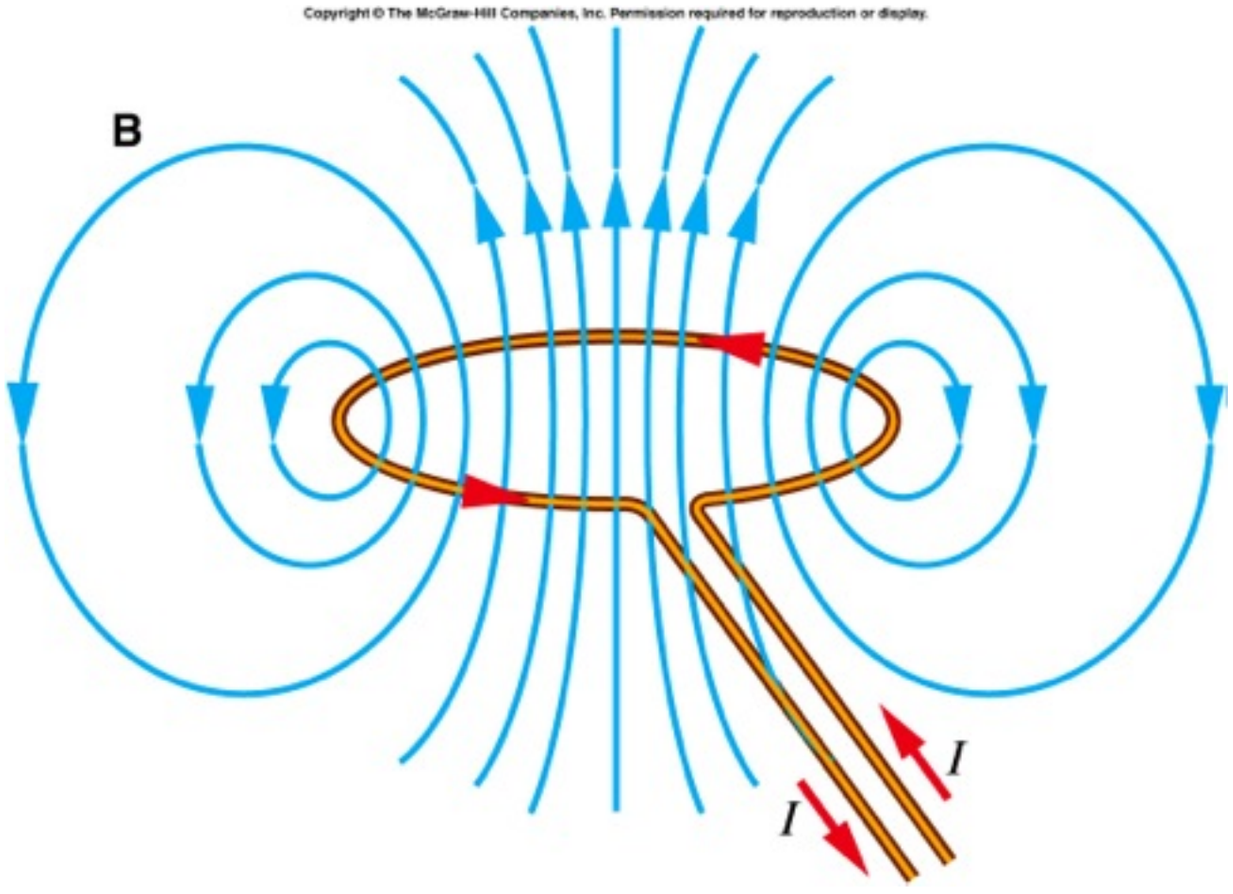
Not a joke



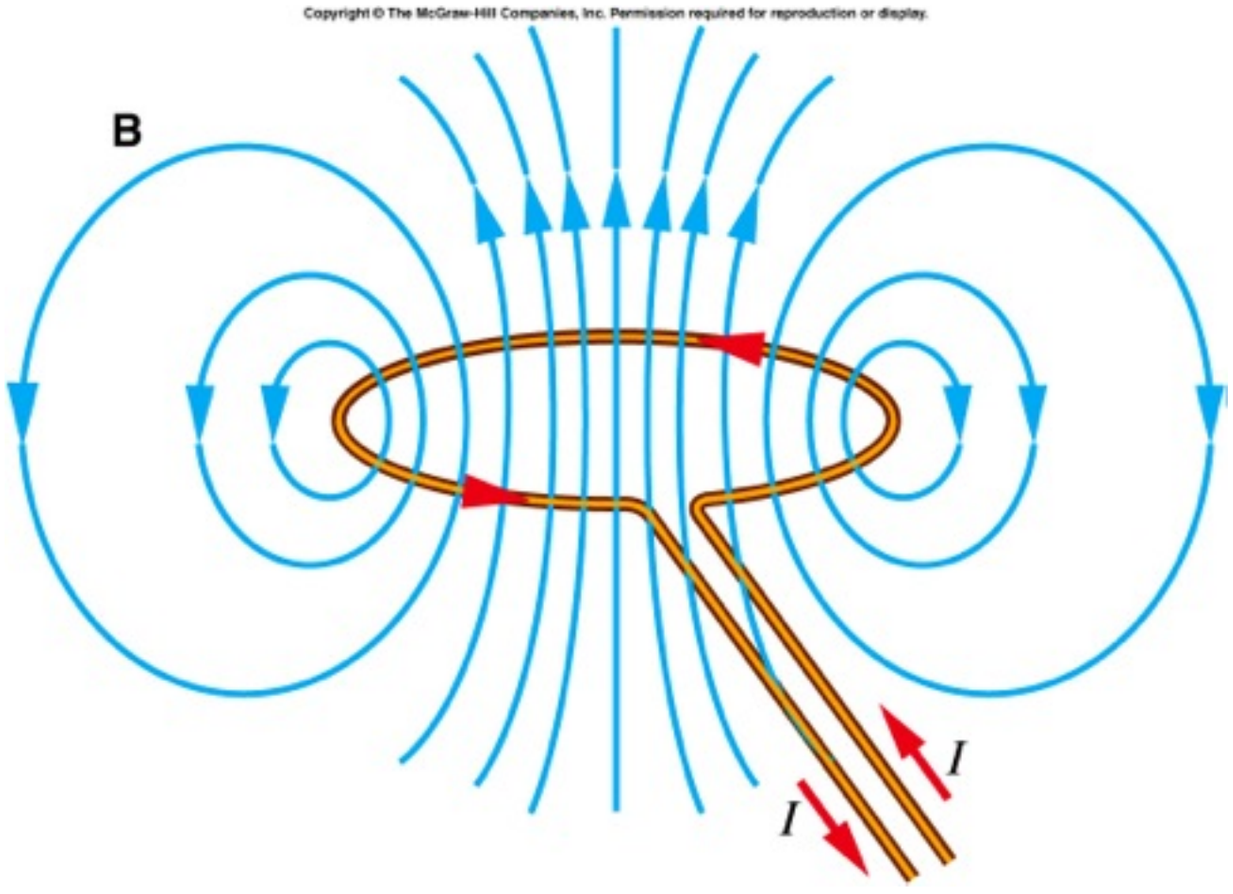
Six known types of quarks and their **official** names.
So *spin* is not that bad.

http://www.howequipmentworks.com/physics/medical_imaging/mri/magnetic_resonance_imaging.html

MAGNETIC MOMENT

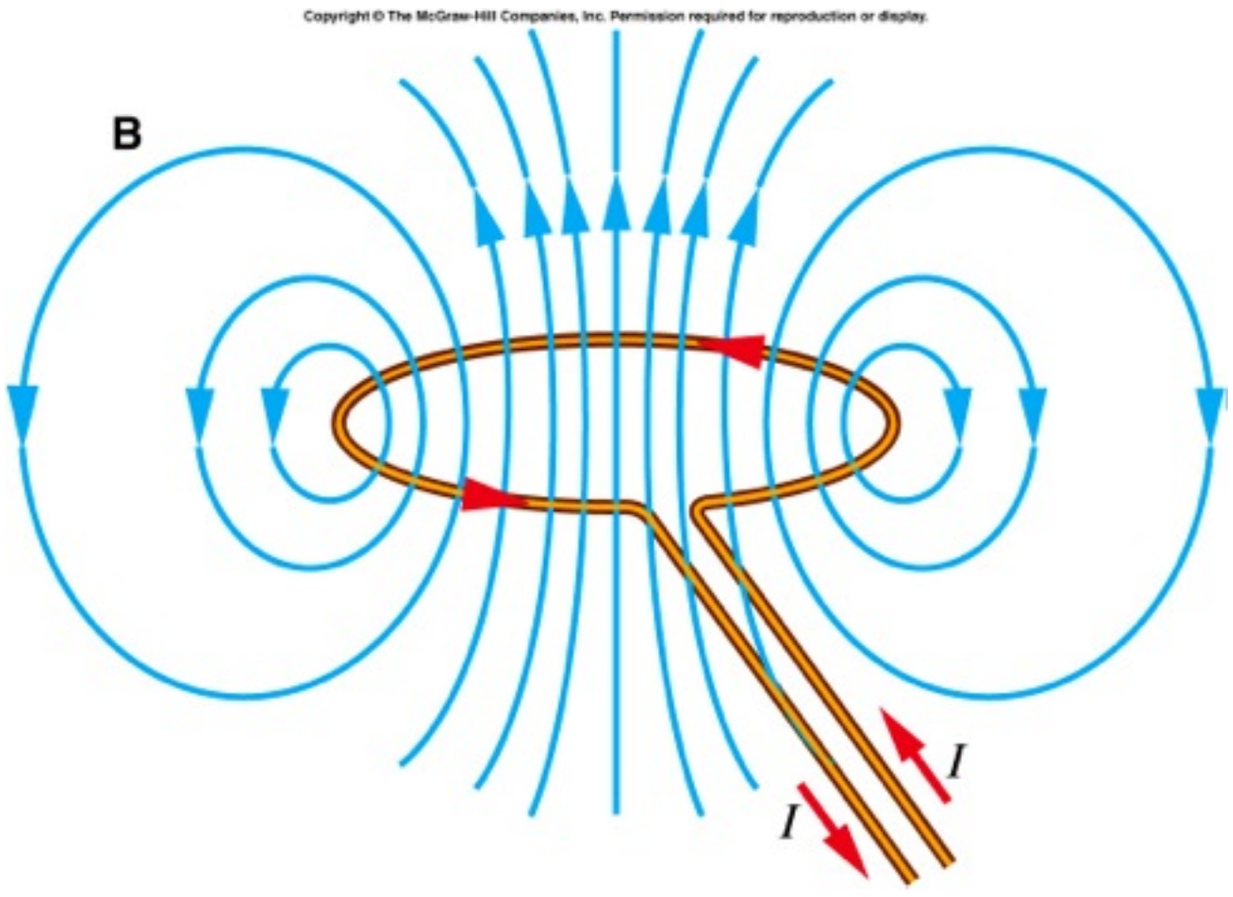


MAGNETIC MOMENT



Particle with **non-zero** nuclear spin is like a small **magnet**.

MAGNETIC MOMENT



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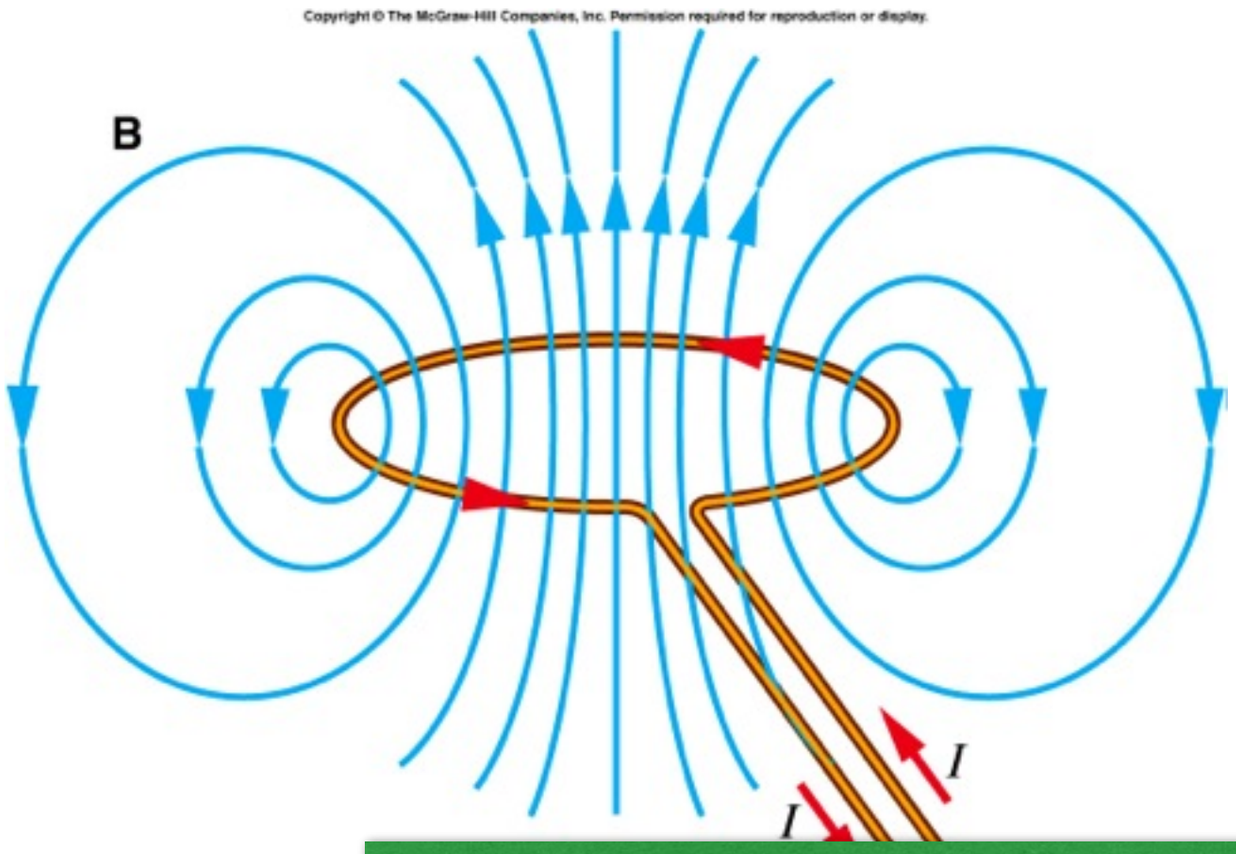
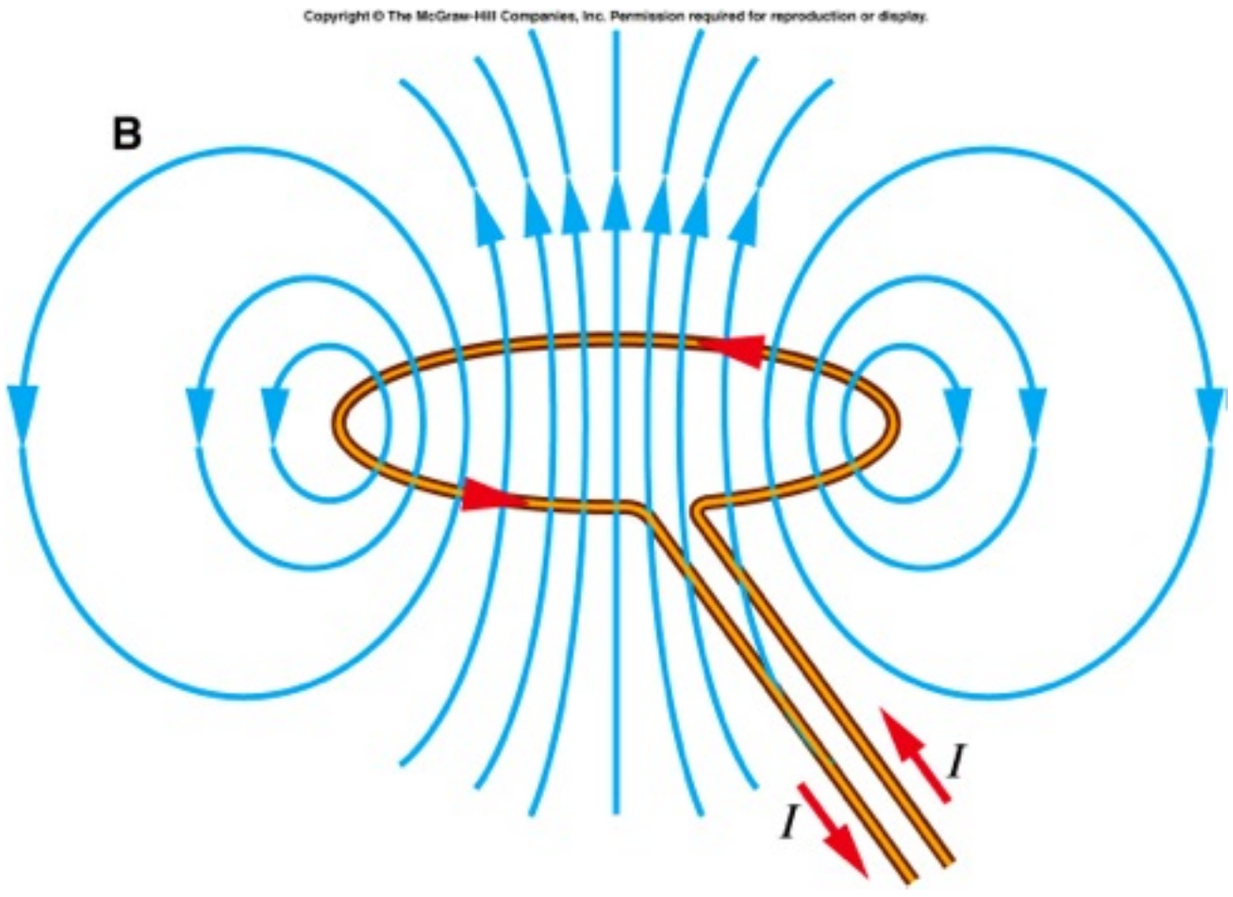
MAGNETIC MOMENT



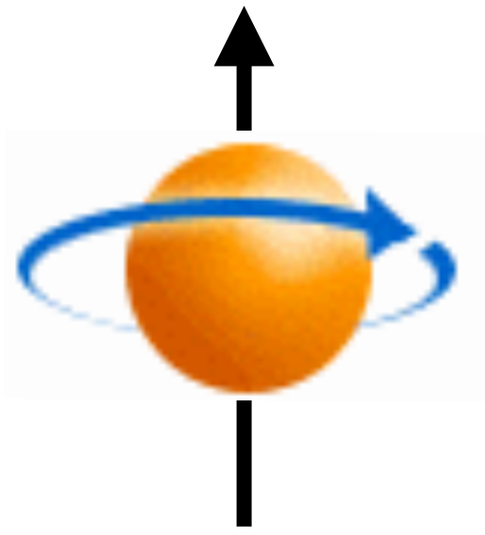
Particle with **non-zero** nuclear spin is like a small **magnet**.

or ?

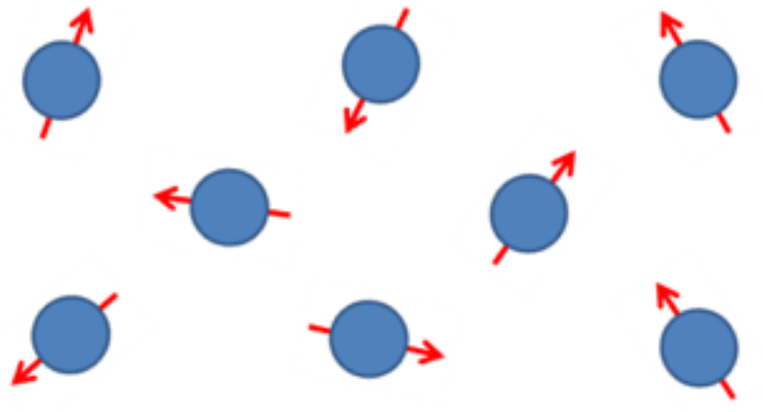
MAGNETIC MOMENT



Particle with **non-zero** nuclear spin is like a small **magnet**.

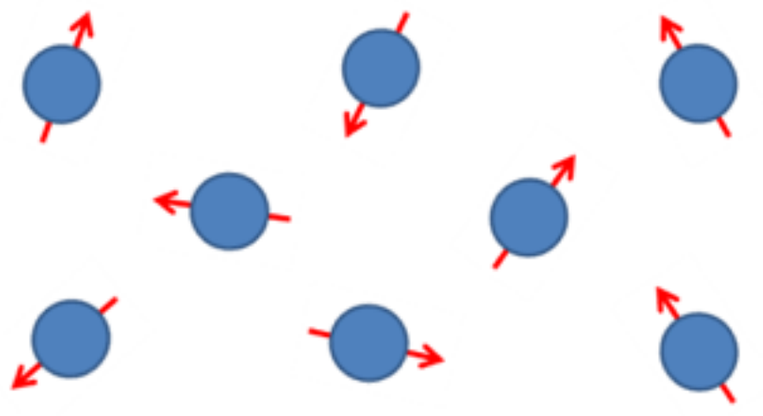


In a magnetic field



What happens to a magnet if you put it in a magnetic field?

In a magnetic field



What happens to a magnet if you put it in a magnetic field?

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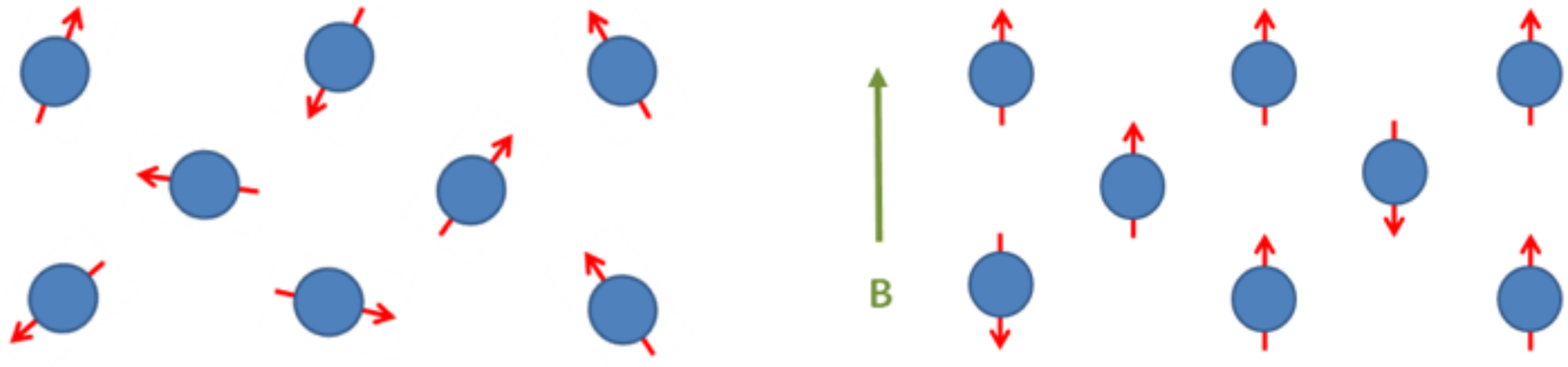
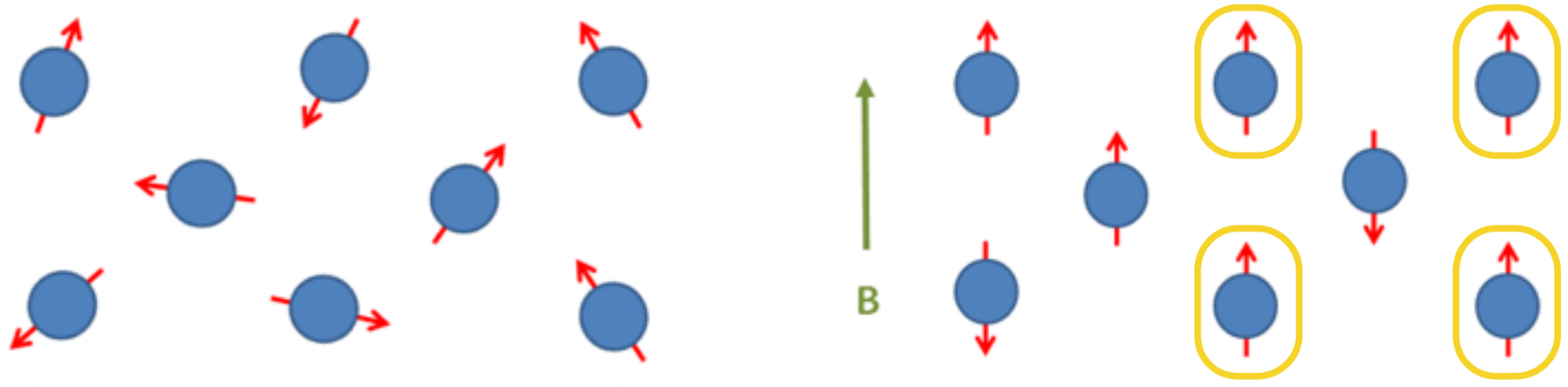
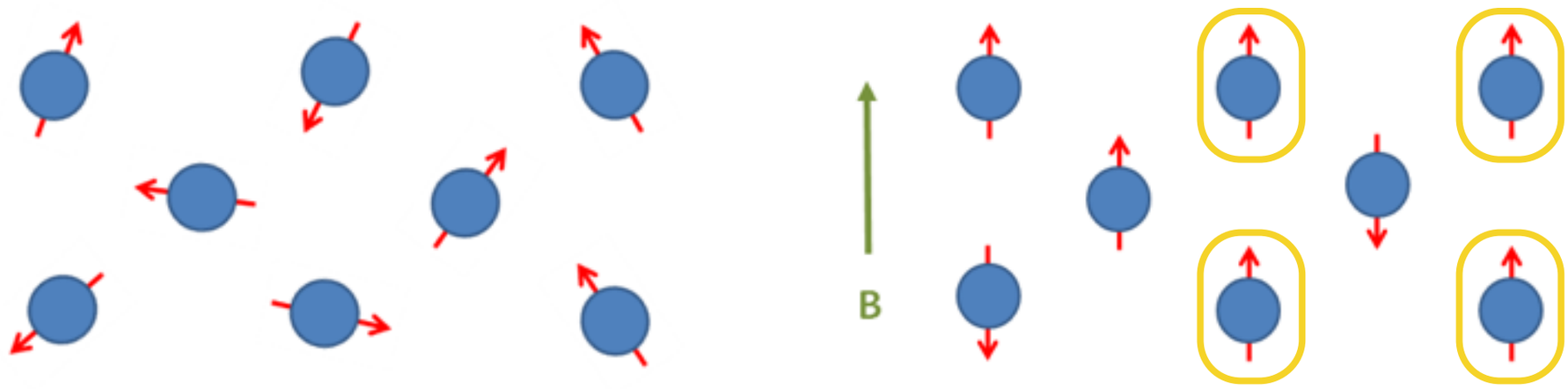
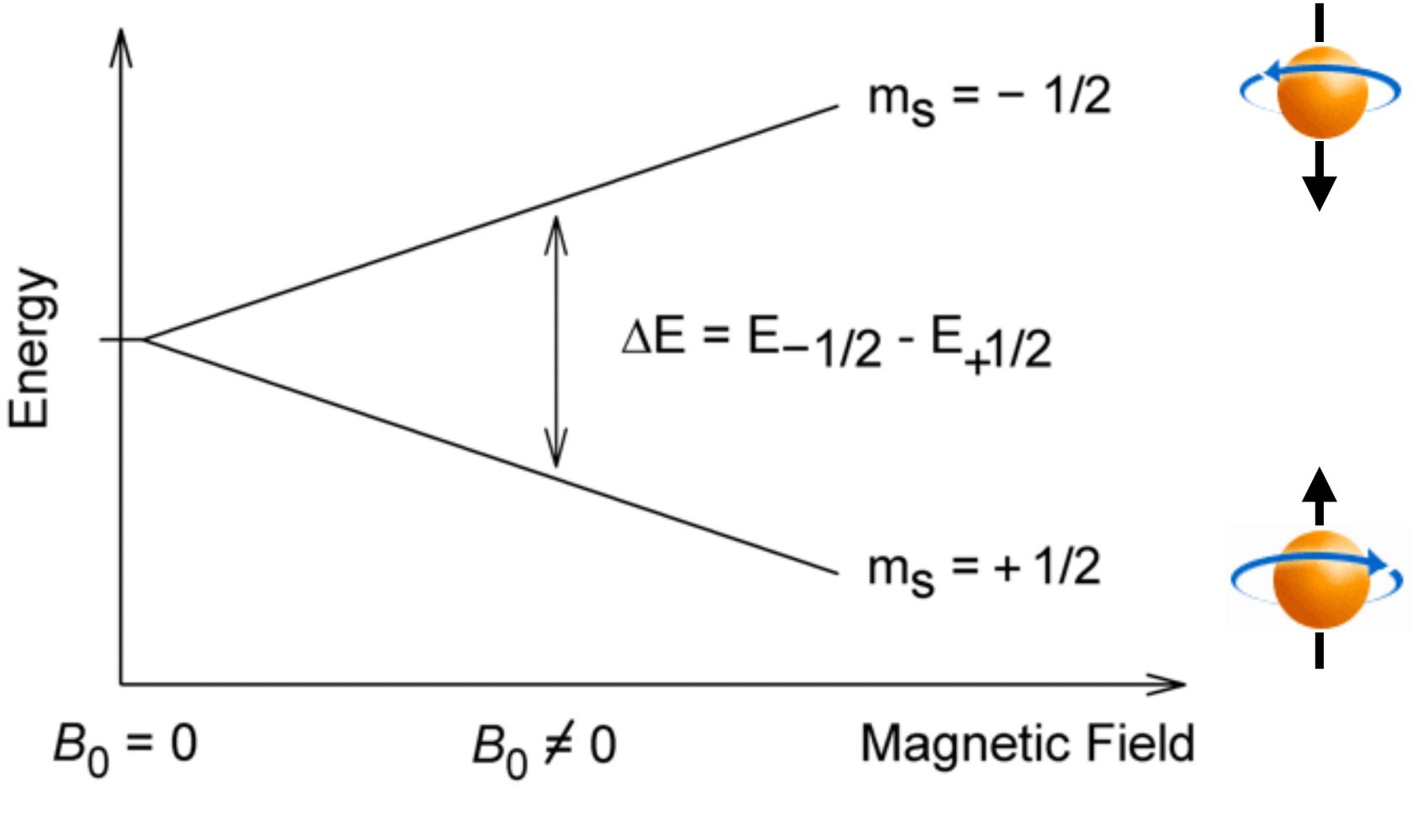


IN A MAGNETIC FIELD

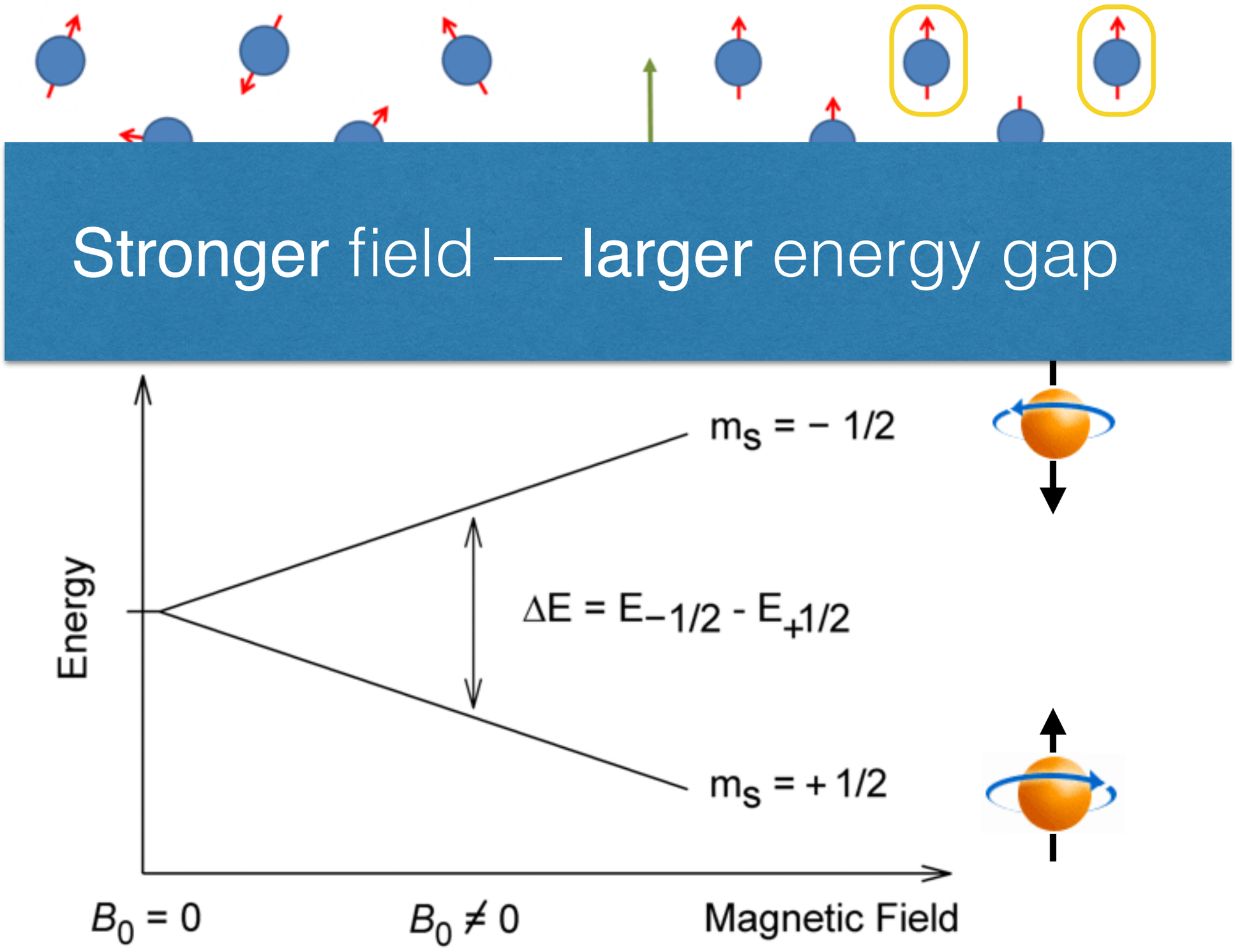


IN A MAGNETIC FIELD





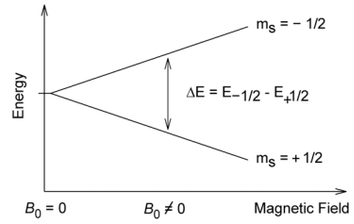
In a magnetic field



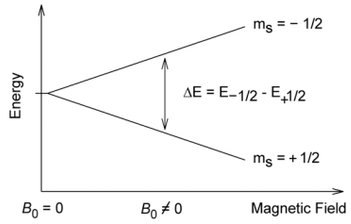
Nuclear Magnetic Resonance

Nuclear Magnetic Resonance

Nuclear Magnetic Resonance

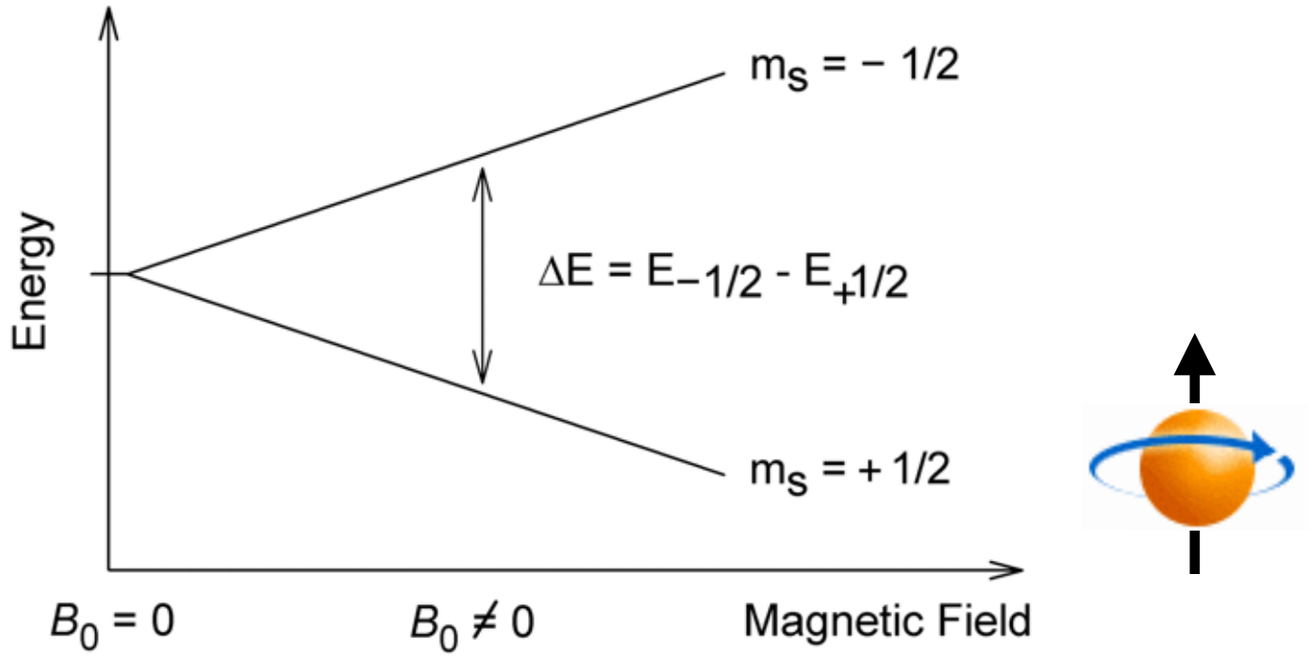


Nuclear Magnetic Resonance

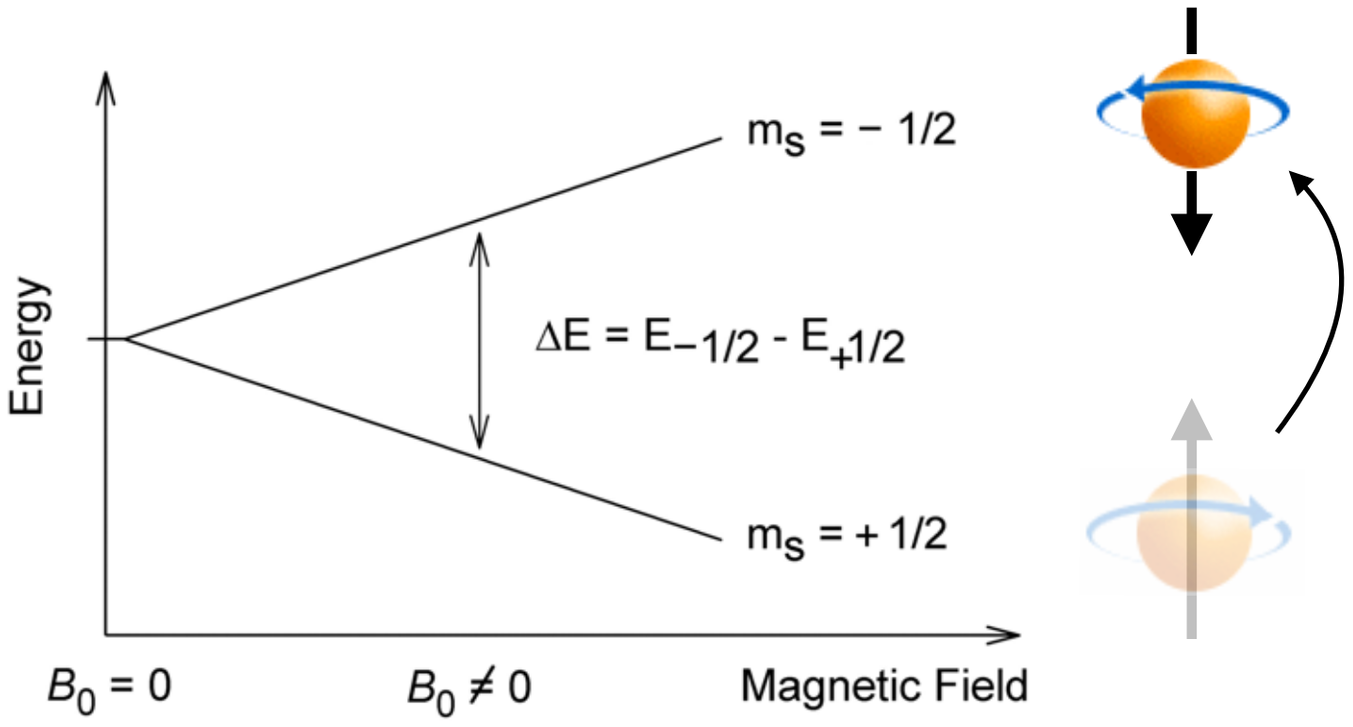


?

RADIO FREQUENCY PULSE

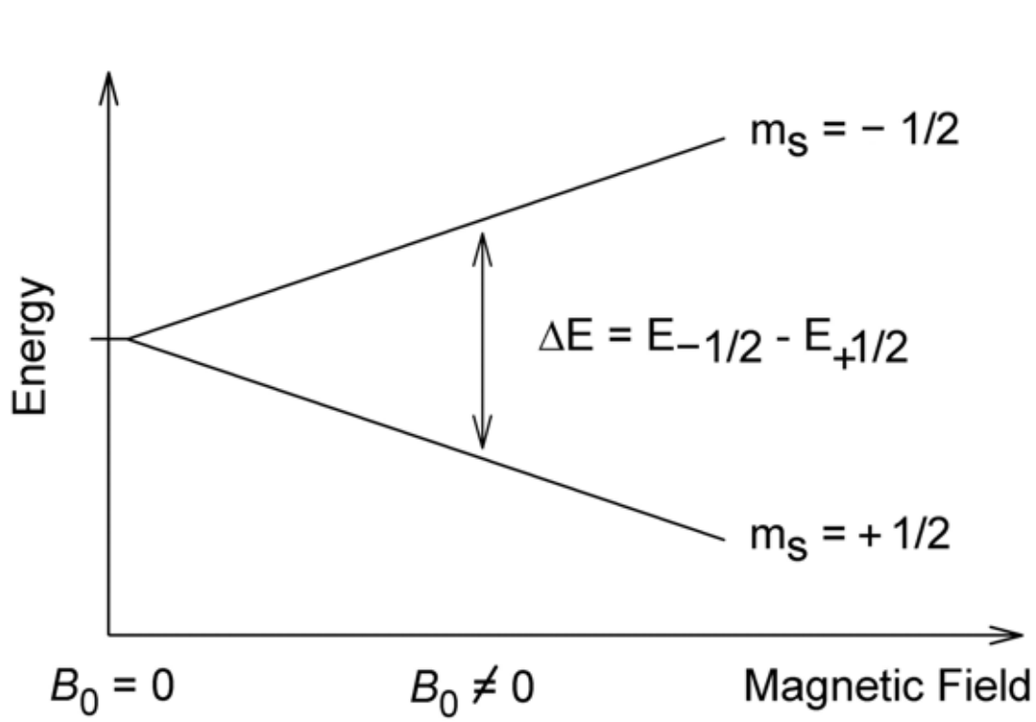


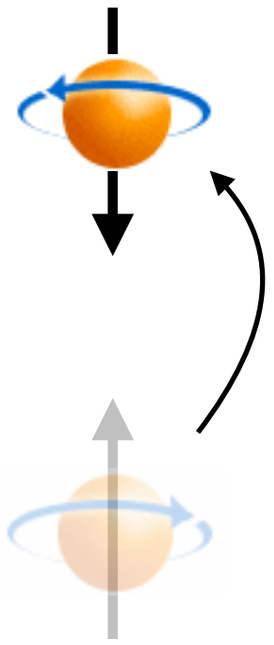
RADIO FREQUENCY PULSE



We can **give energy** to a particle and move it to a **higher** energy level

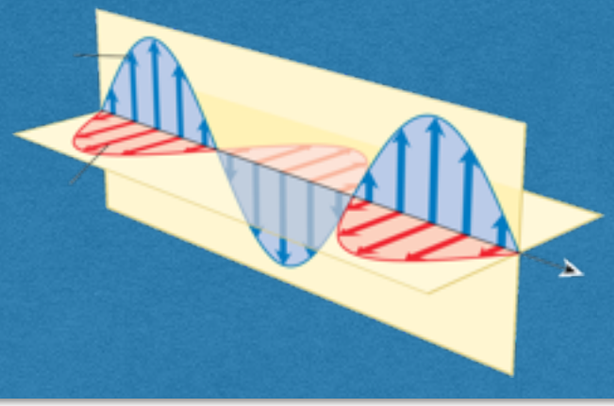
RADIO FREQUENCY PULSE



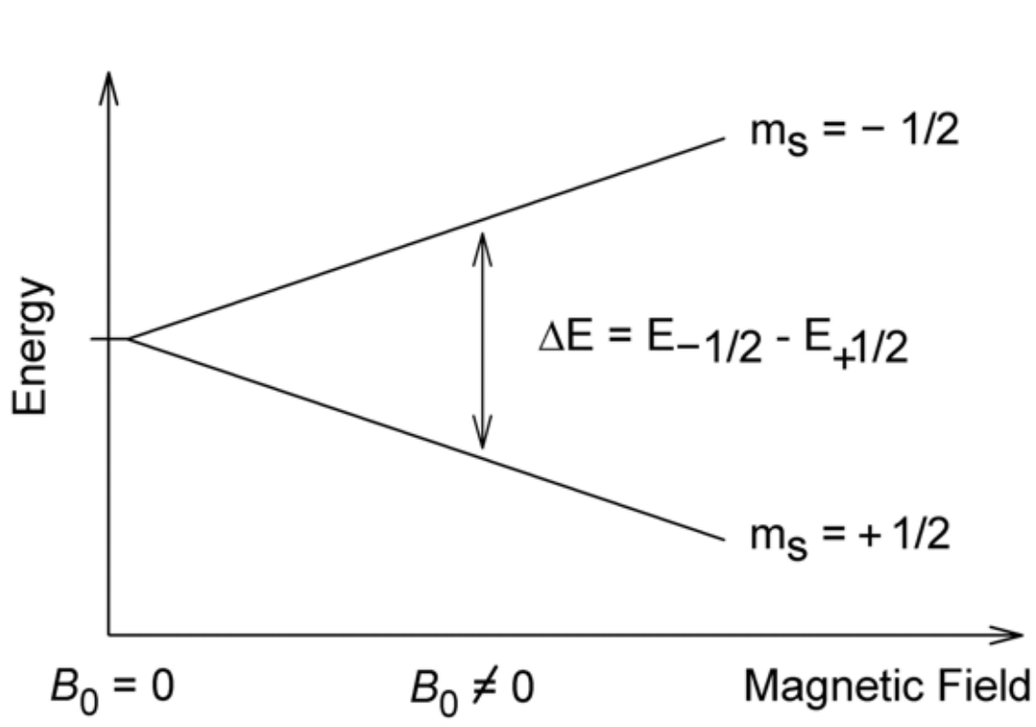


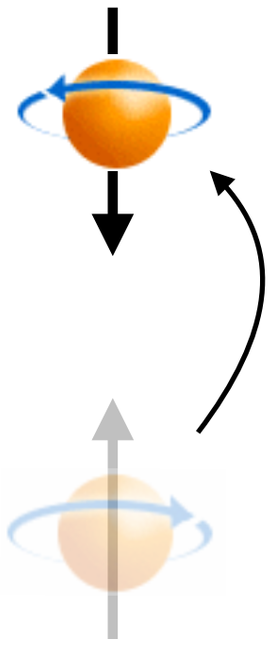
We can **give energy** to a particle and move it to a **higher** energy level

To do that we send an **electromagnetic** wave



RADIO FREQUENCY PULSE





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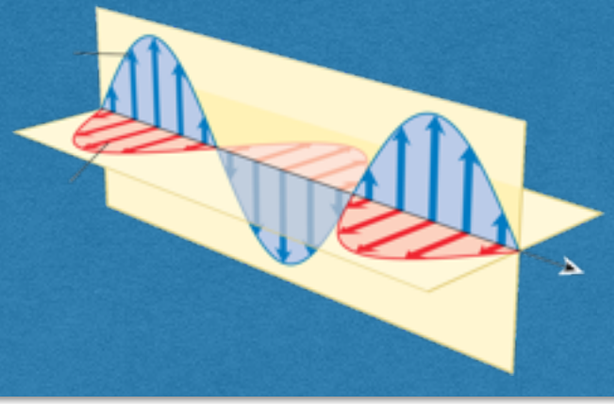


Nucleus will **absorb** energy only if **frequency** of the wave is **correct** for

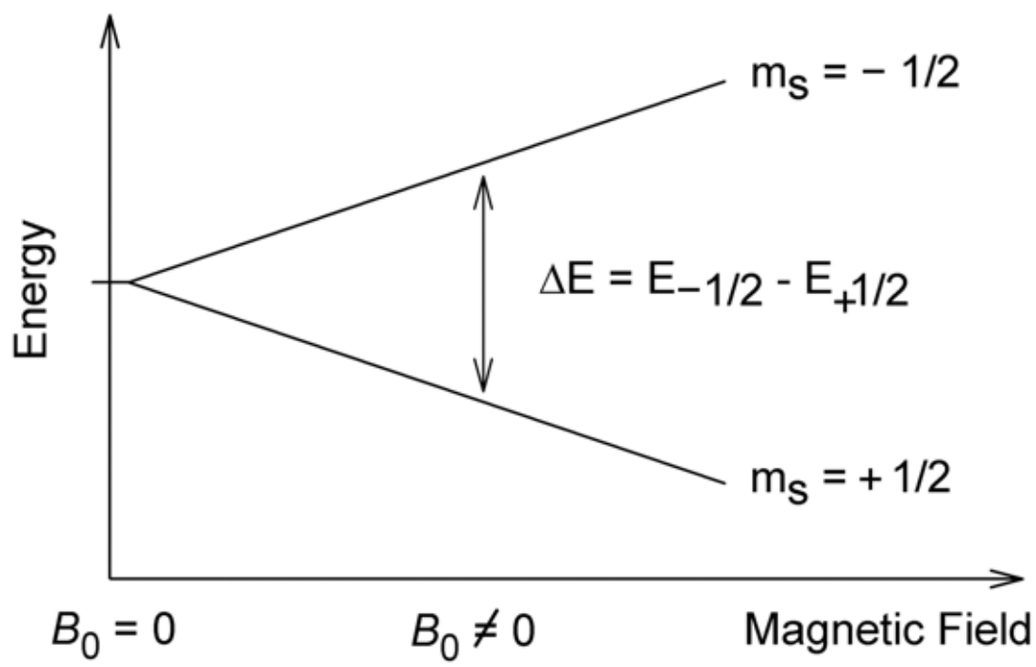
- the **nucleus** we work with
- **strength** of the magnetic **field**

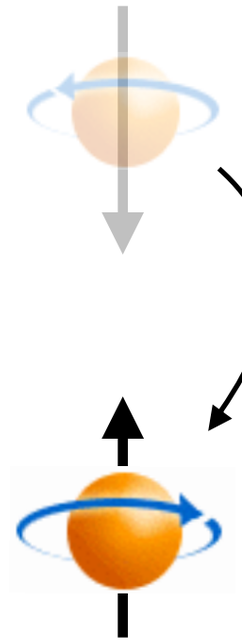
Relaxation

Now we stop the pulse

Relaxation

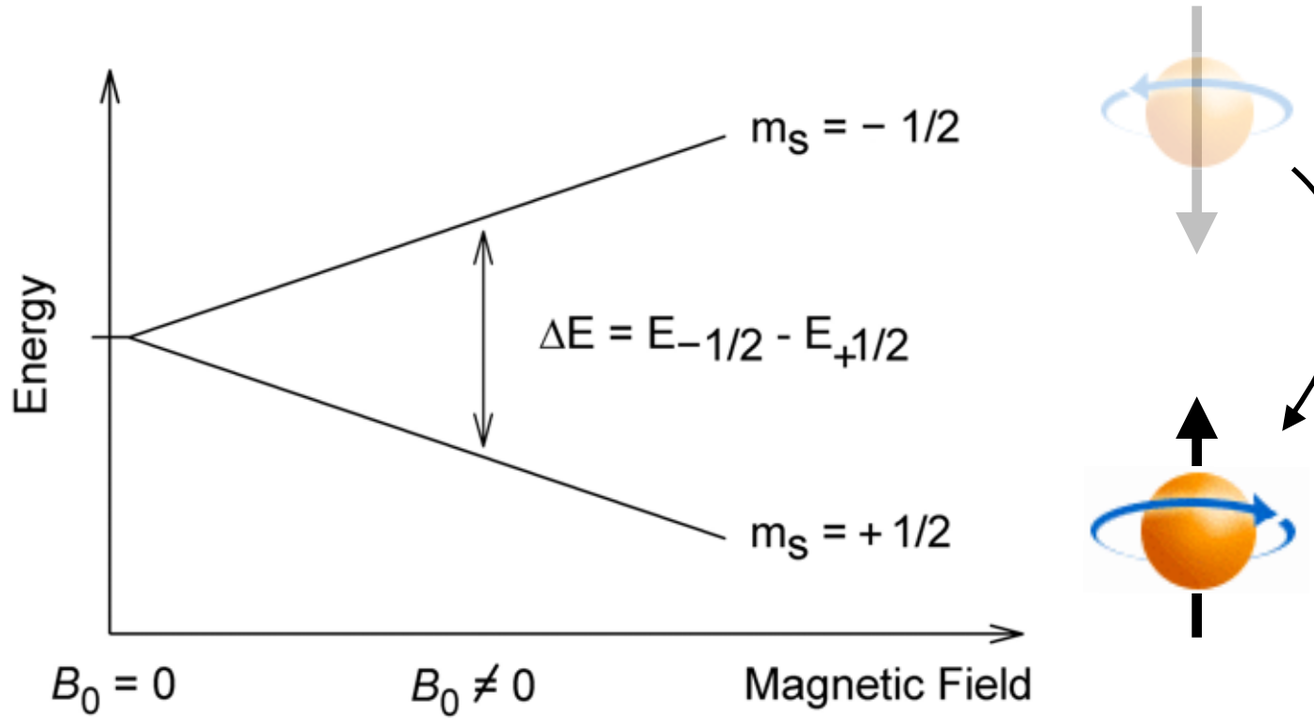
Now we stop the pulse





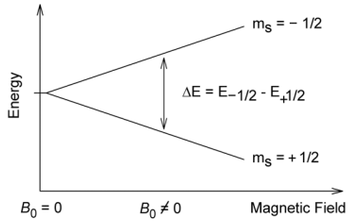
Relaxation

Now we stop the pulse

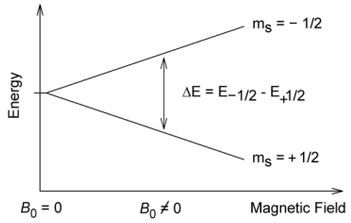


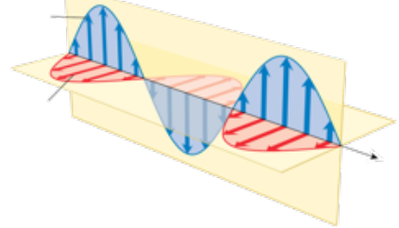
Nucleus will **give out** same amount of **energy** in the form of **electromagnetic** radiation.

Nuclear Magnetic Resonance

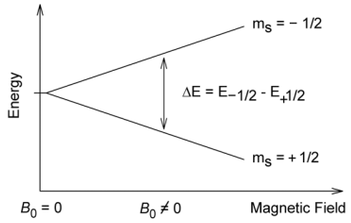


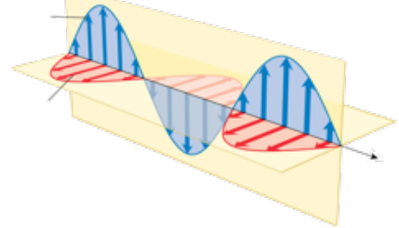
Nuclear Magnetic Resonance Imaging





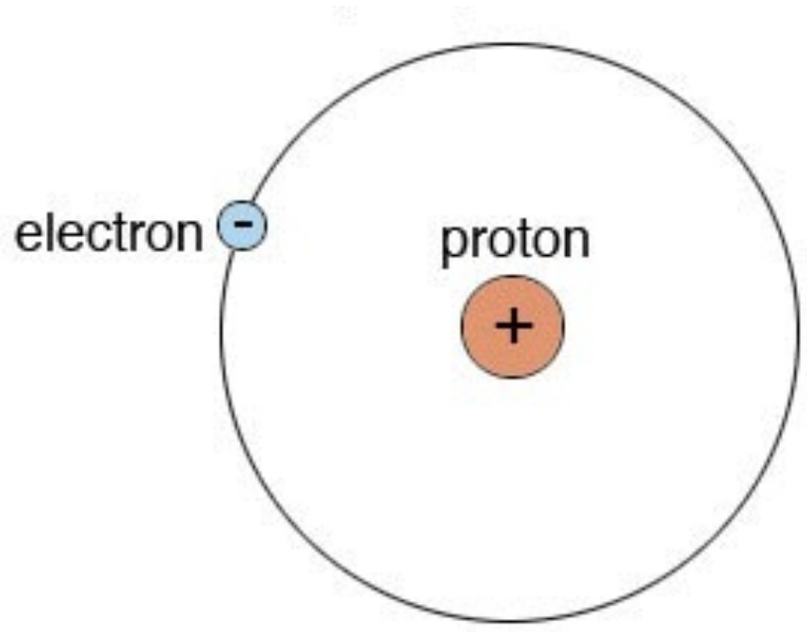
Nuclear Magnetic Resonance Imaging





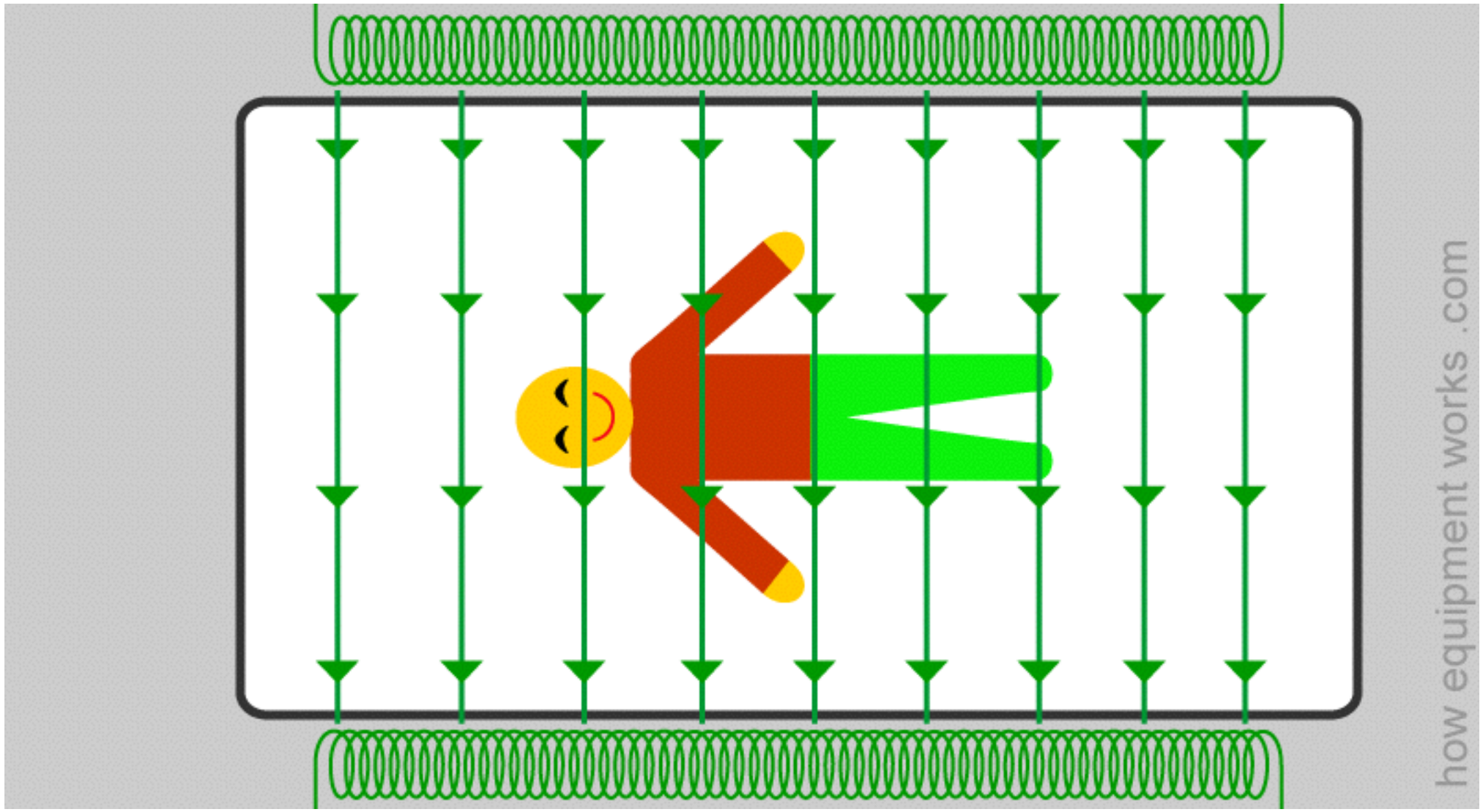
Hydrogen

HYDROGEN



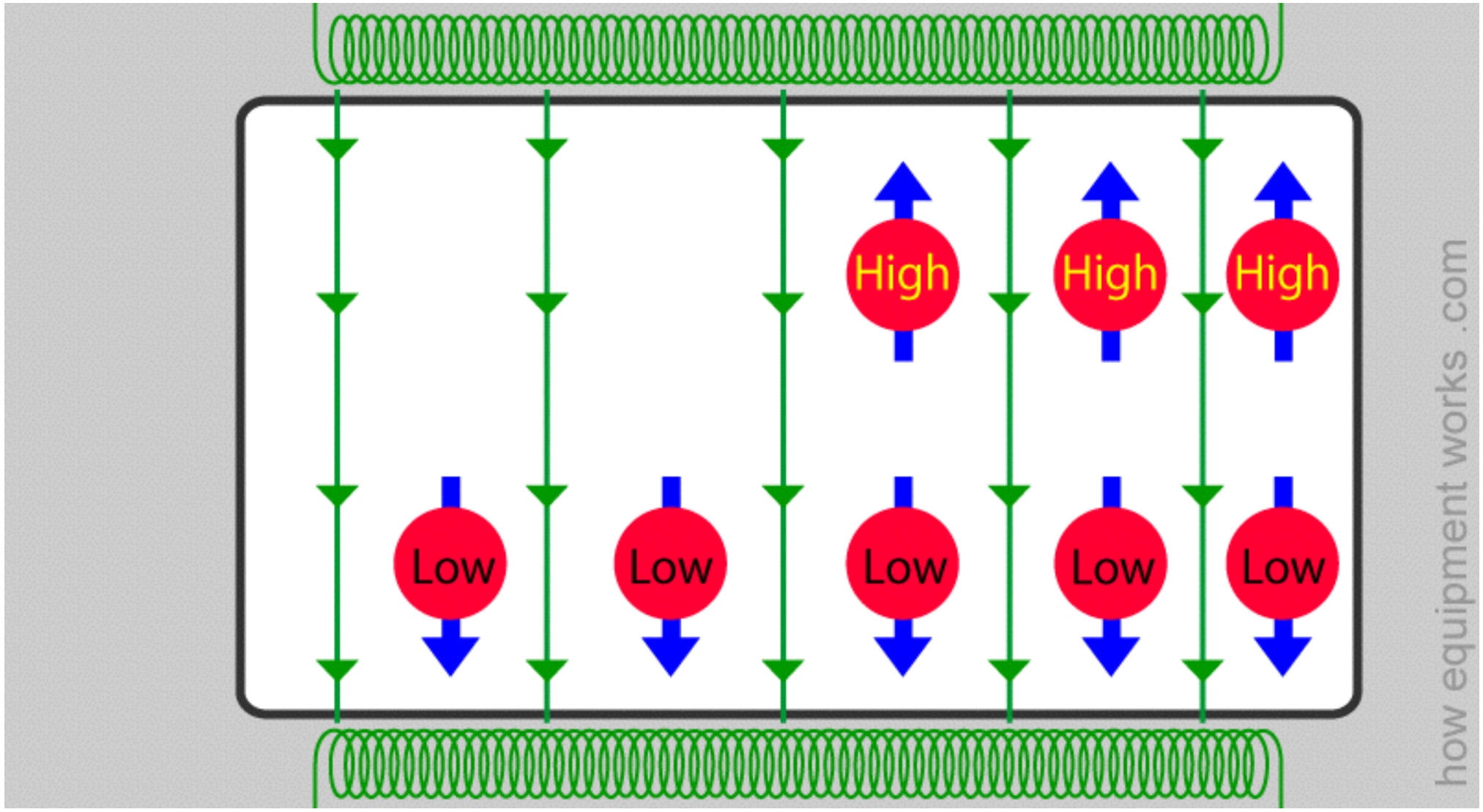
Possible spin states
+1/2 or -1/2

HYDROGEN IN A MAGNETIC FIELD



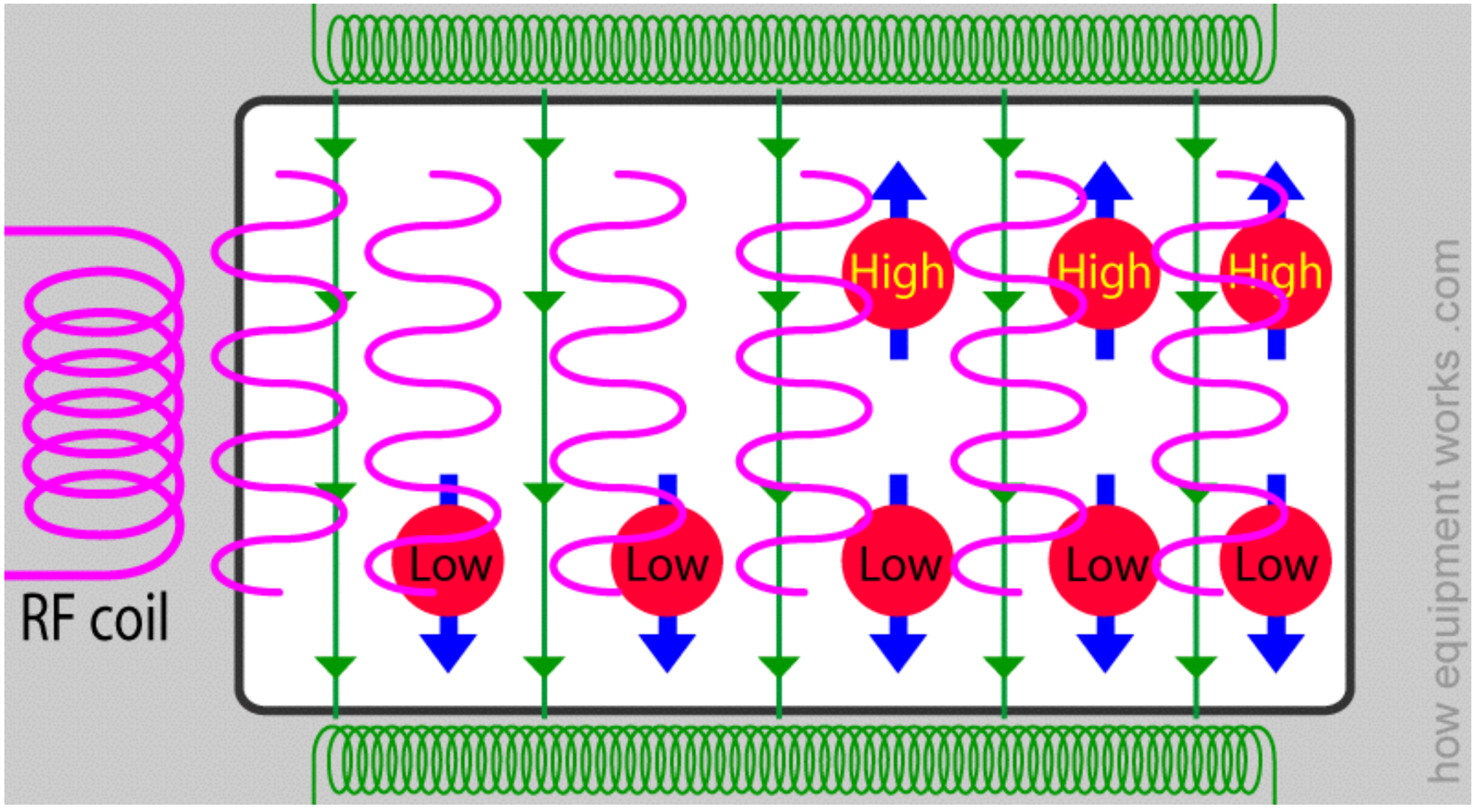
http://www.howequipmentworks.com/physics/medical_imaging/mri/magnetic_resonance_imaging.html

HYDROGEN IN A MAGNETIC FIELD



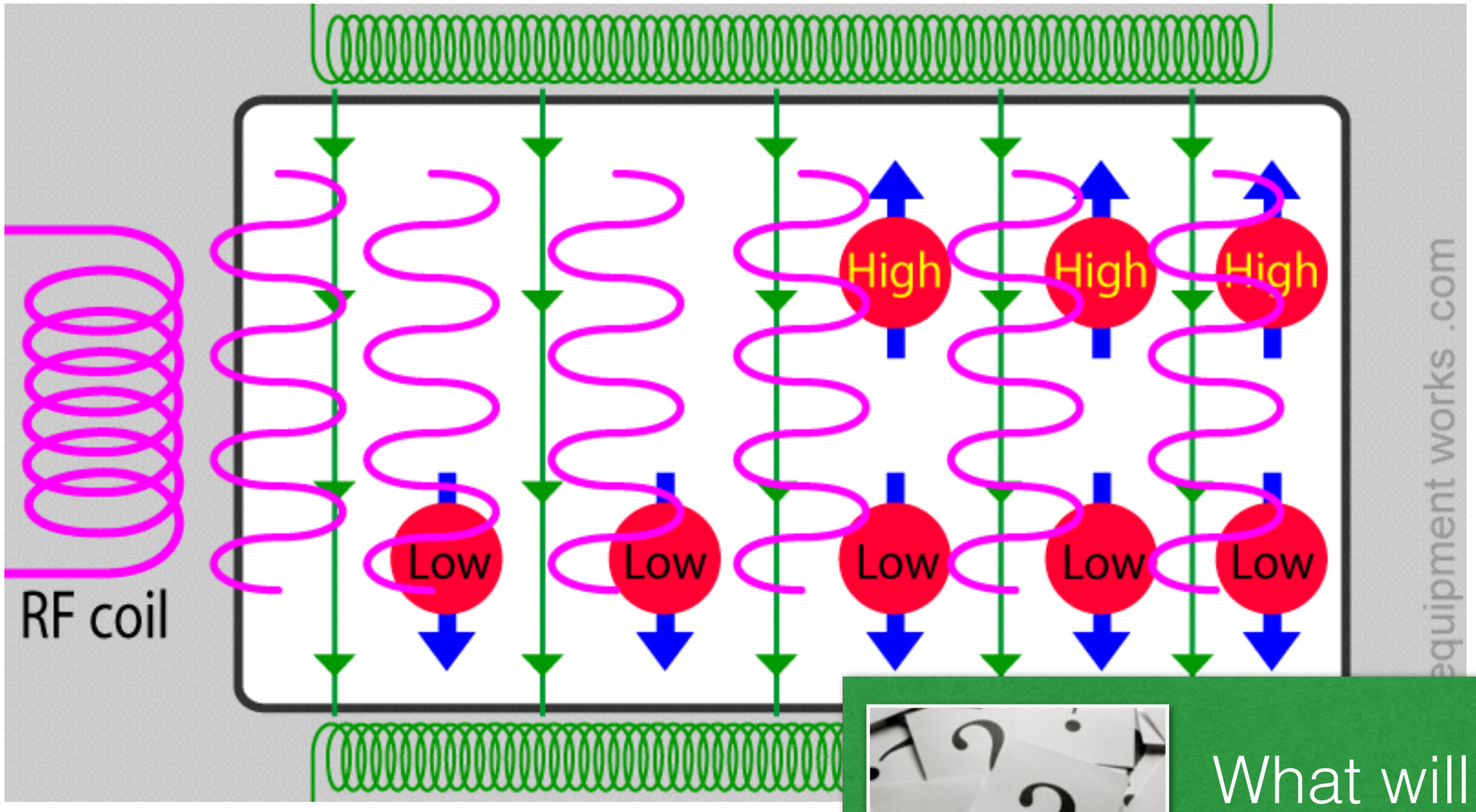
http://www.howequipmentworks.com/physics/medical_imaging/mri/magnetic_resonance_imaging.html

RF Pulse



http://www.howequipmentworks.com/physics/medical_imaging/mri/magnetic_resonance_imaging.html

RF Pulse



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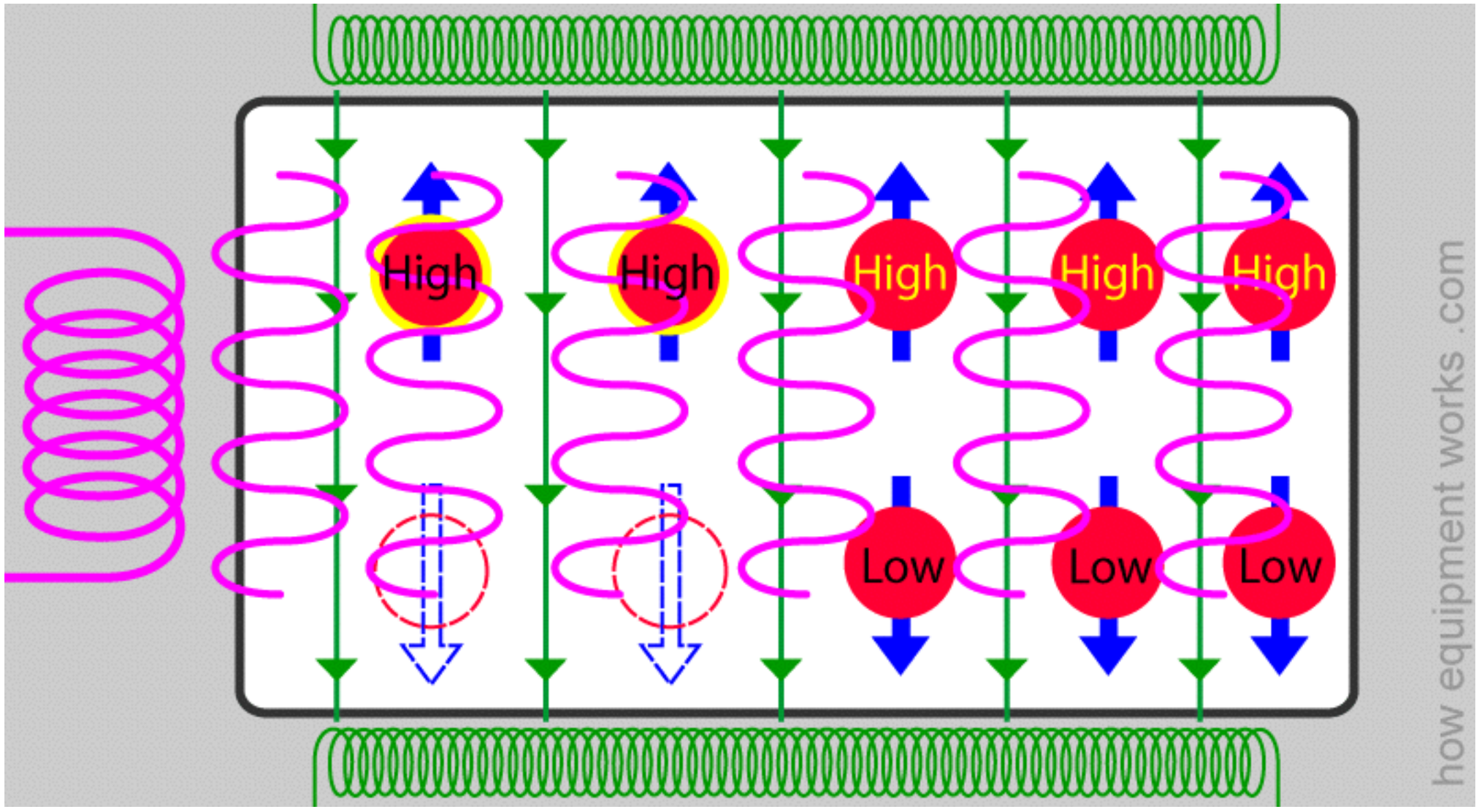
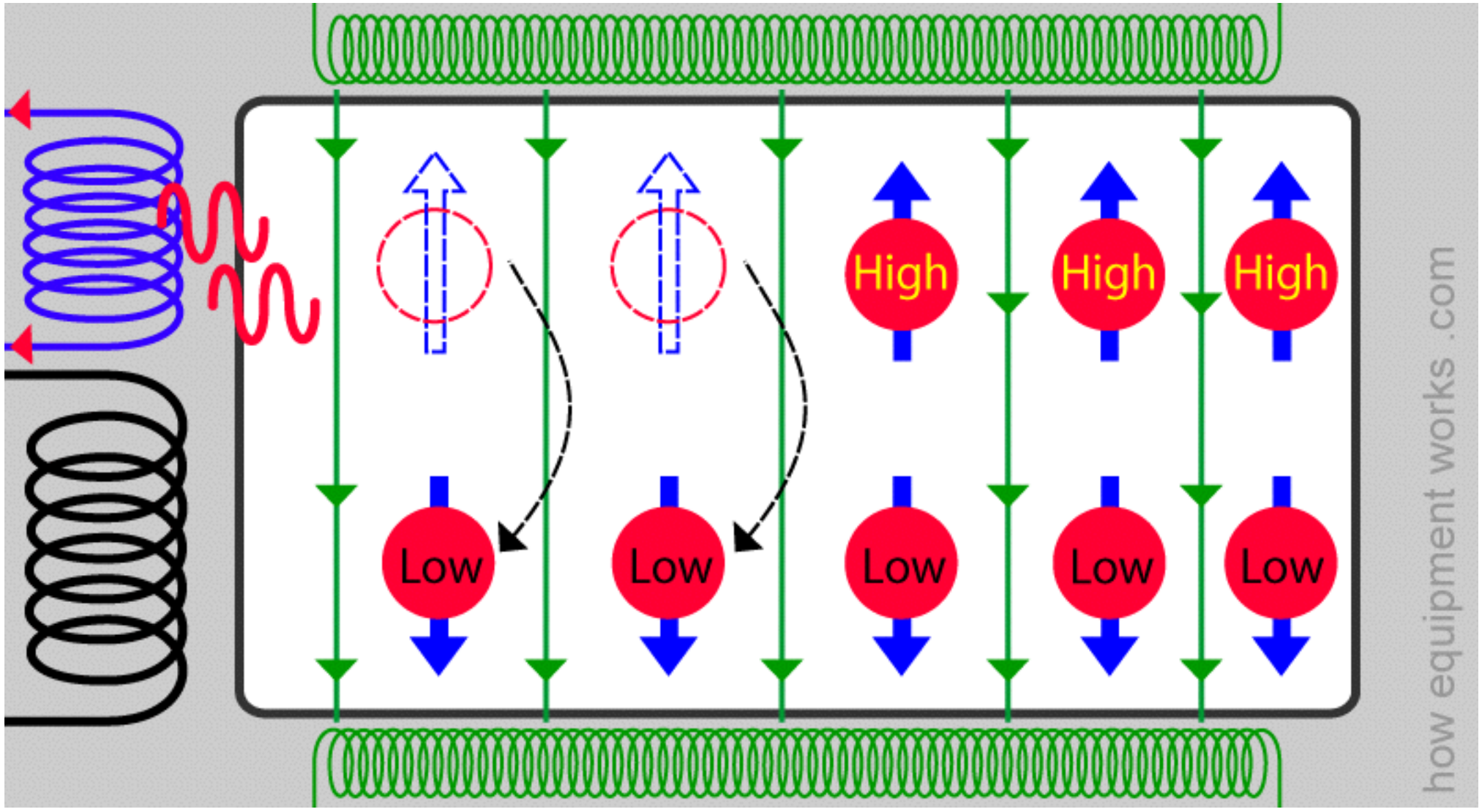
RF Pulse



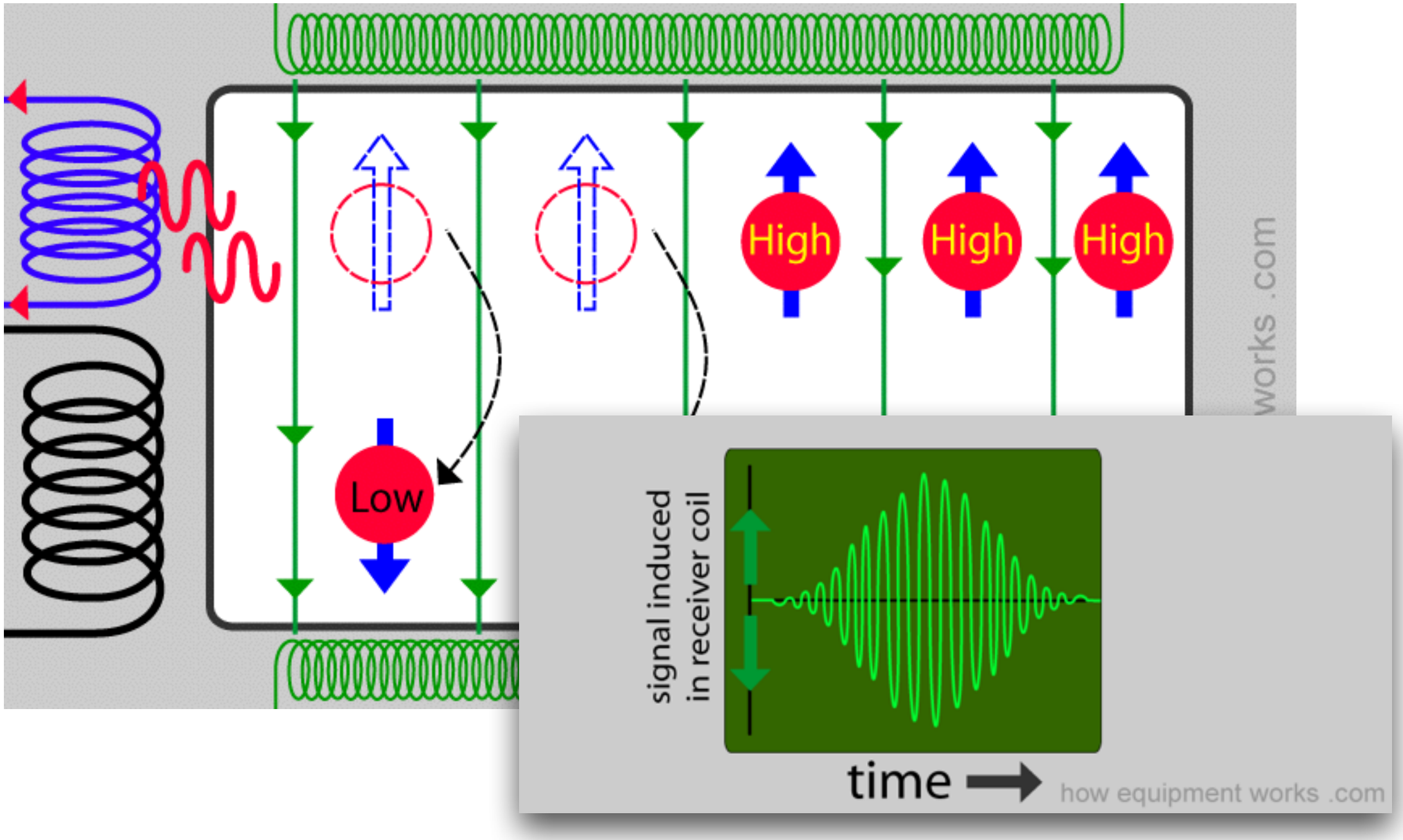
http://www.howequipmentworks.com/physics/medical_imaging/mri/magnetic_resonance_imaging.html

Relaxation



http://www.howequipmentworks.com/physics/medical_imaging/mri/magnetic_resonance_imaging.html

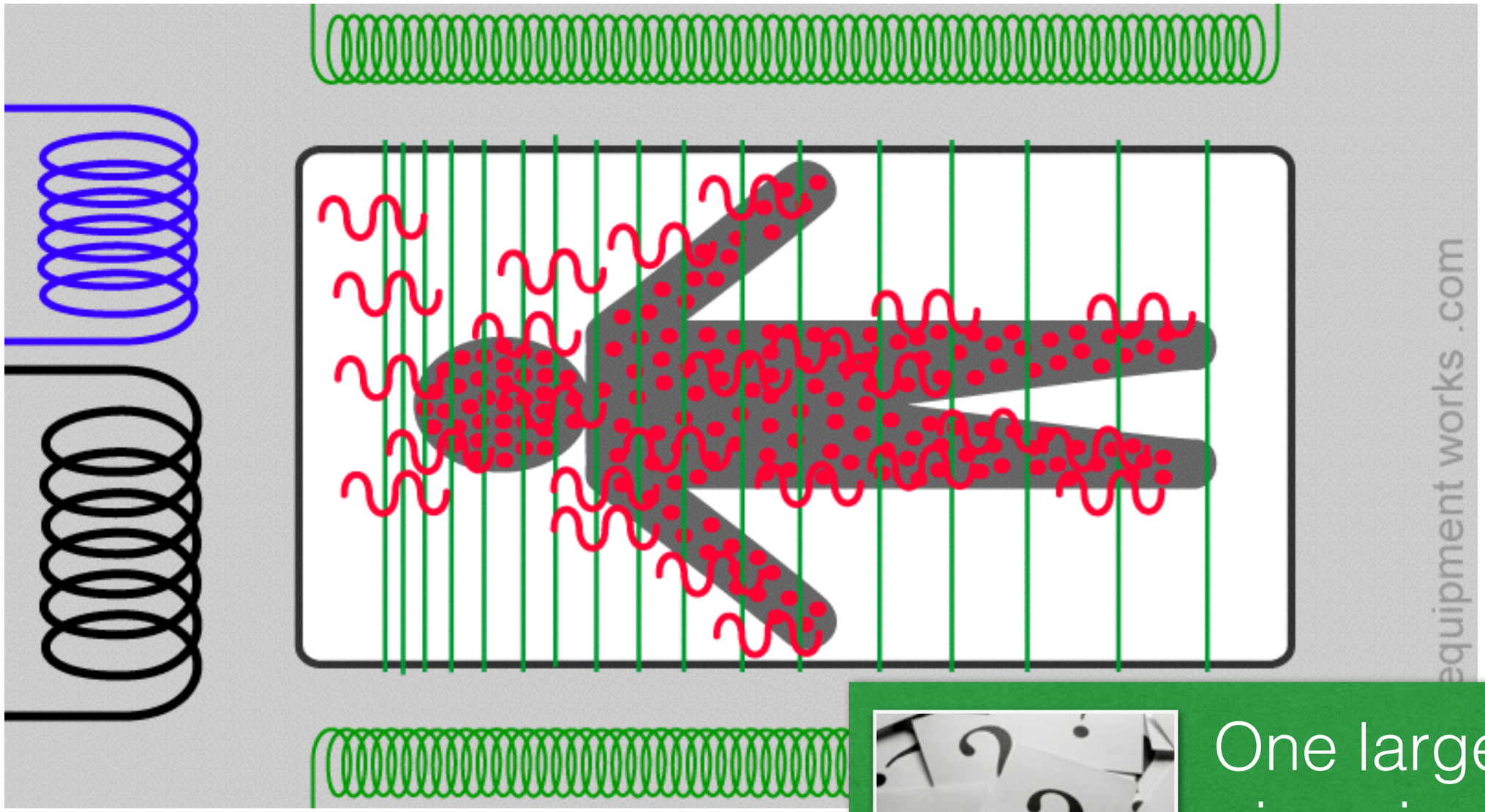
Relaxation



http://www.howequipmentworks.com/physics/medical_imaging/mri/magnetic_resonance_imaging.html

For different **tissues**
the time of **relaxation**
is **different**

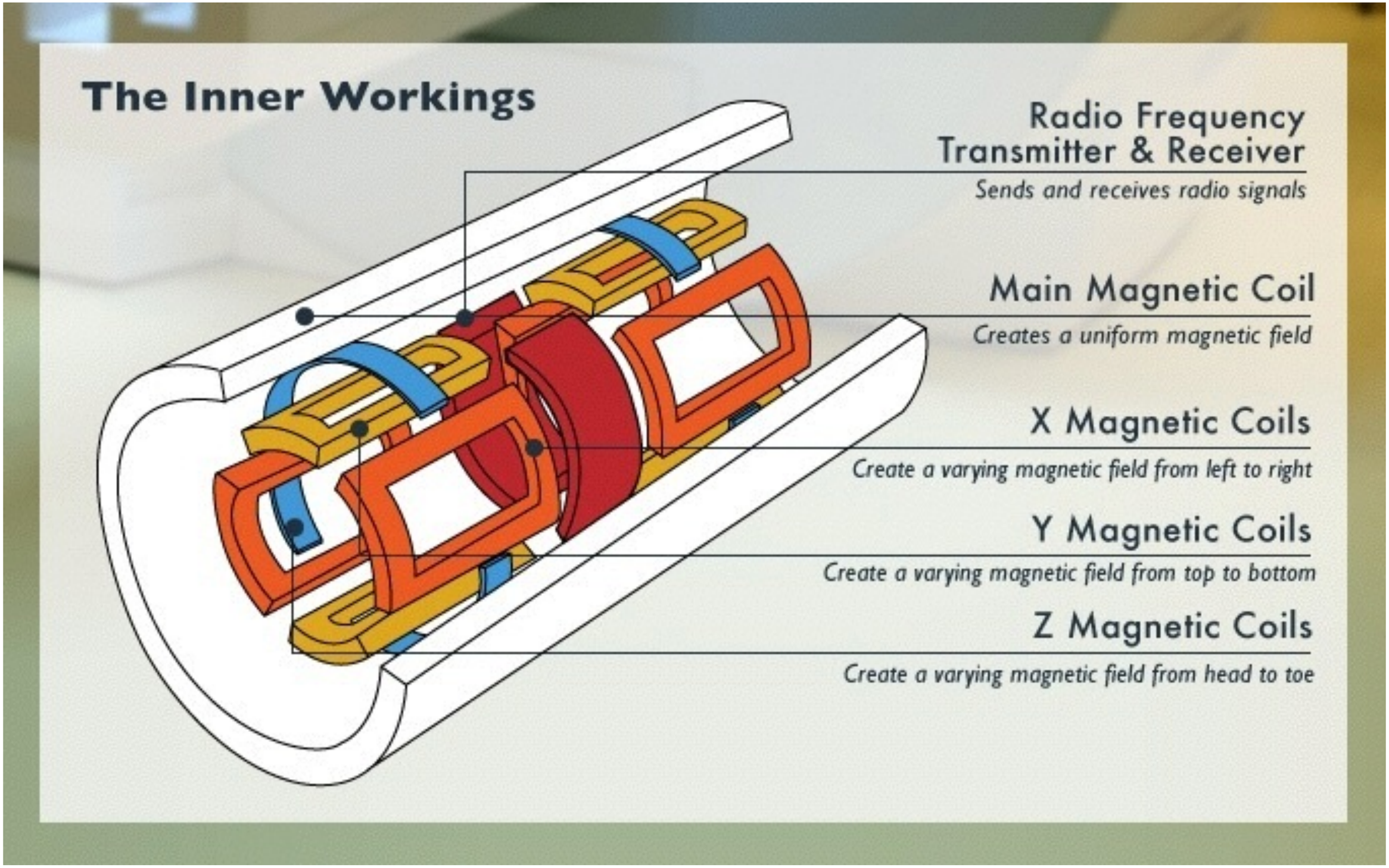
Nuclei send signals



One large piece is still missing…

http://www.howequipmentworks.com/physics/medical_imaging/mri/magnetic_resonance_imaging.html

GRADIENT COILS



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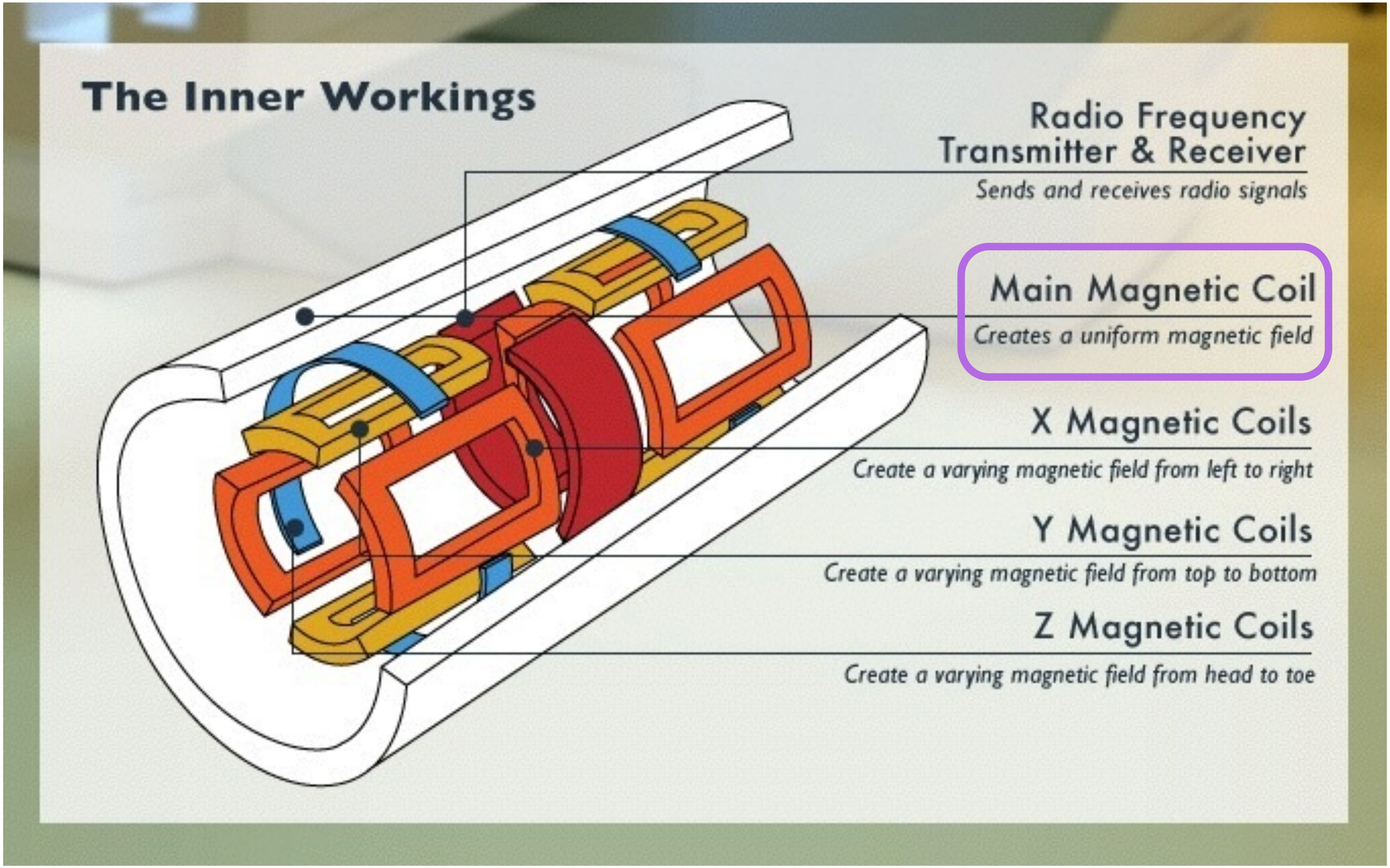
GRADIENT COILS



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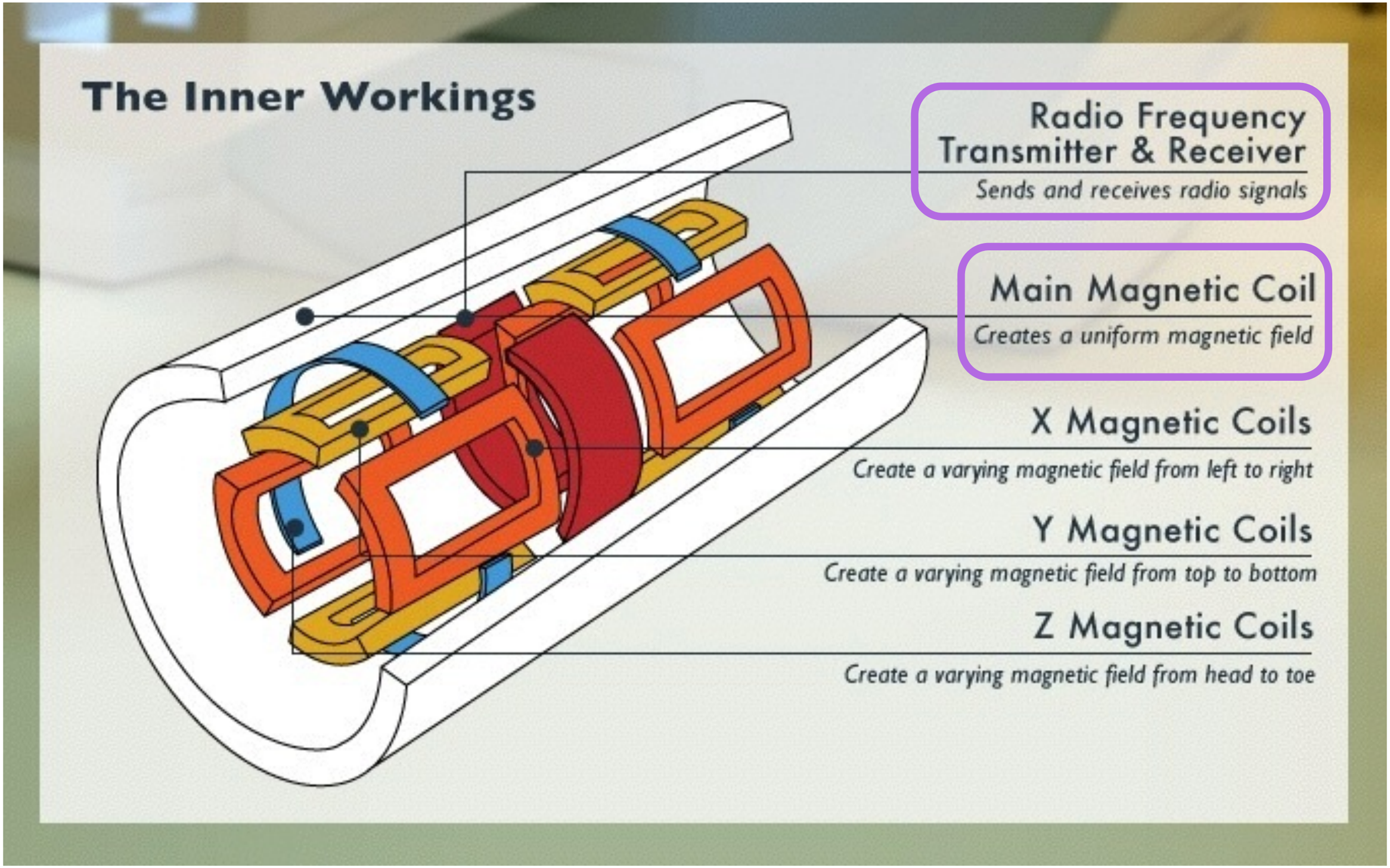

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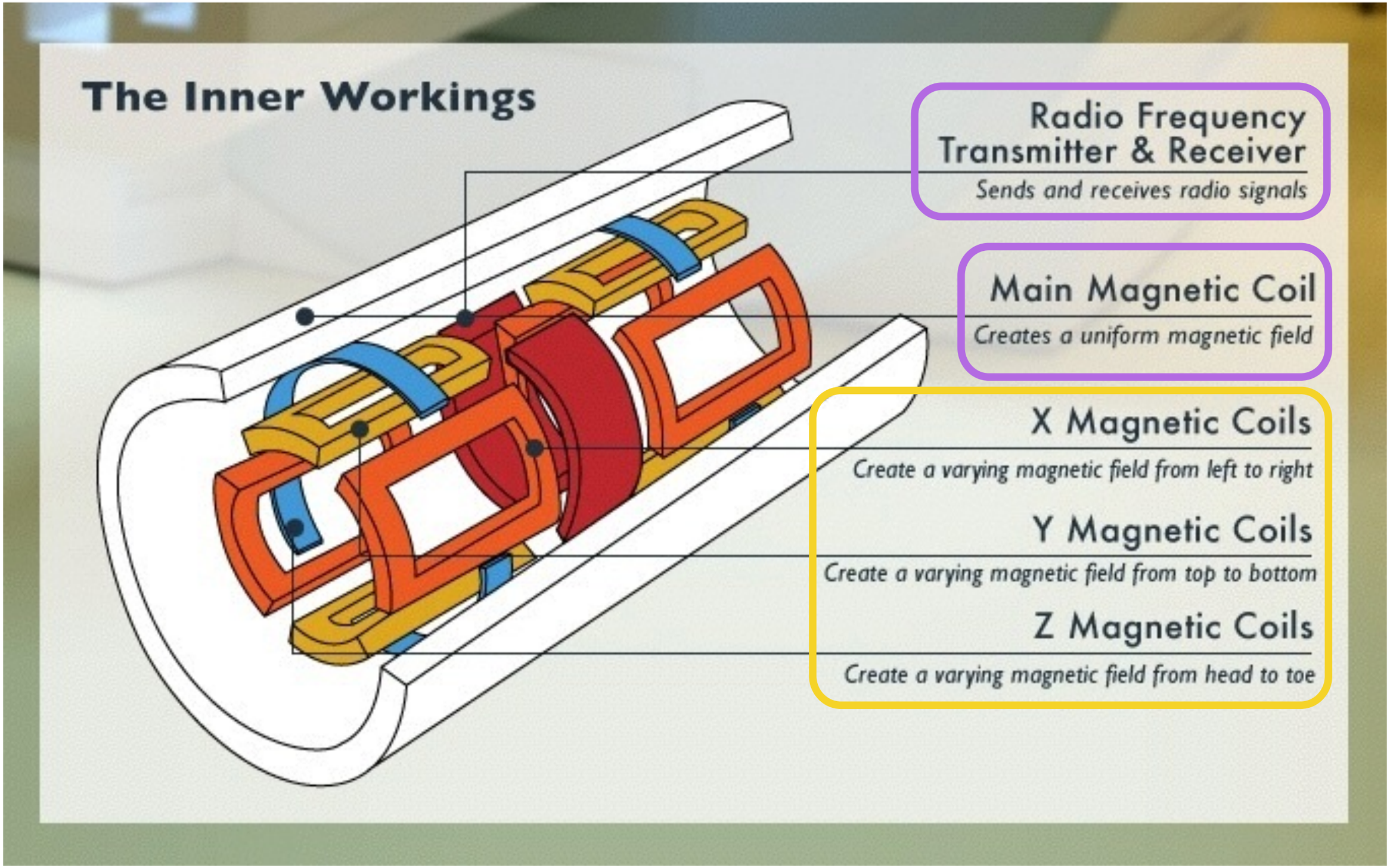

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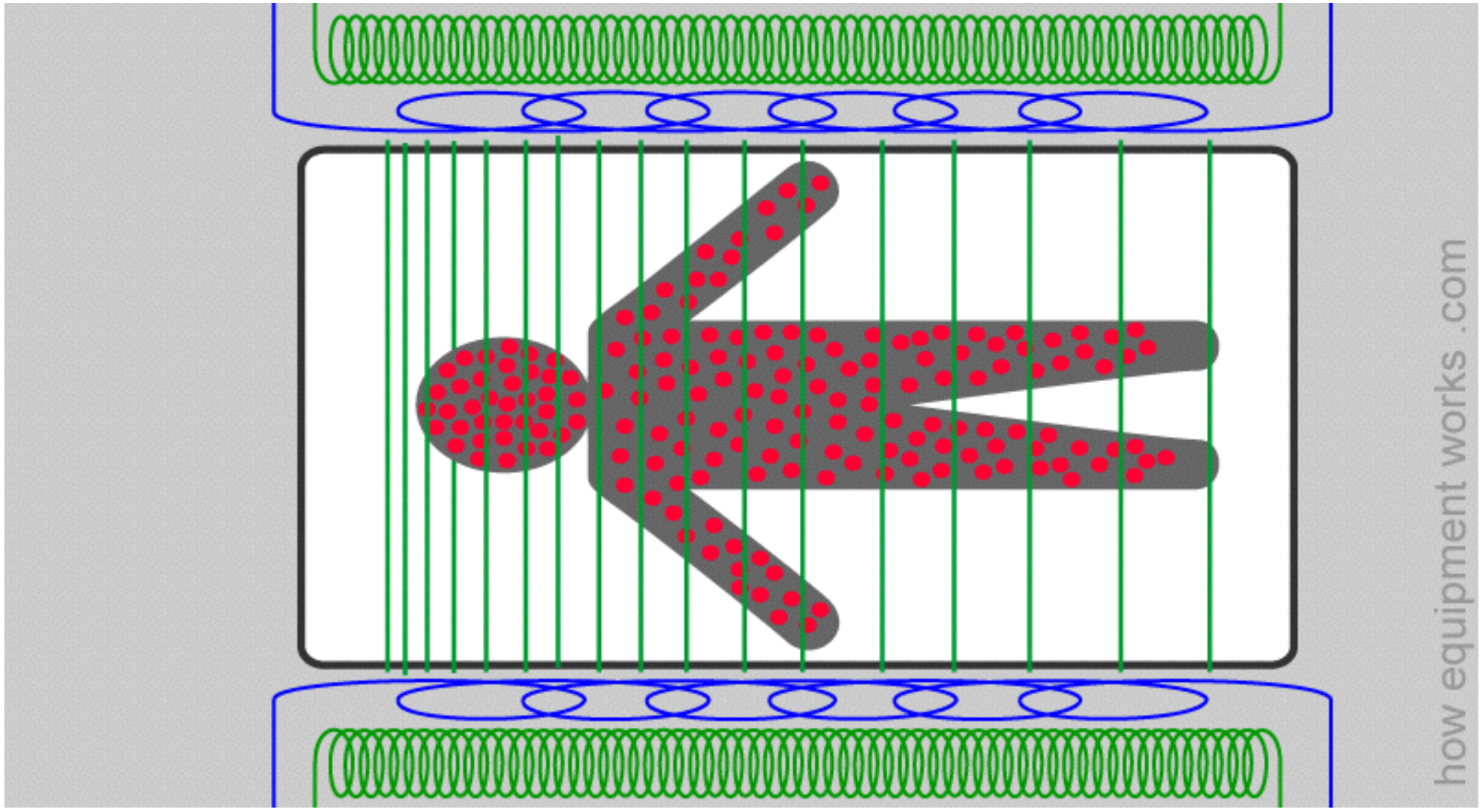

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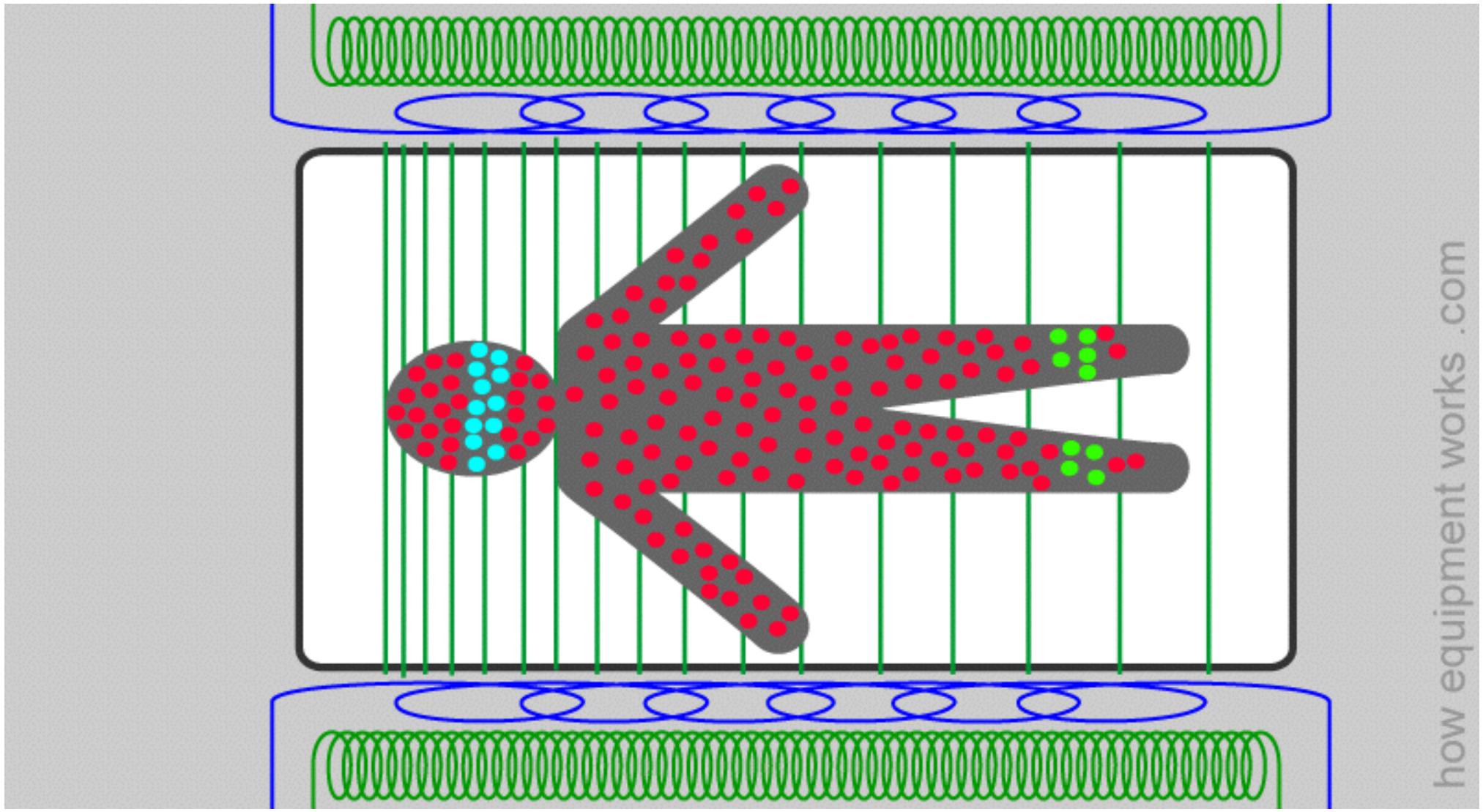

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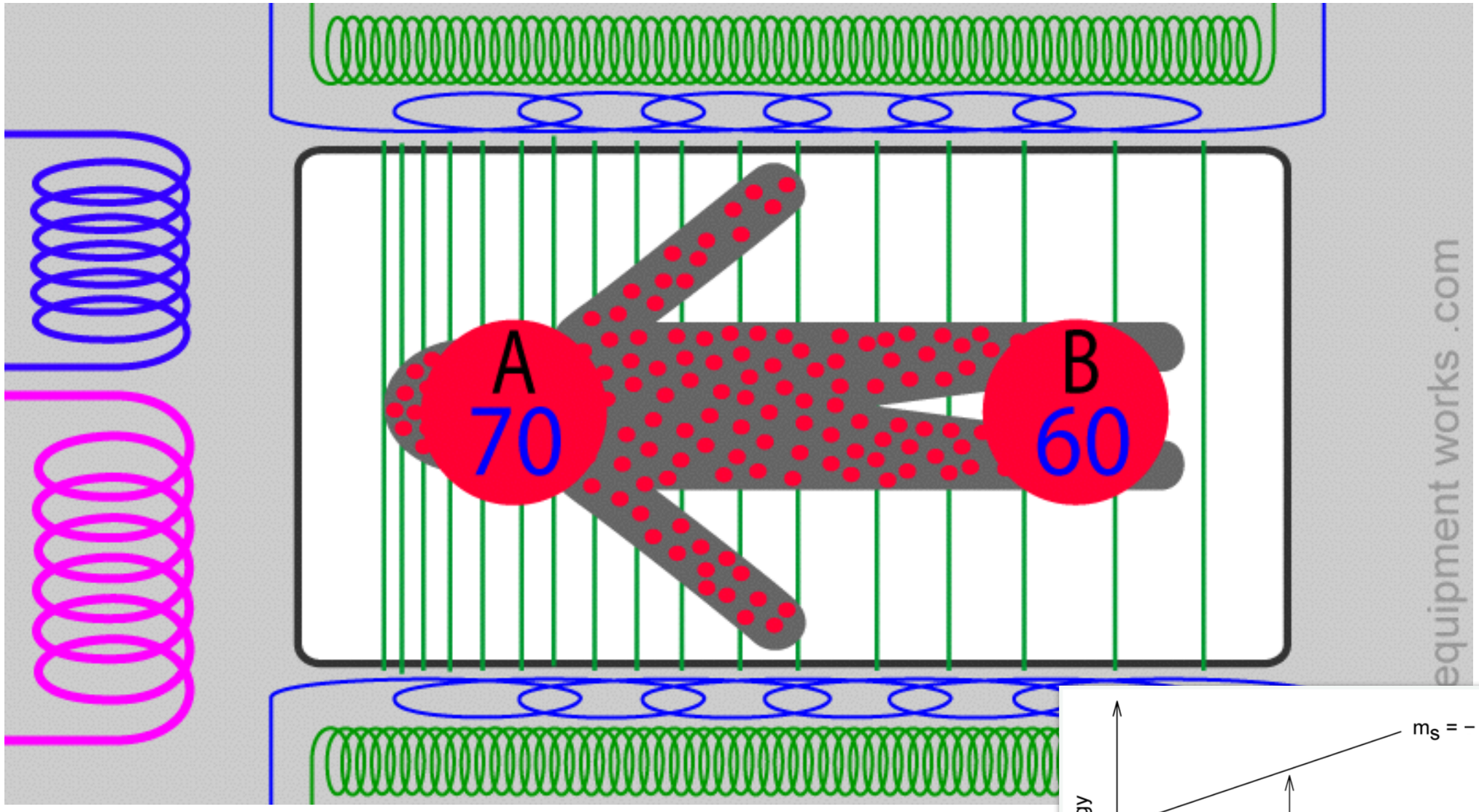

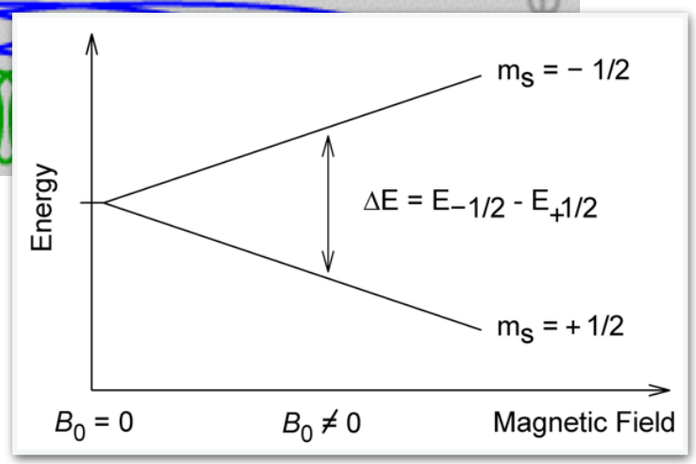

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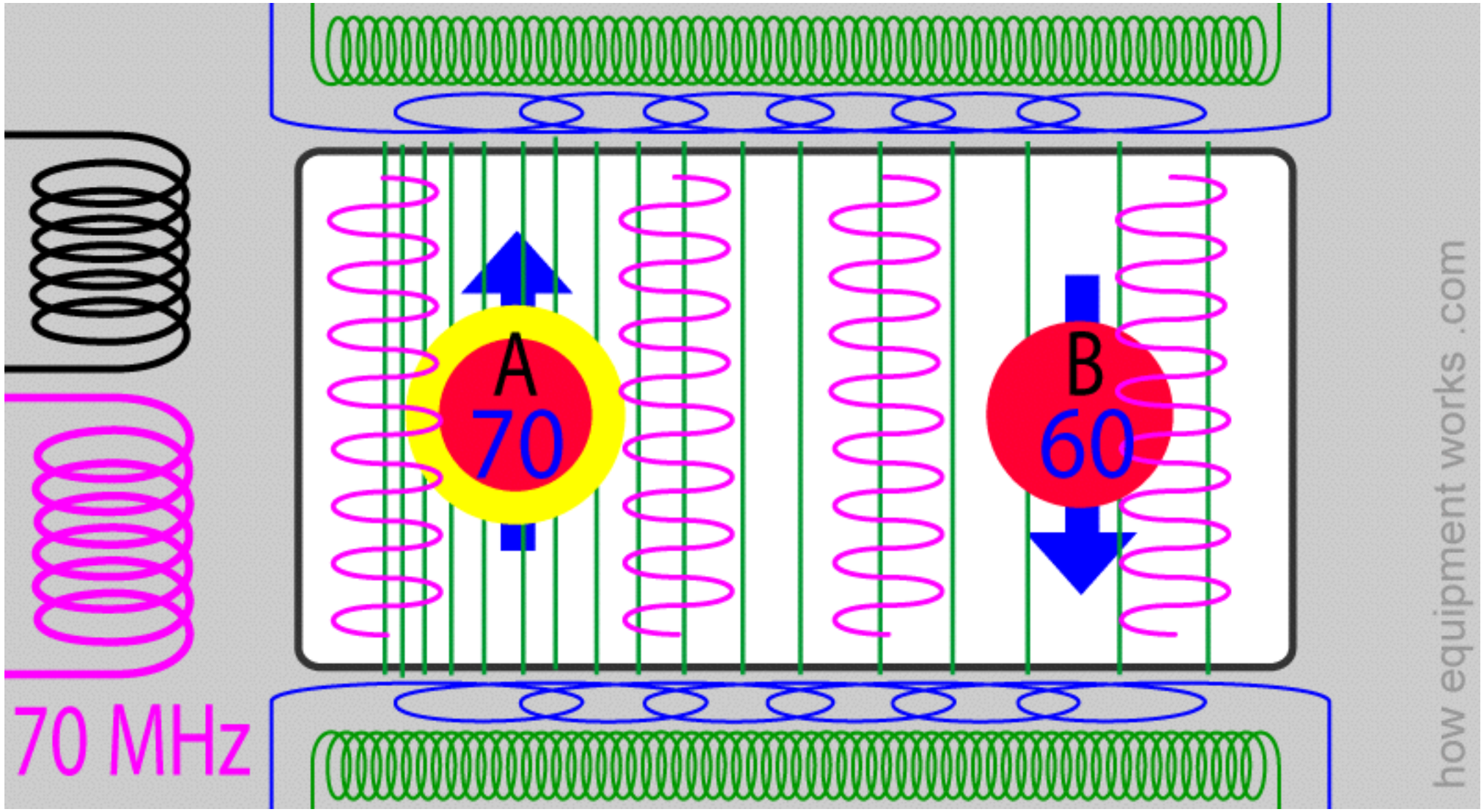

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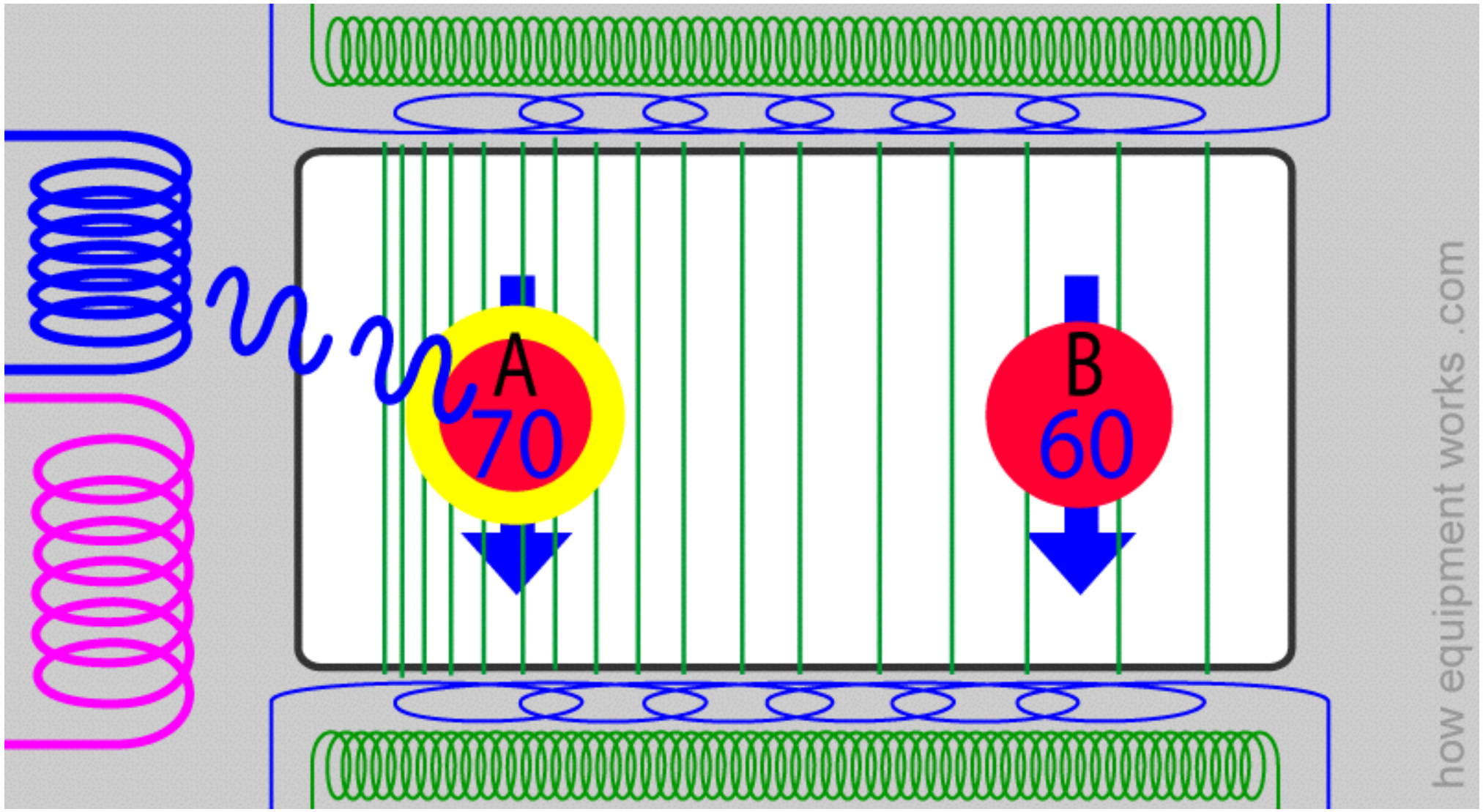

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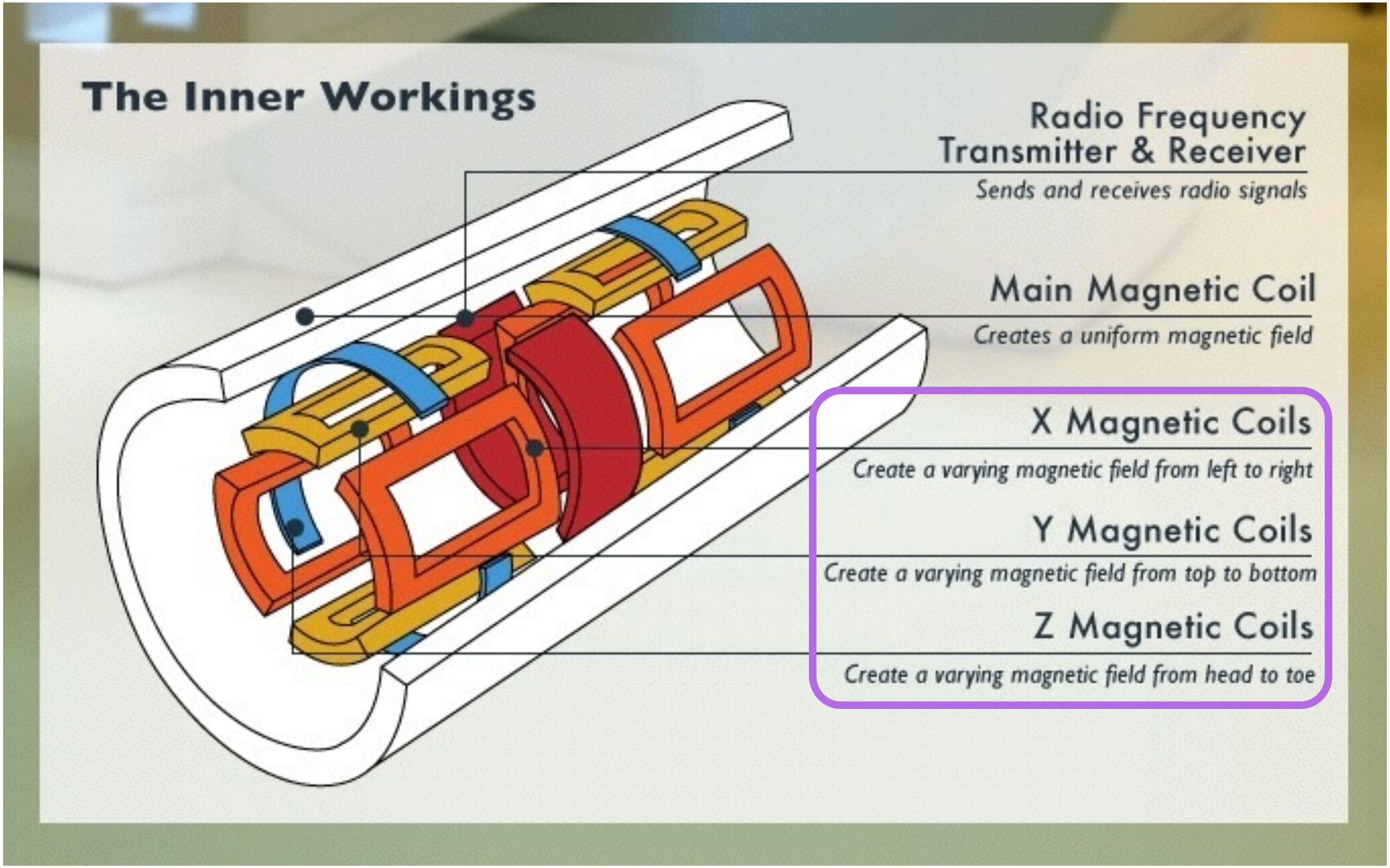


http://www.howequipmentworks.com/physics/medical_imaging/mri/magnetic_resonance_imaging.html

FMRI

F FOR FUNCTIONAL

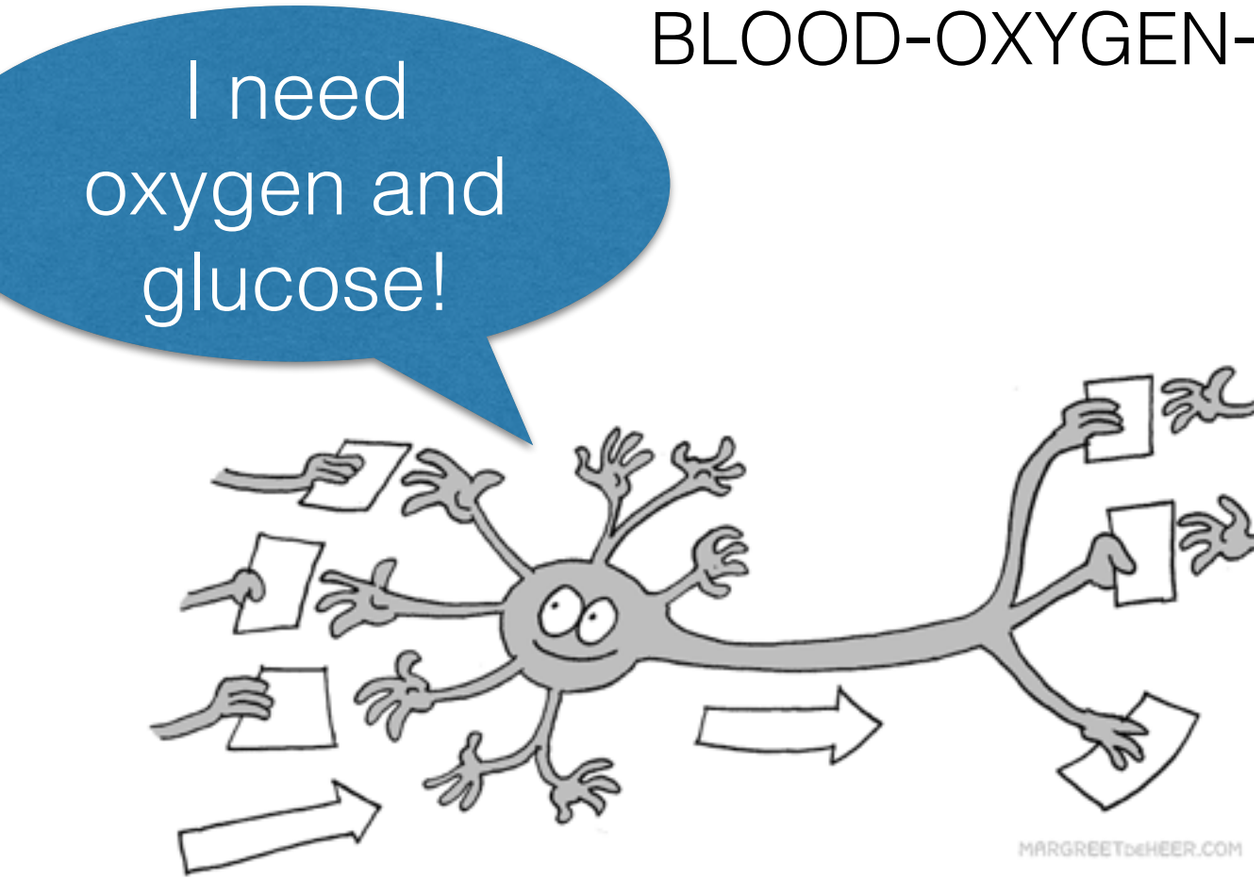
FMRI

F FOR FUNCTIONAL*

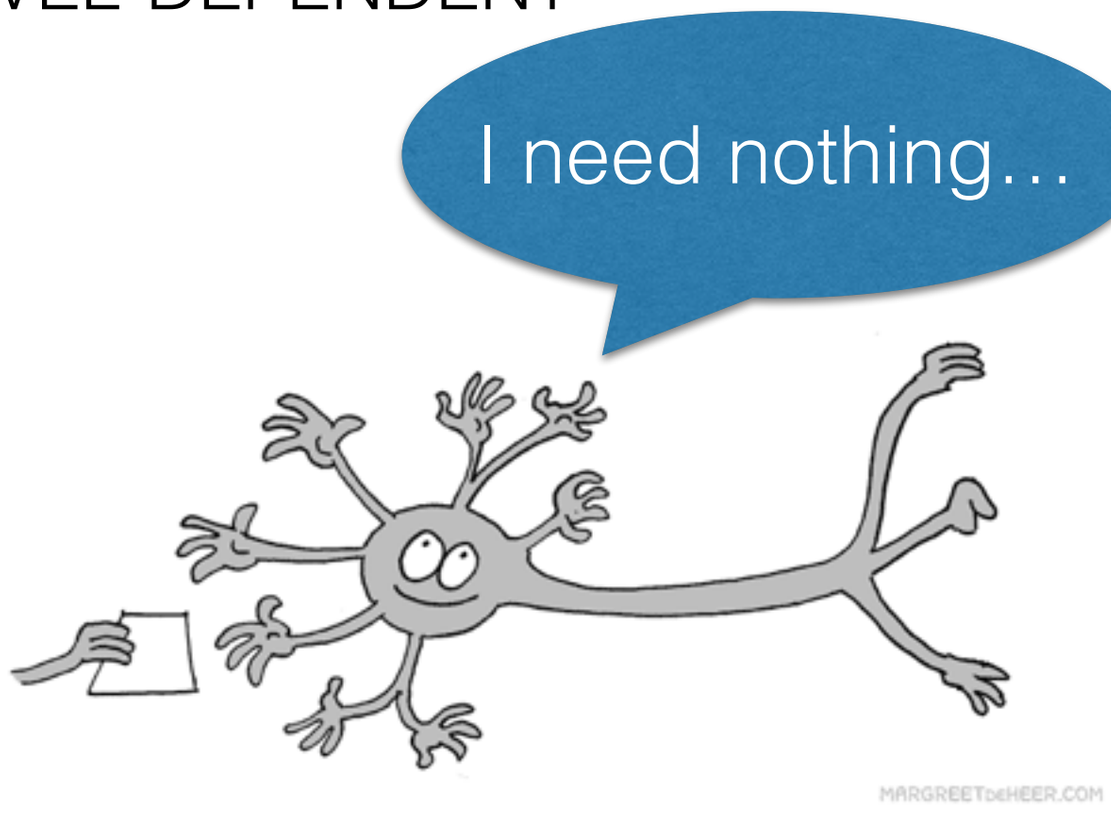
*MRI signals associated with **functional** brain activity

BOLD

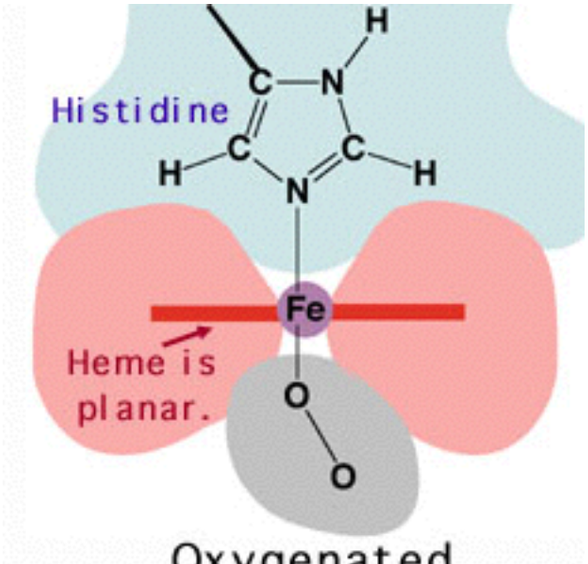
BLOOD-OXYGEN-LEVEL DEPENDENT



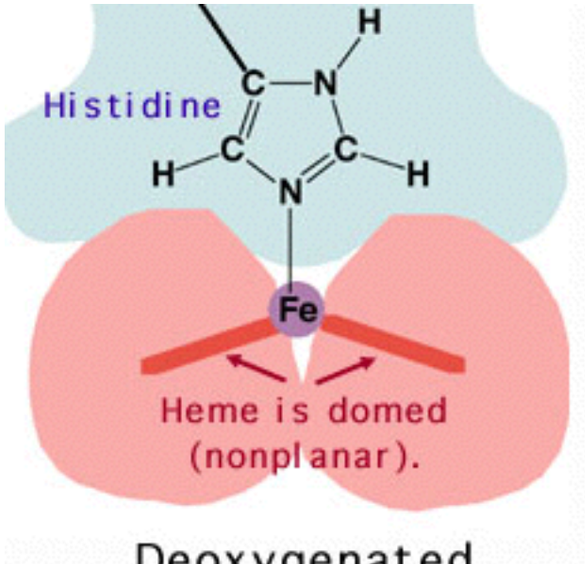
Active neuron



Passive neuron

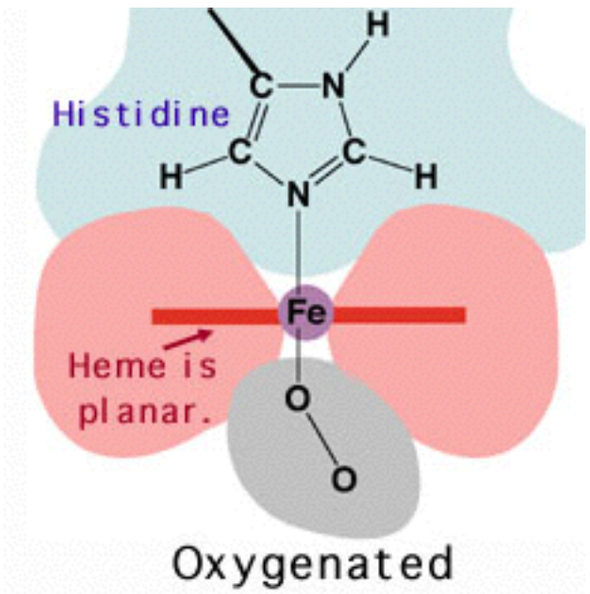


Oxygenated

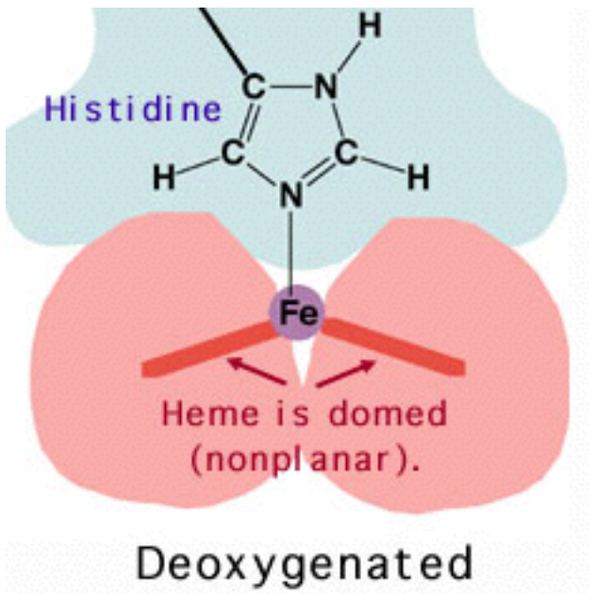


Deoxygenated

FMRI



Oxygenated

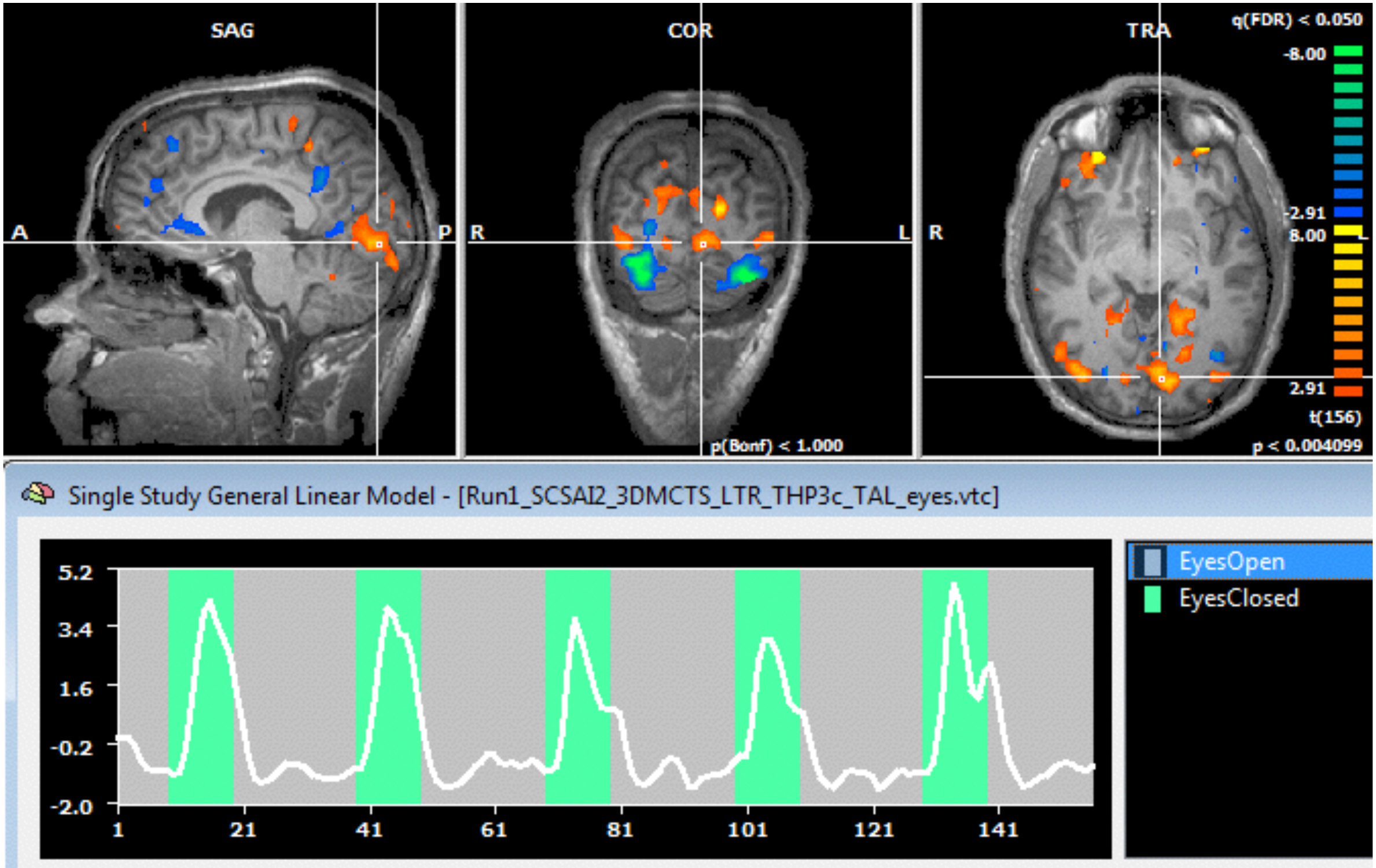


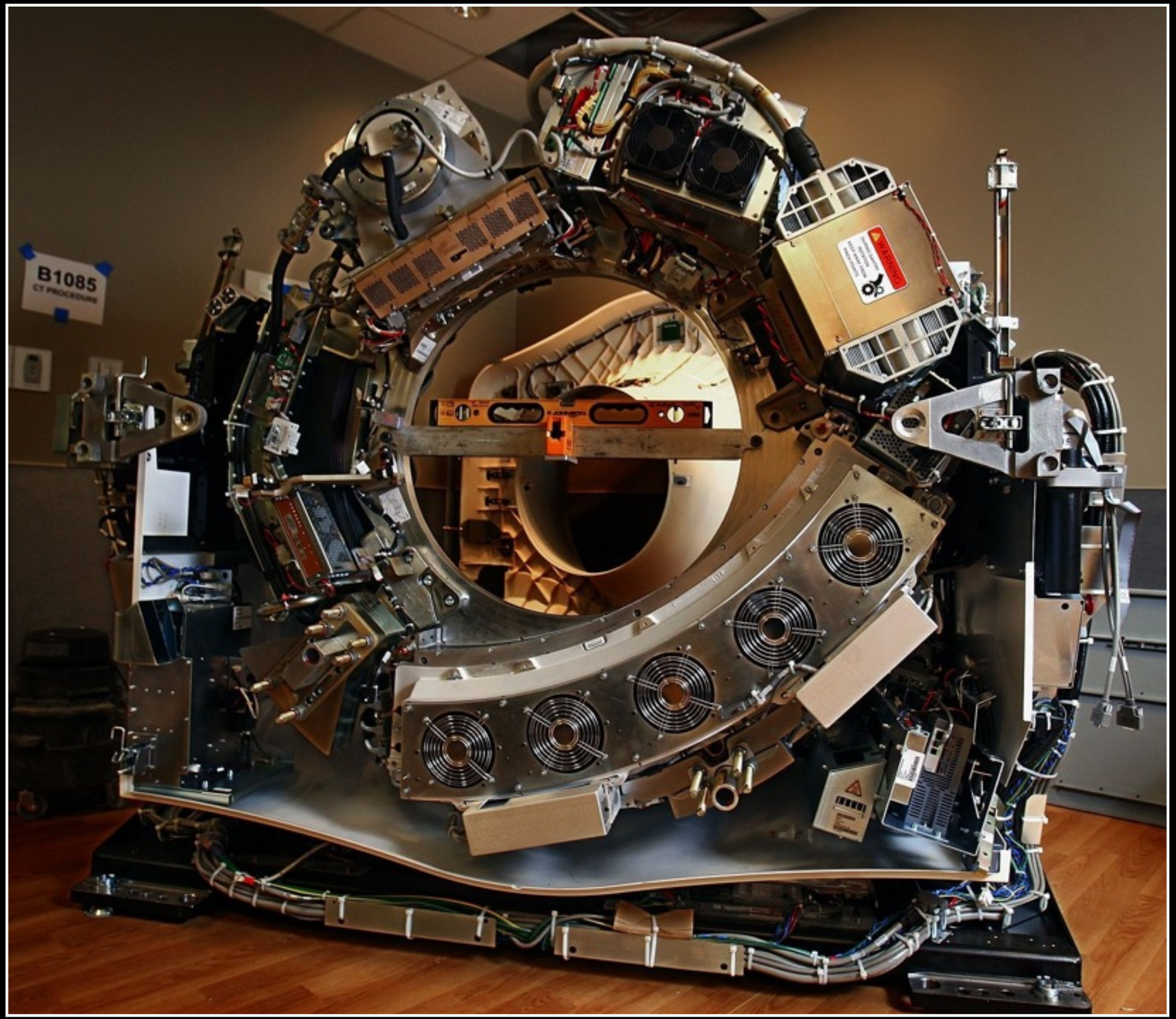
Deoxygenated

Have **different** magnetic resonance

Distinguishable by MRI

fMRI Data


SAG
A
P
COR
R
L
TRA
R
q(FDR) < 0.050
-8.00
-2.91
8.00
L
2.91
t(156)
p(Bonf) < 1.000
p < 0.004099
Single Study General Linear Model - [Run1_SCSAI2_3DMCTS_LTR_THP3c_TAL_eyes.vtc]
5.2
3.4
1.6
-0.2
-2.0
1
21
41
61
81
101
121
141
EyesOpen
EyesClosed


B1085
CT PROCEDURE
WARNING

SUMMARY

- High spatial resolution
- No surgery!
- Records whole brain

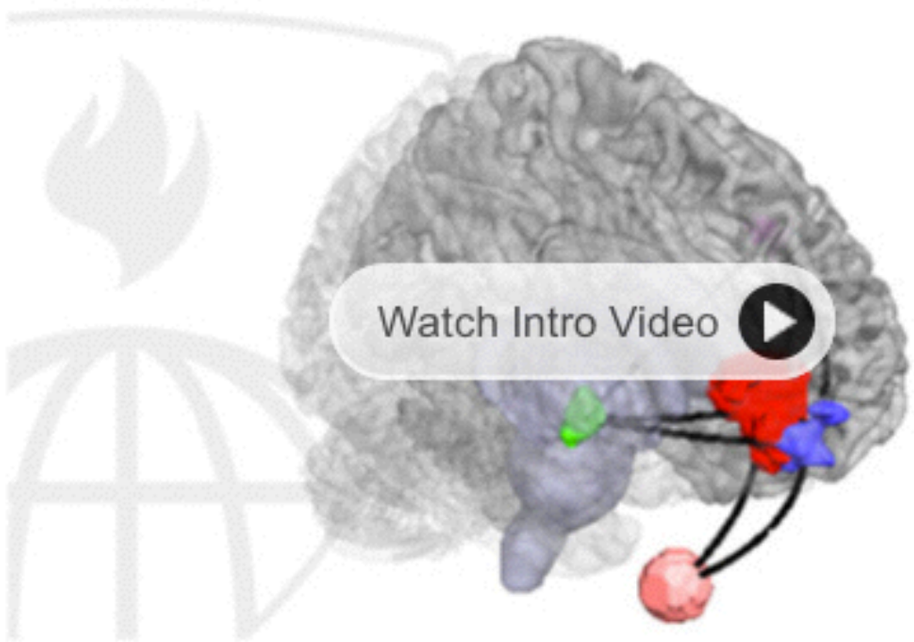
- Low temporal resolution
- Cost
- Size

Still pretty informative and **precise**, does **not** require a **surgery**, but is **huge** and **costs** a lot.

JOHNS HOPKINS
BLOOMBERG SCHOOL
of PUBLIC HEALTH

Statistical Analysis of fMRI Data

Explore the intersection of statistics and functional magnetic resonance imaging (fMRI), a non-invasive technique for studying brain activity.



About the Course

In this course we will explore the intersection of statistics and functional magnetic resonance imaging, or fMRI, which is a non-invasive technique for studying brain activity. We will discuss the analysis of fMRI data, from its acquisition to its use in locating brain activity, making inference about brain connectivity and predictions about psychological or disease states. A standard fMRI study gives rise to massive amounts of noisy data with a complicated spatio-temporal correlation structure.

Sessions

Jul 21st 2014 - Sep 1st 2014

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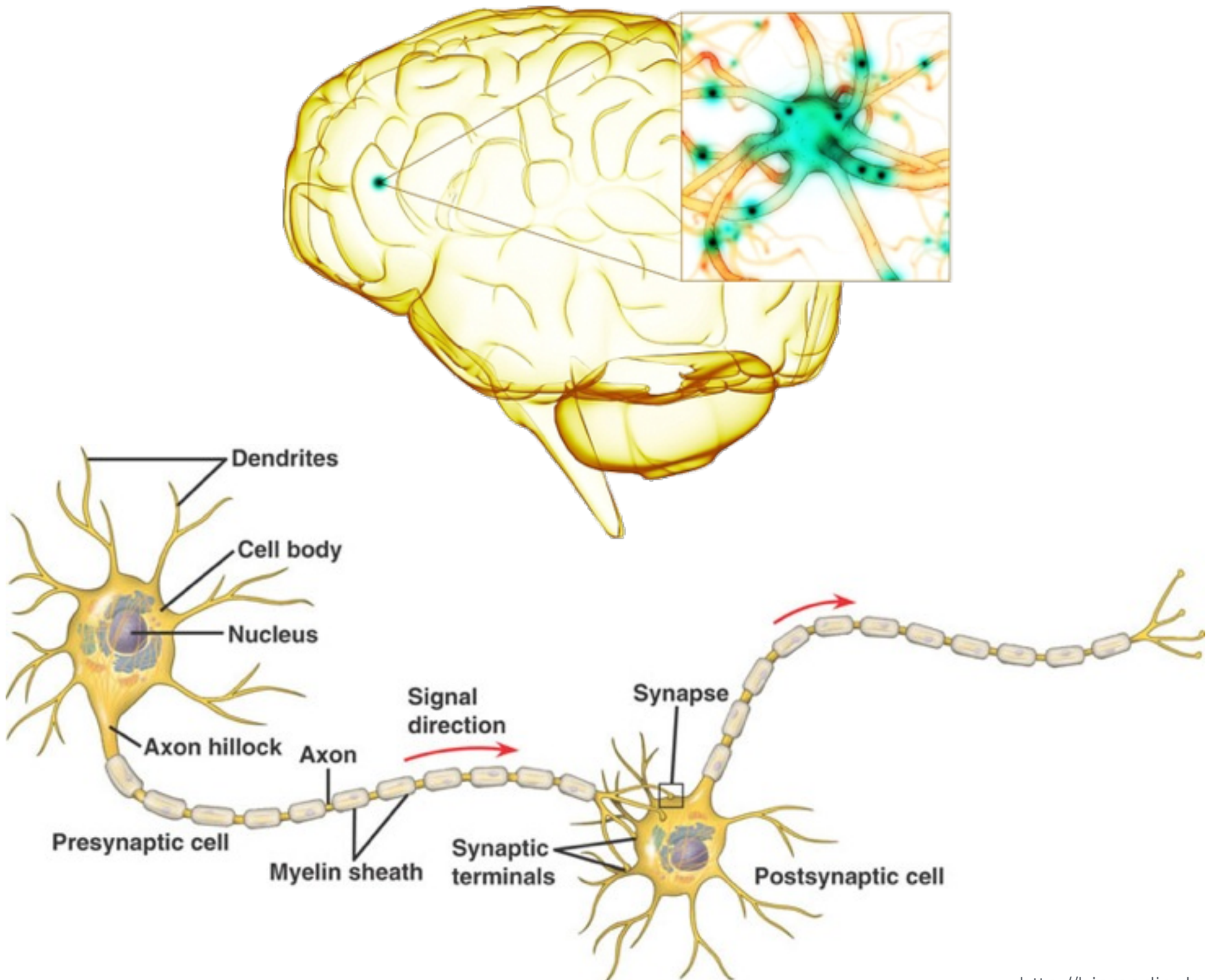
Earn a Verified Certificate

https://www.coursera.org/course/fmri

PART III
EEG

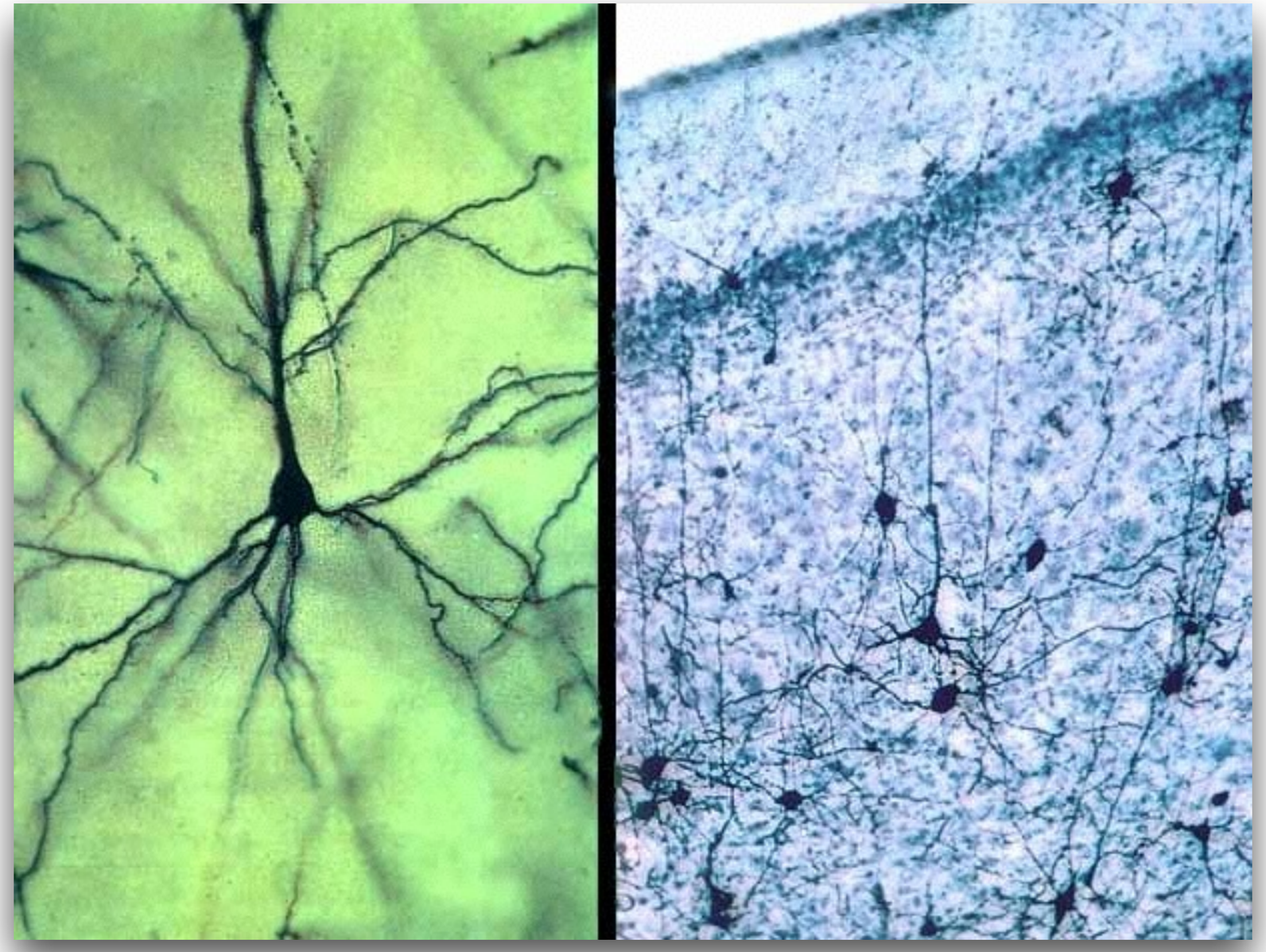
http://infantlab.psych.sc.edu/PWREEGDemoBaby

Neurons



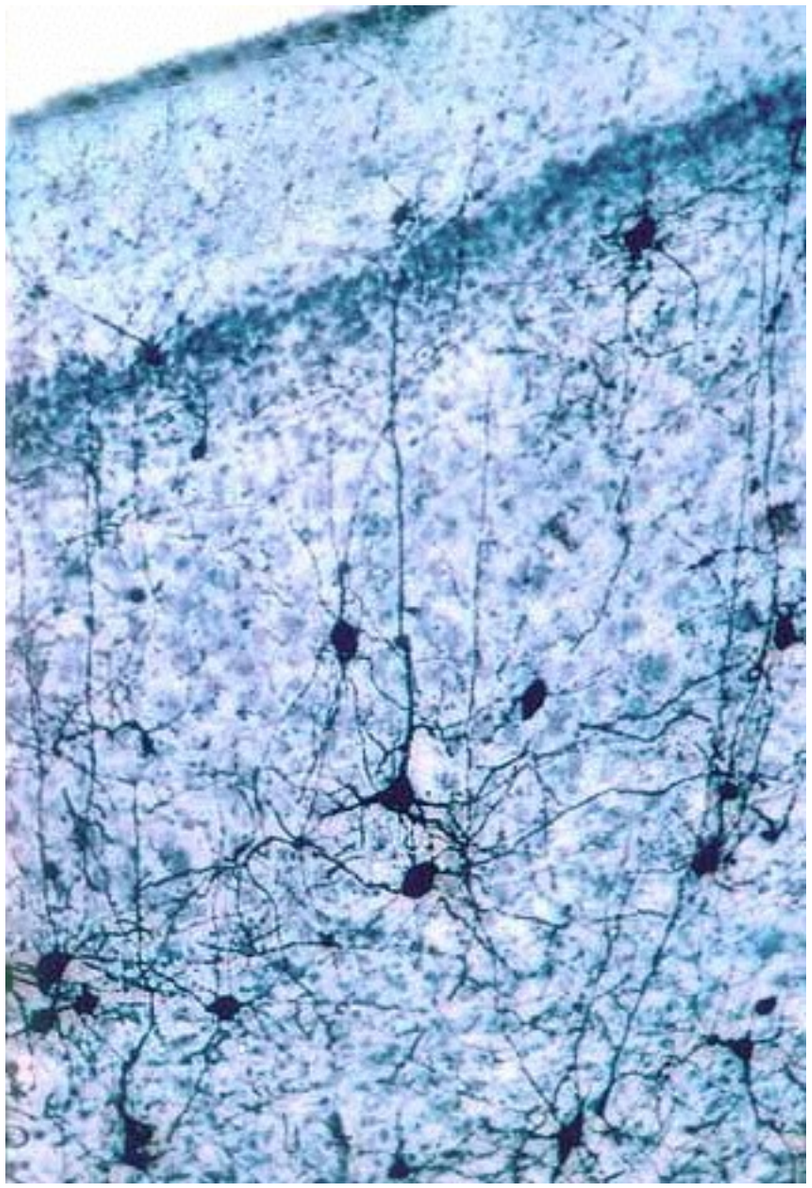
http://biomedicalengineering.yolasite.com

Neurons



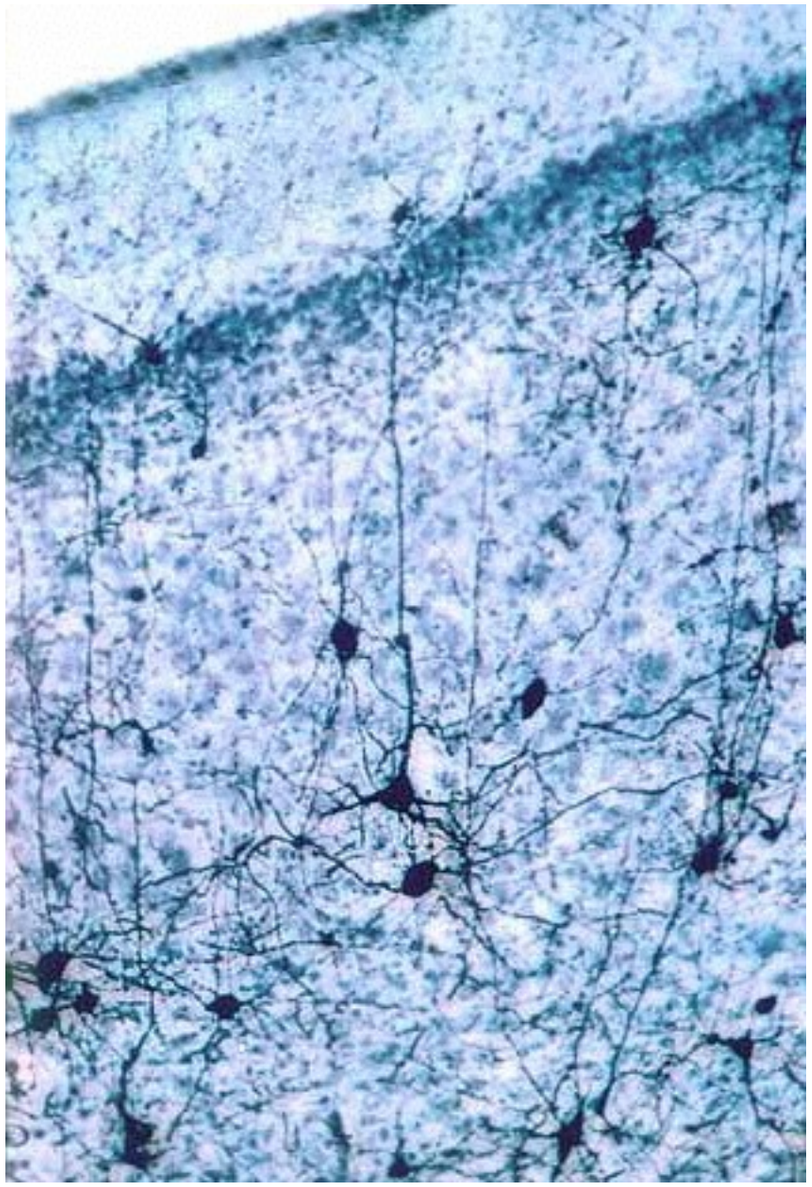
http://www.conncad.com/gallery/single_cells.html

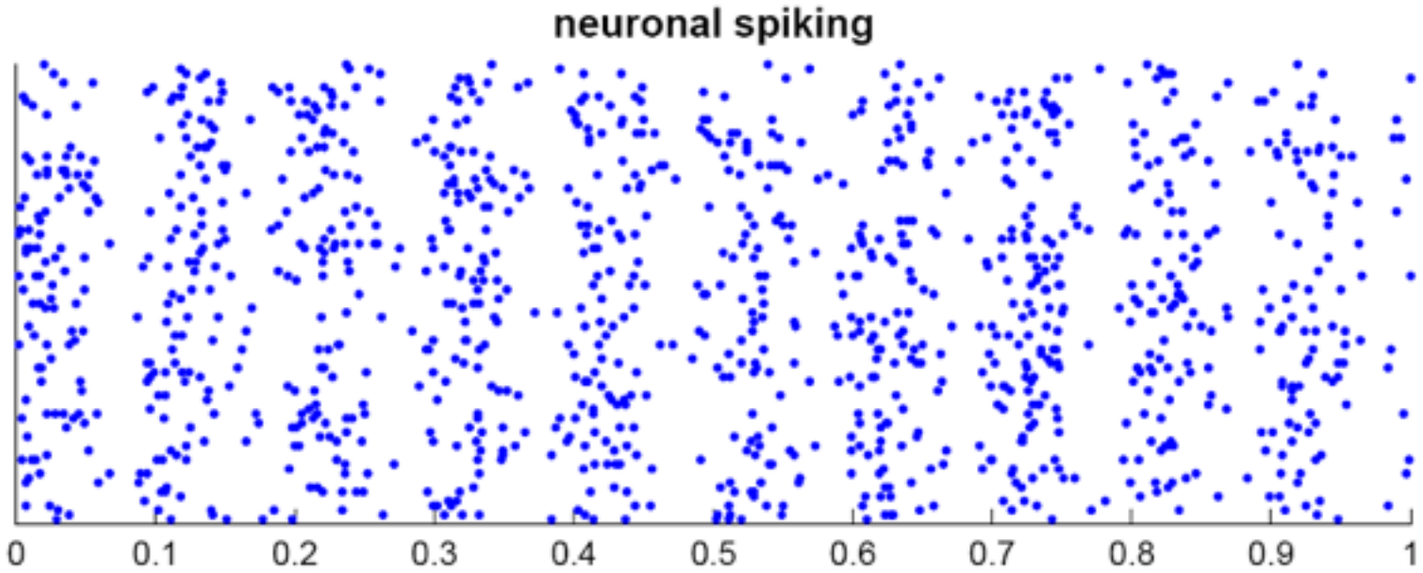
Neurons



http://en.wikipedia.org/wiki/Neural_oscillation

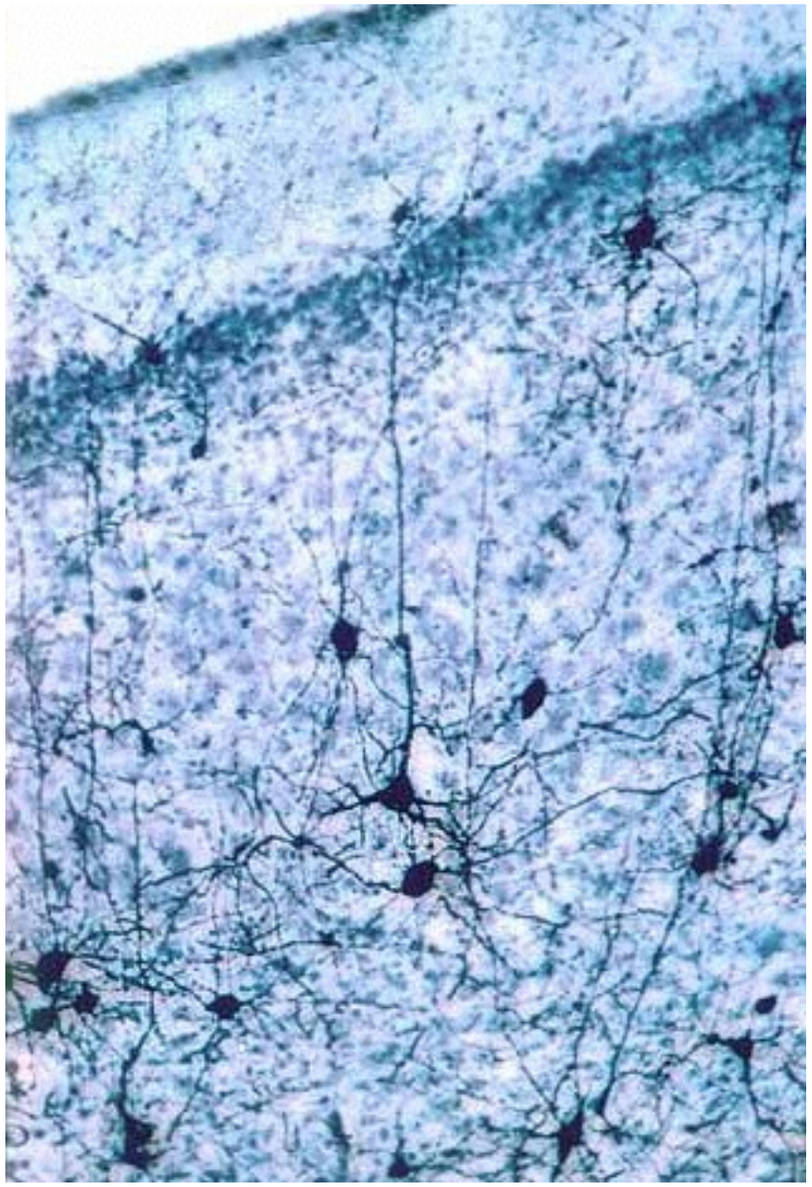
NEURONS

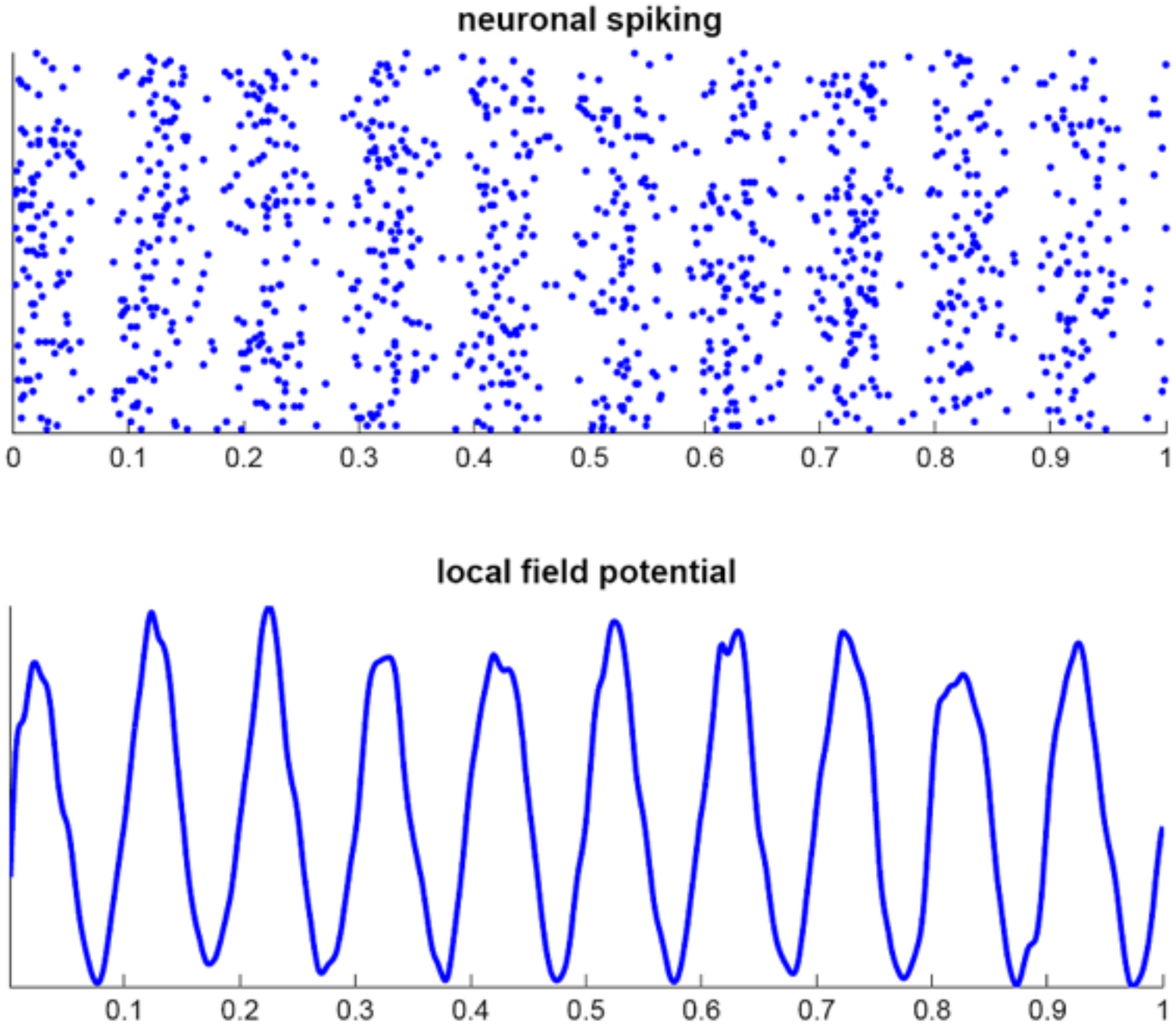




http://en.wikipedia.org/wiki/Neural_oscillation

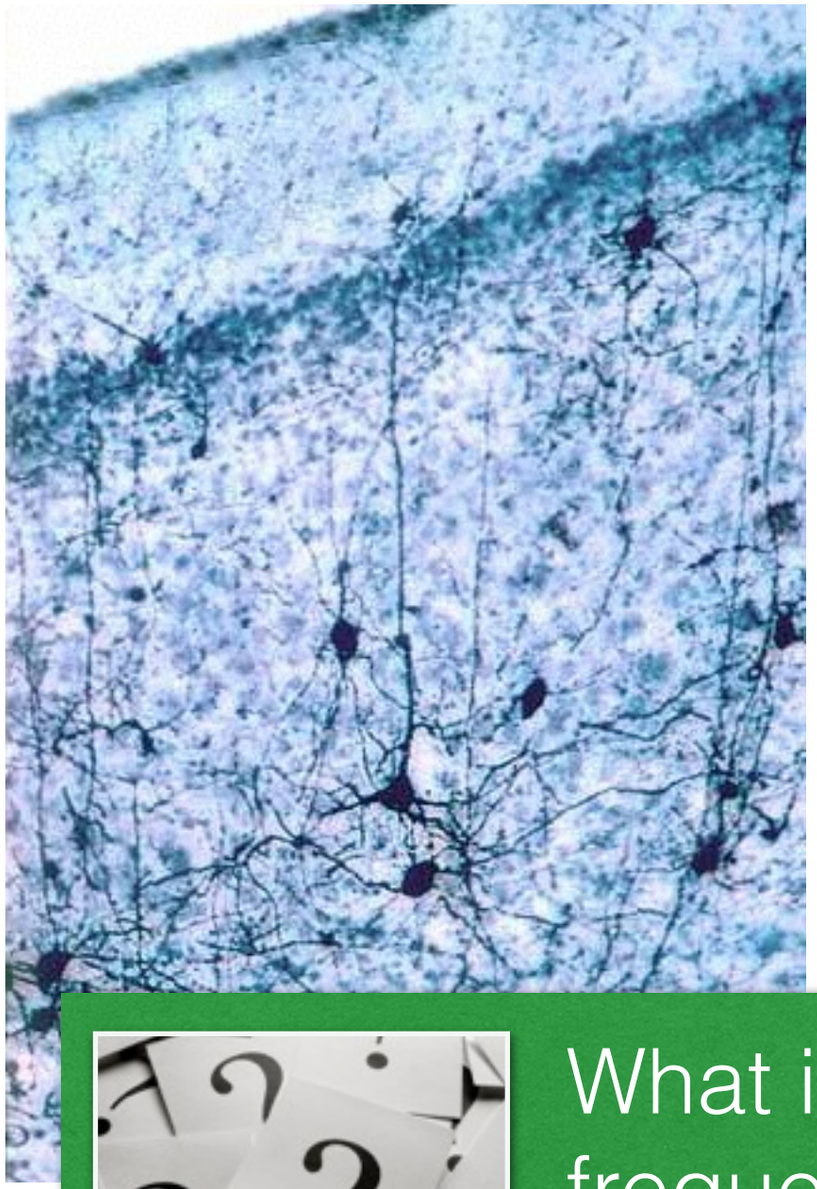
NEURONS

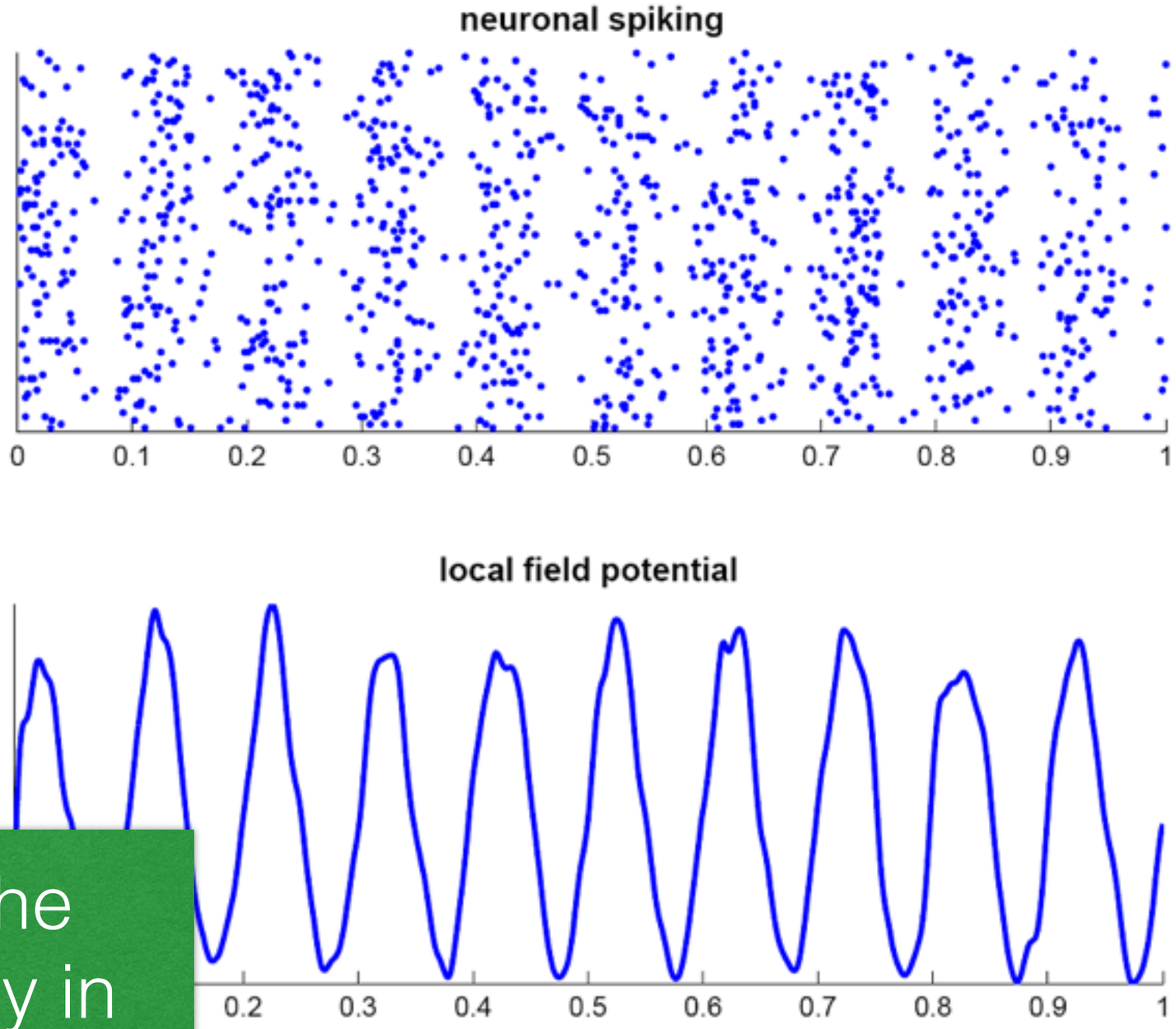




http://en.wikipedia.org/wiki/Neural_oscillation

NEURONS

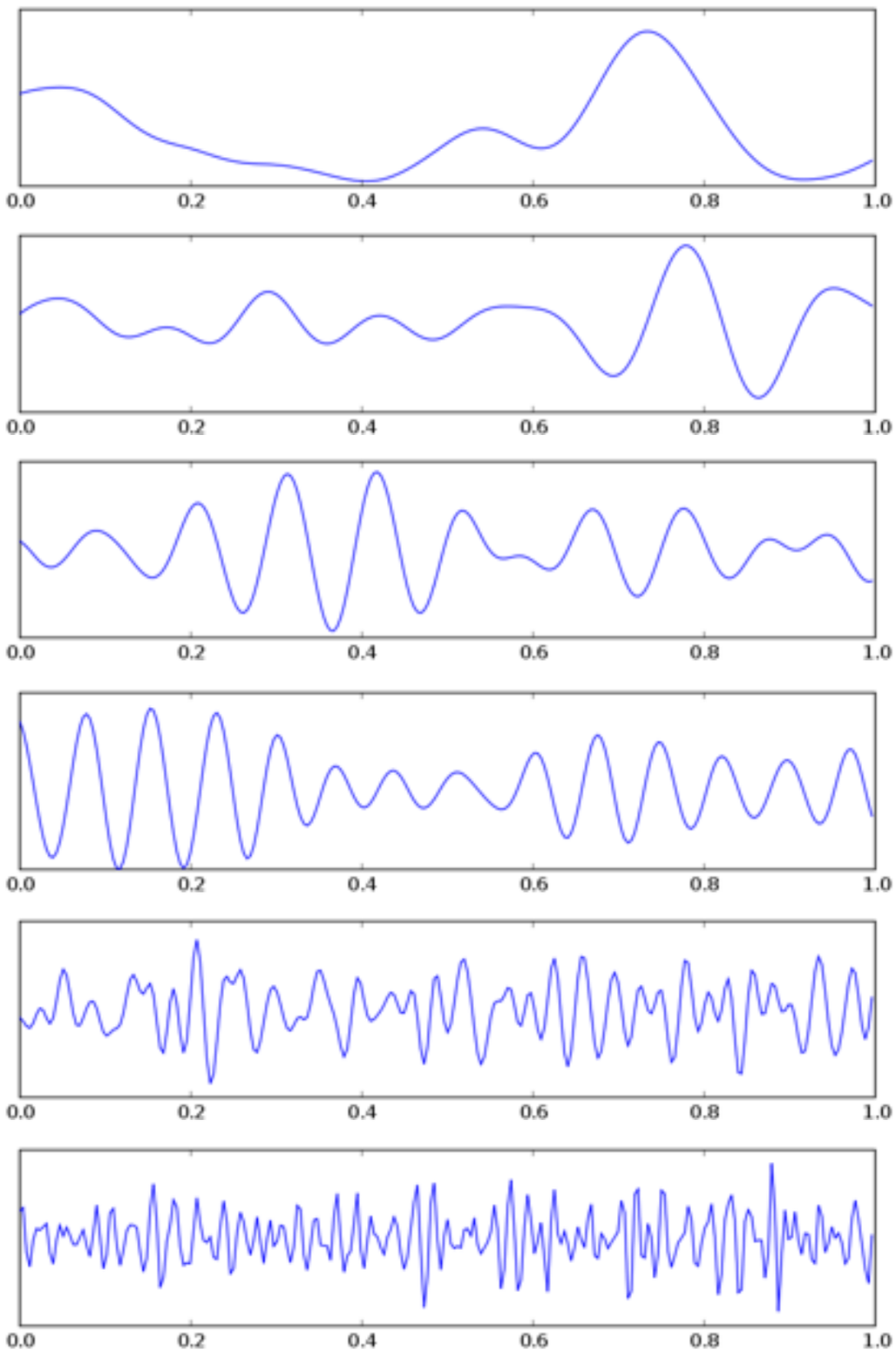




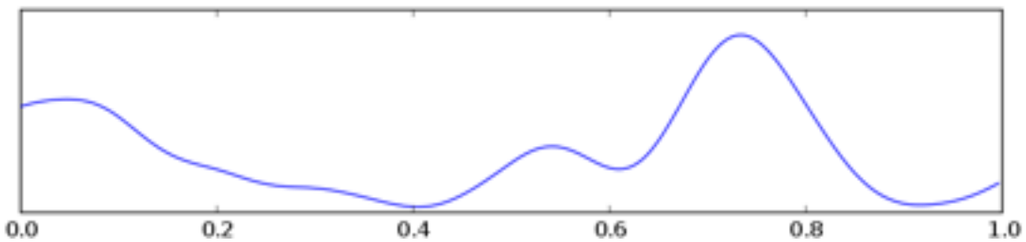
What is the frequency in this example?

http://en.wikipedia.org/wiki/Neural_oscillation

Brainwaves

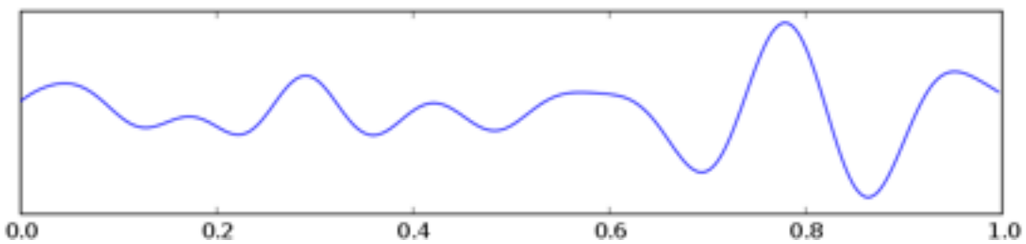


Brainwaves



Delta

0-4 Hz

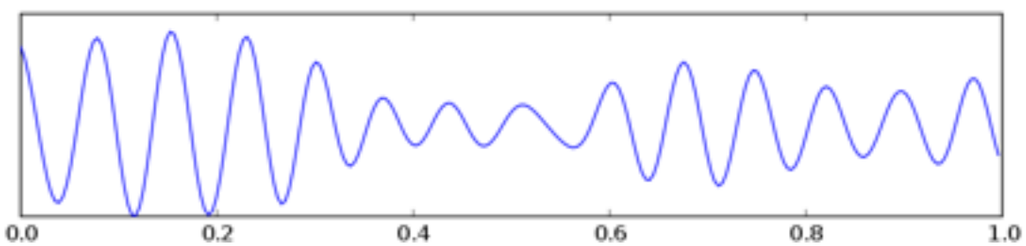


Theta

4-7 Hz

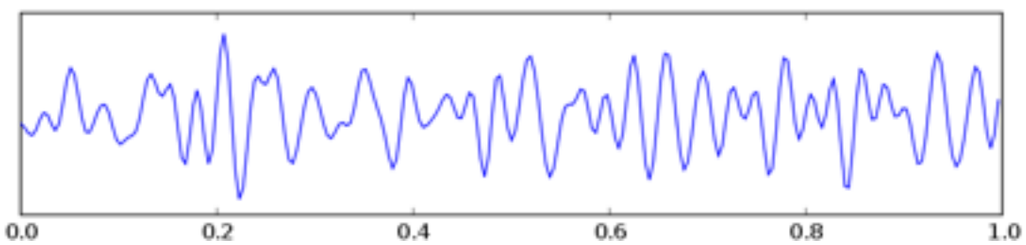
Alpha

7-14 Hz



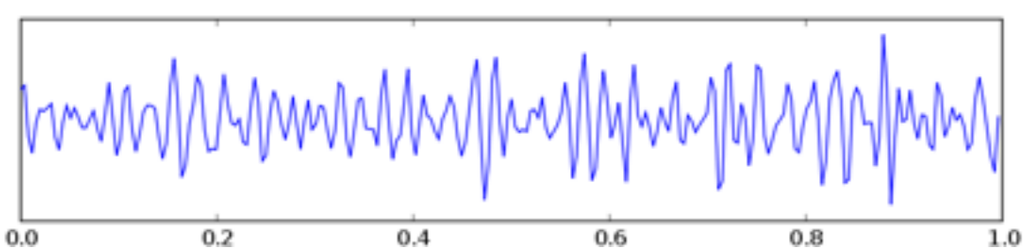
Mu

8-13 Hz



Beta

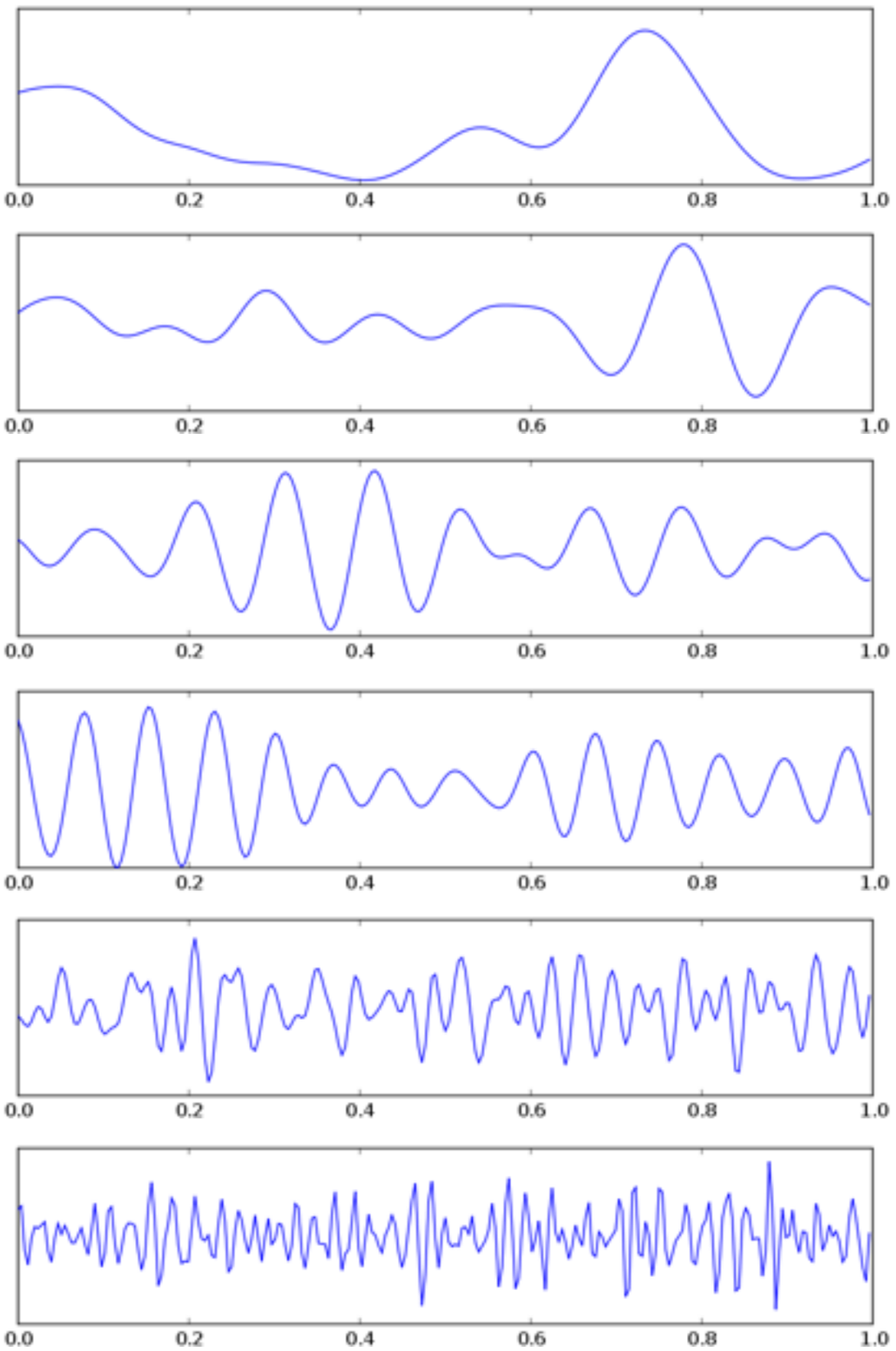
15-30 Hz



Gamma

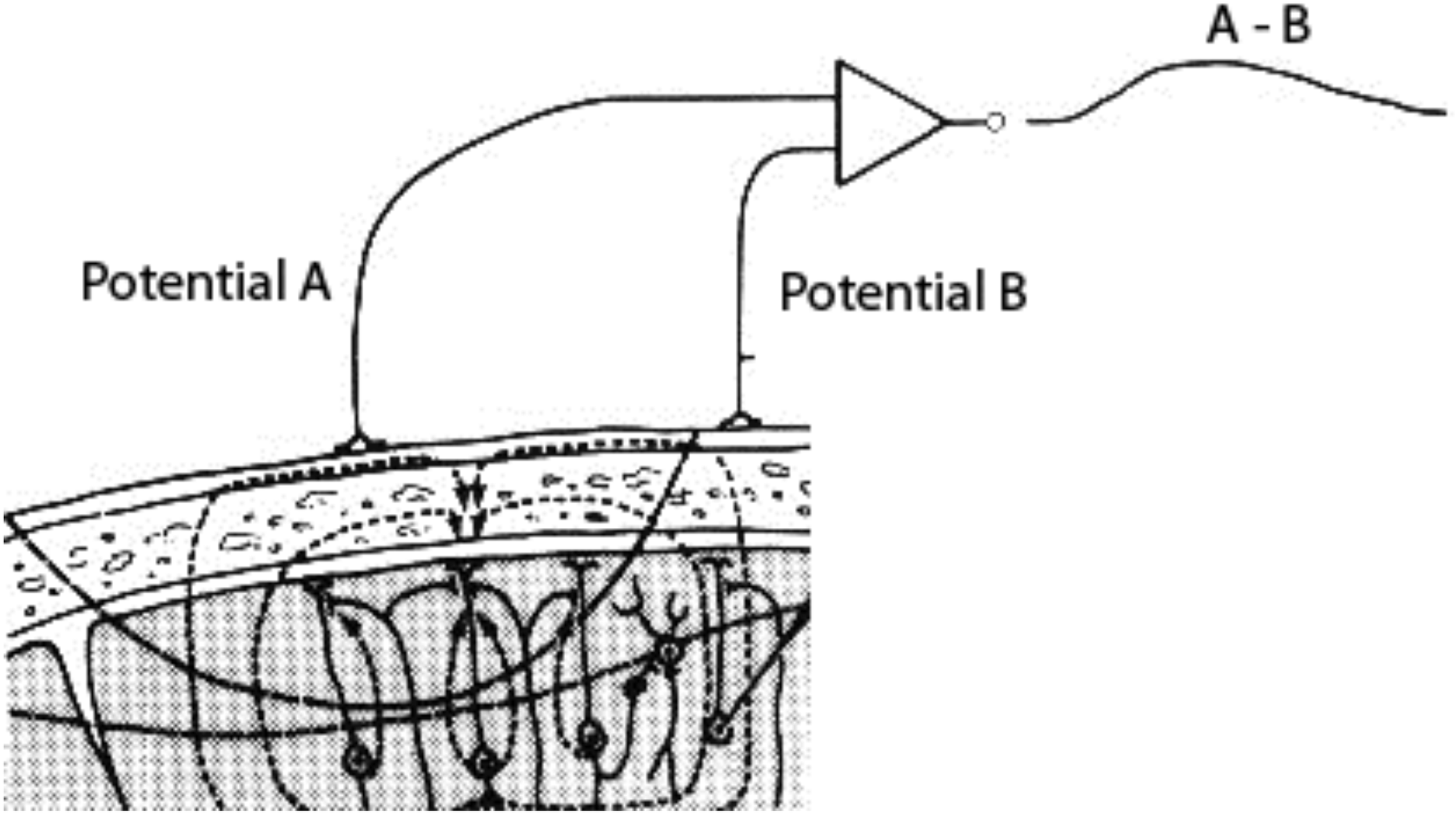
30-100 Hz

BRAINWAVES



Delta 0-4 Hz	slow wave sleep, babies, lesions
Theta 4-7 Hz	children, drowsiness, meditation, relaxed
Alpha 7-14 Hz	closed eyes, relaxed
Mu 8-13 Hz	motor neuron in rest, mirror neurons
Beta 15-30 Hz	motor activity, anxious thinking, concentration
Gamma 30-100 Hz	networking between populations of neurons

EEG



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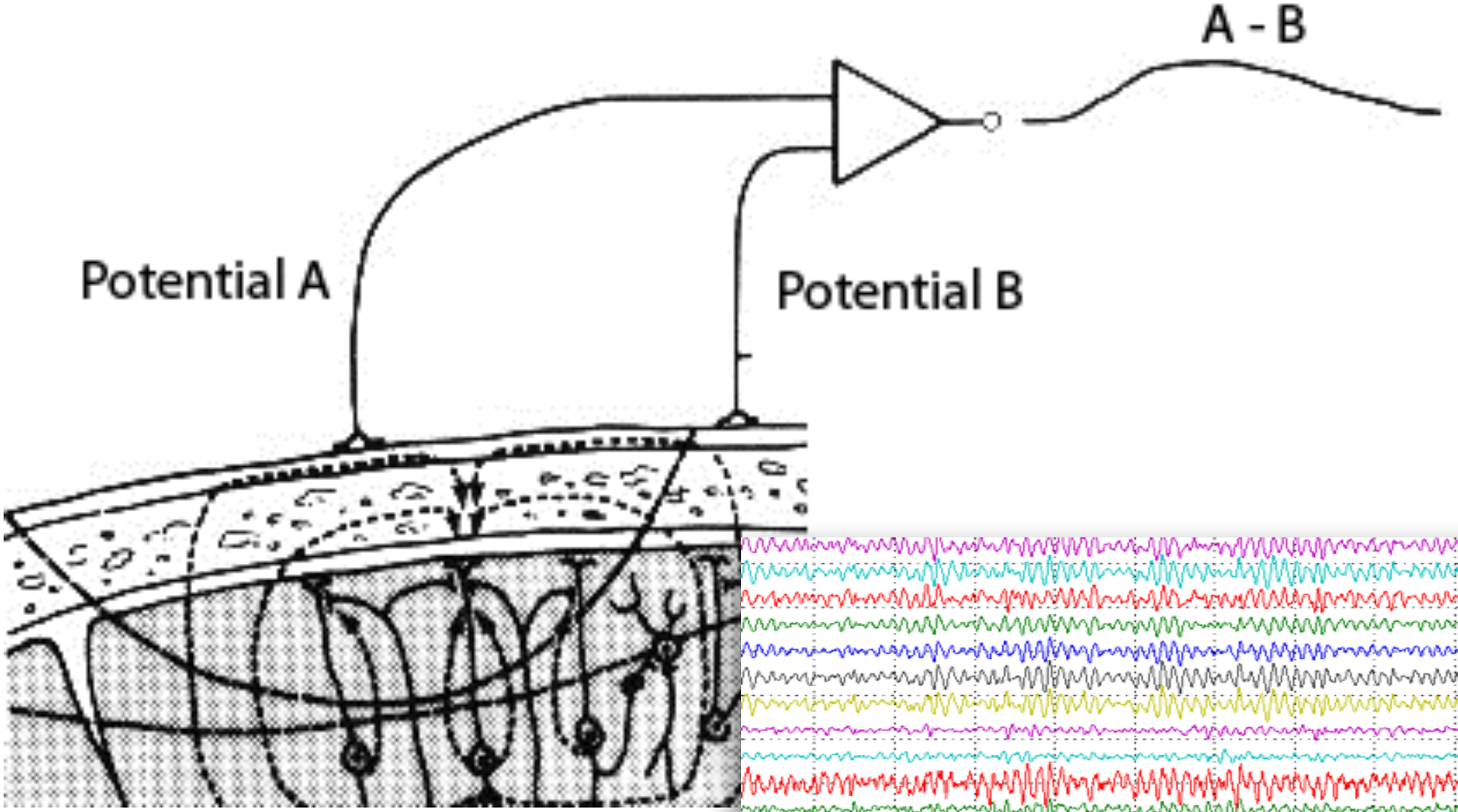

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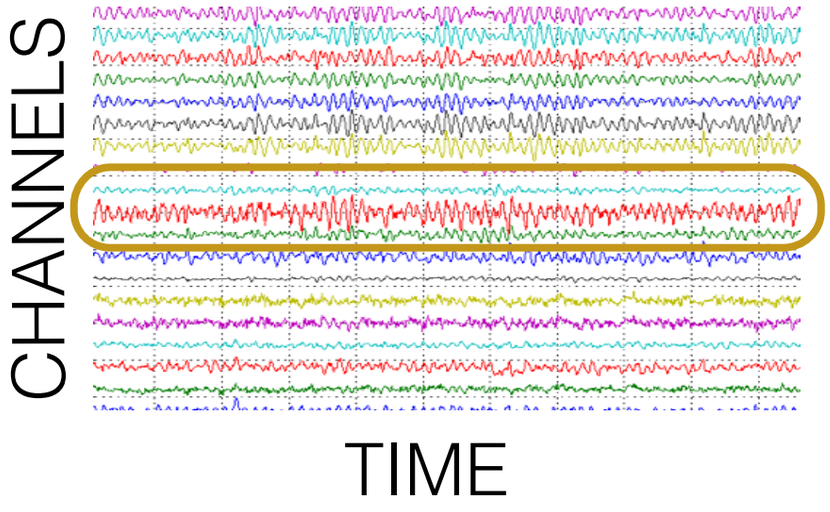

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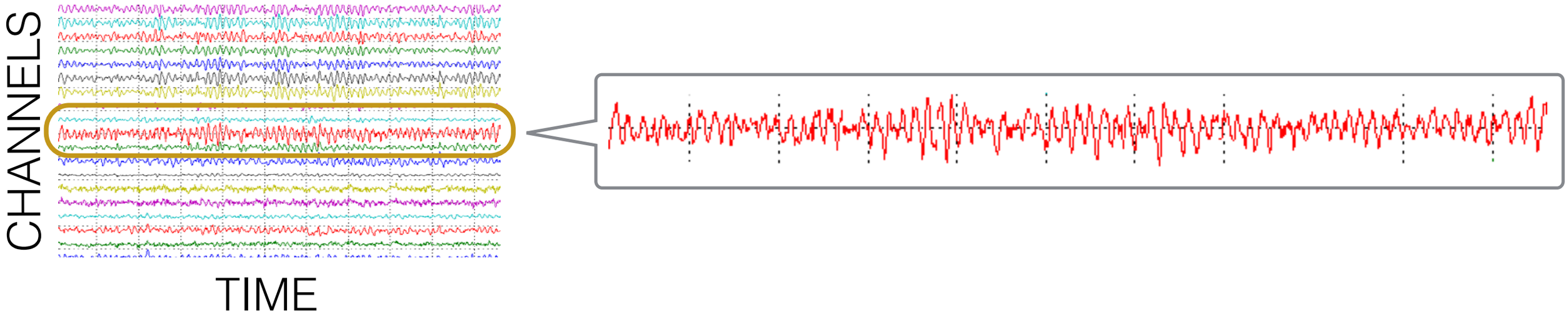

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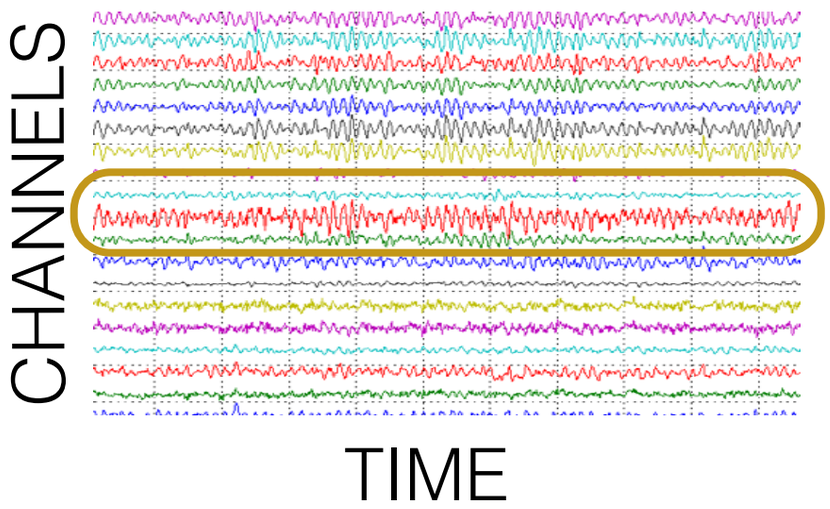
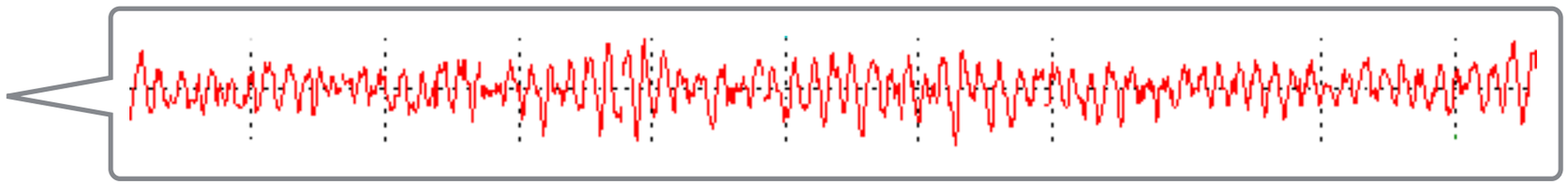
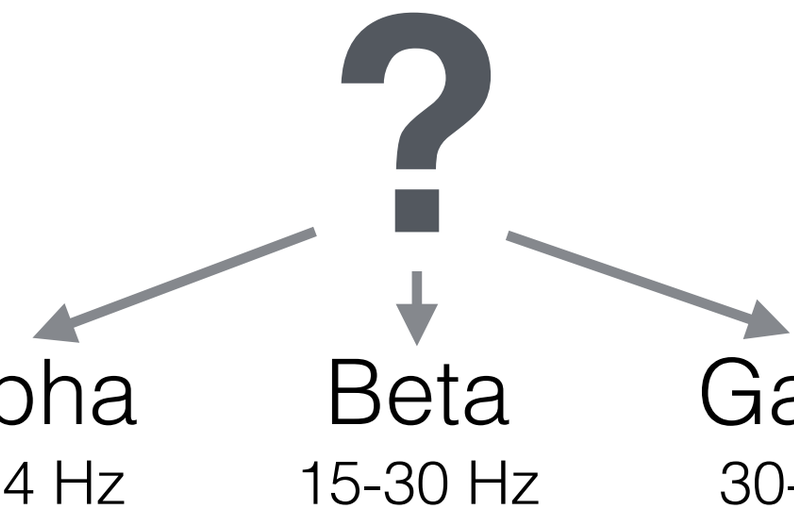
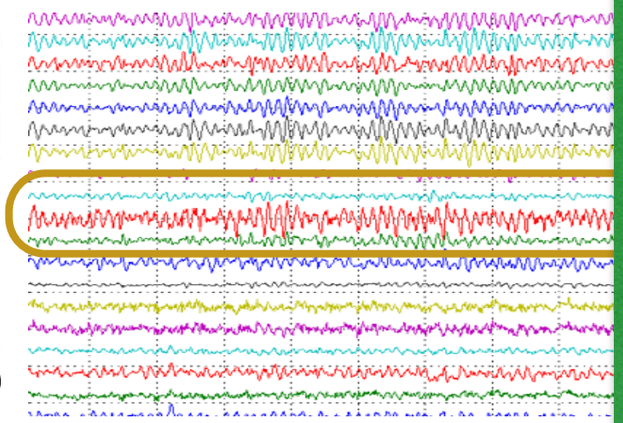






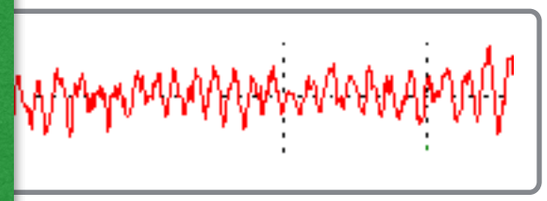
EEG

CHANNELS



TIME

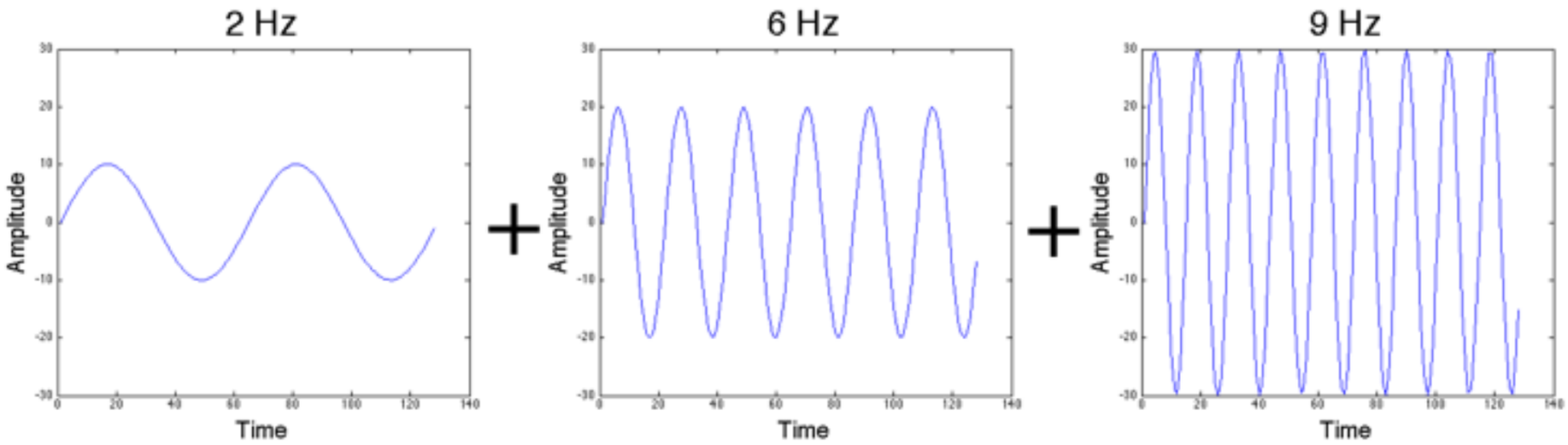
Jean Baptiste Joseph Fourier
1768 — 1830



Gamma
30-100 Hz

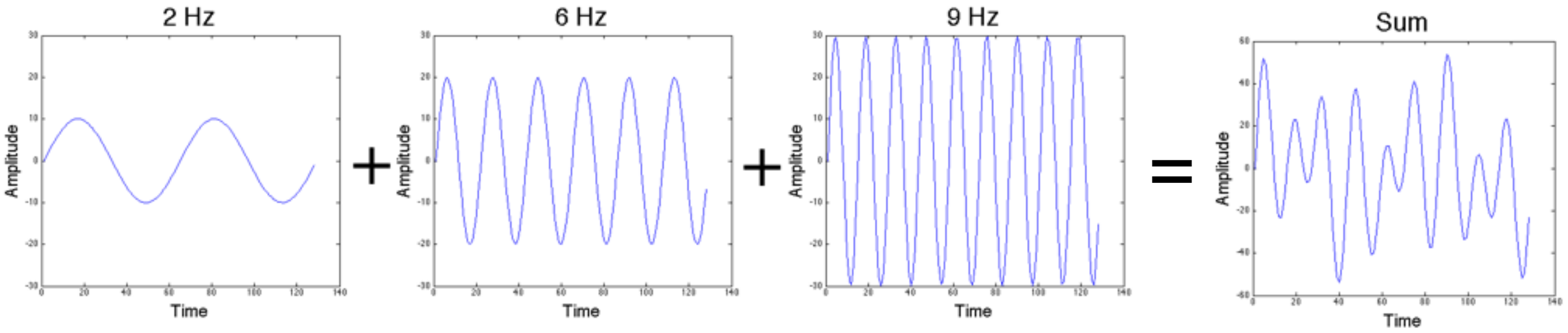
Fourier transform

FOURIER TRANSFORM*



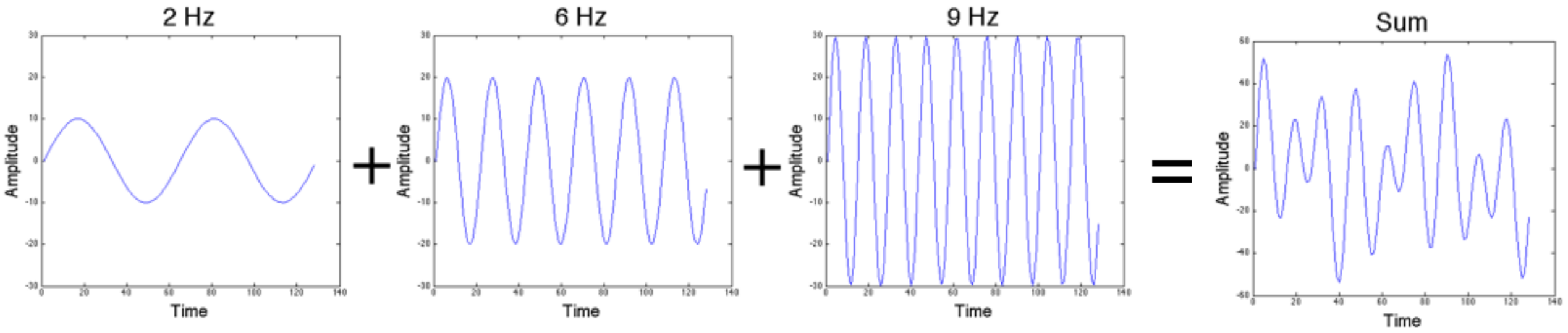
*discrete

FOURIER TRANSFORM*



*discrete

FOURIER TRANSFORM*

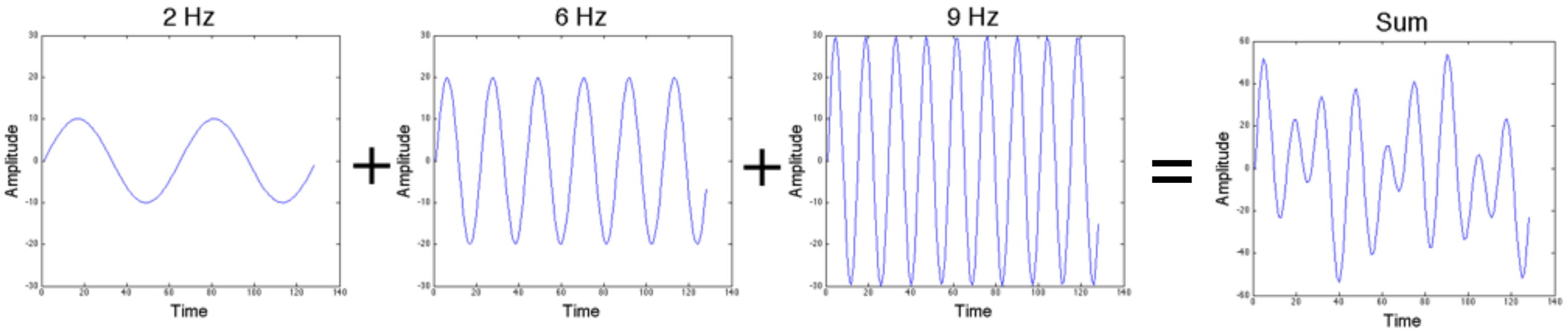


$$X_k = \sum_{t=0}^{N-1} x_t e^{-i 2\pi k \frac{t}{N}}$$

x_t signal at time t
k frequency
X_k complex number

*discrete

FOURIER TRANSFORM*



$$X_k = \sum_{t=0}^{N-1} x_t e^{-i 2\pi k \frac{t}{N}}$$

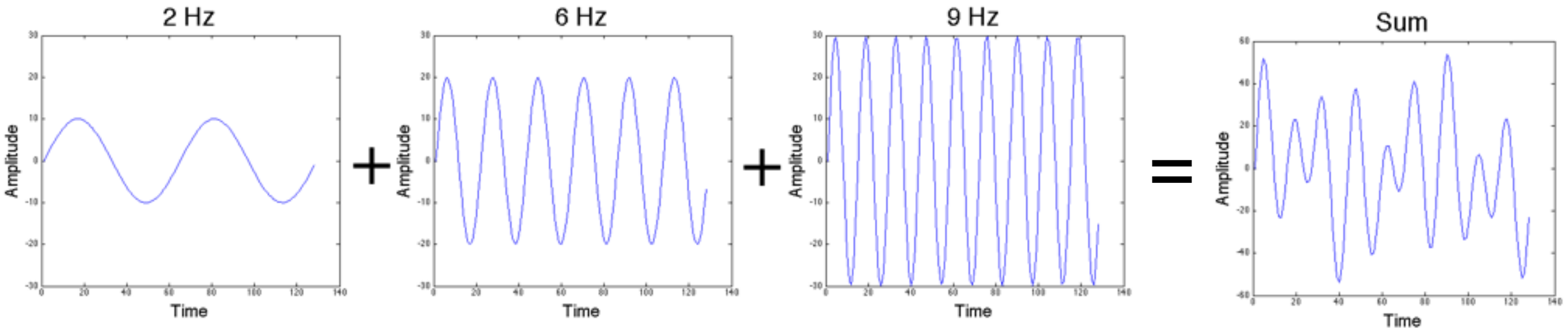
x_t signal at time t
k frequency
X_k complex number

$$\sqrt{Re(X_k)^2 + Im(X_k)^2}$$

Amplitude of the component with frequency *k*

*discrete

FOURIER TRANSFORM*



$$X_k = \sum_{t=0}^{N-1} x_t e^{-i 2\pi k \frac{t}{N}}$$

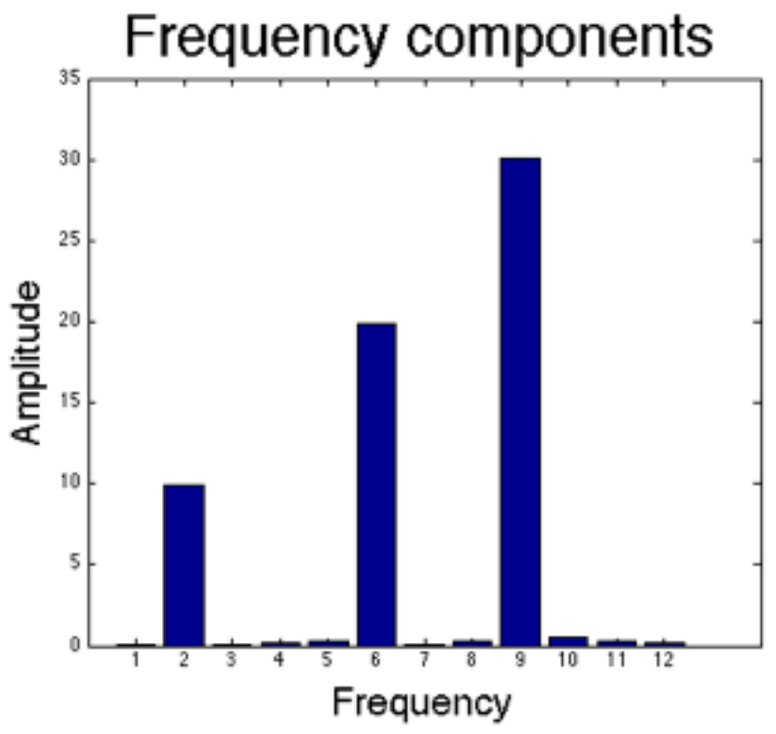
x_t signal at time t

k frequency

X_k complex number

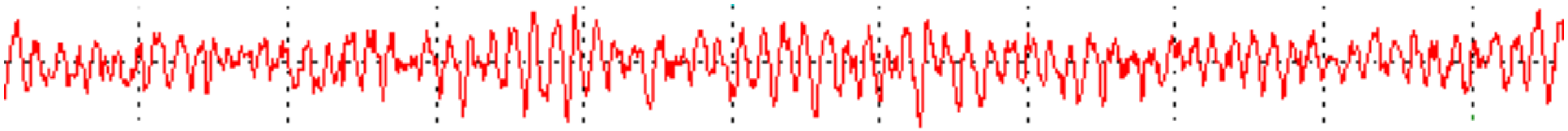
$$\sqrt{Re(X_k)^2 + Im(X_k)^2}$$

Amplitude of the component with frequency *k*



*discrete

EEG DATA



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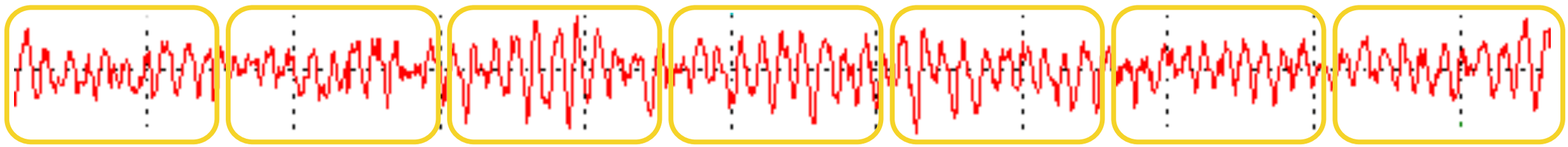

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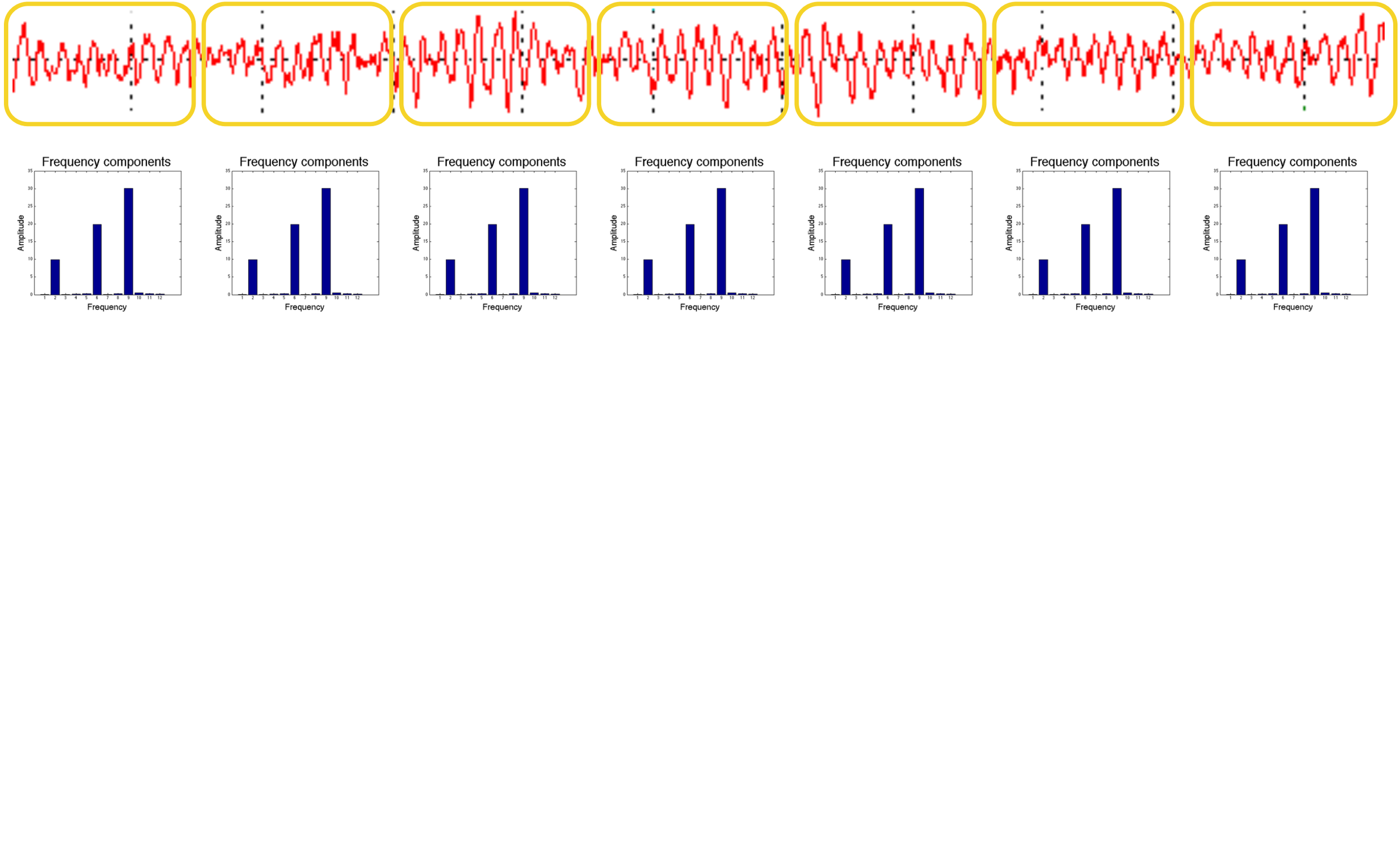
Frequency components
Amplitude
Frequency
Frequency components
Amplitude
Frequency
Frequency components
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Frequency components
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Frequency components
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Frequency components
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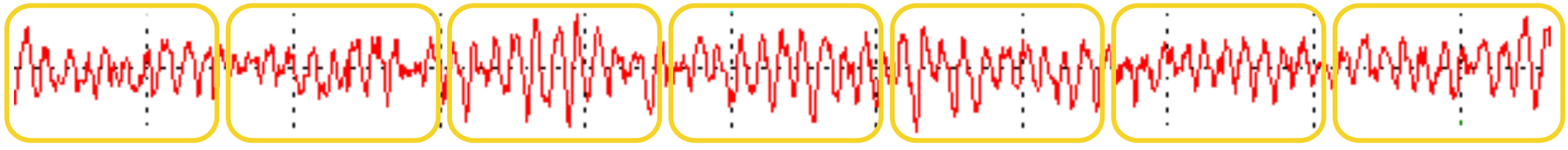
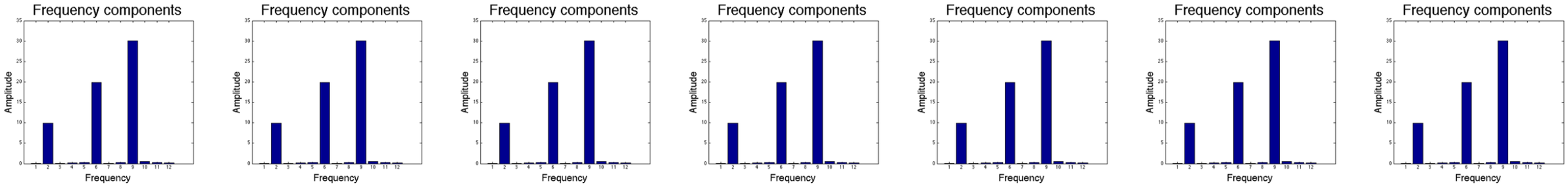
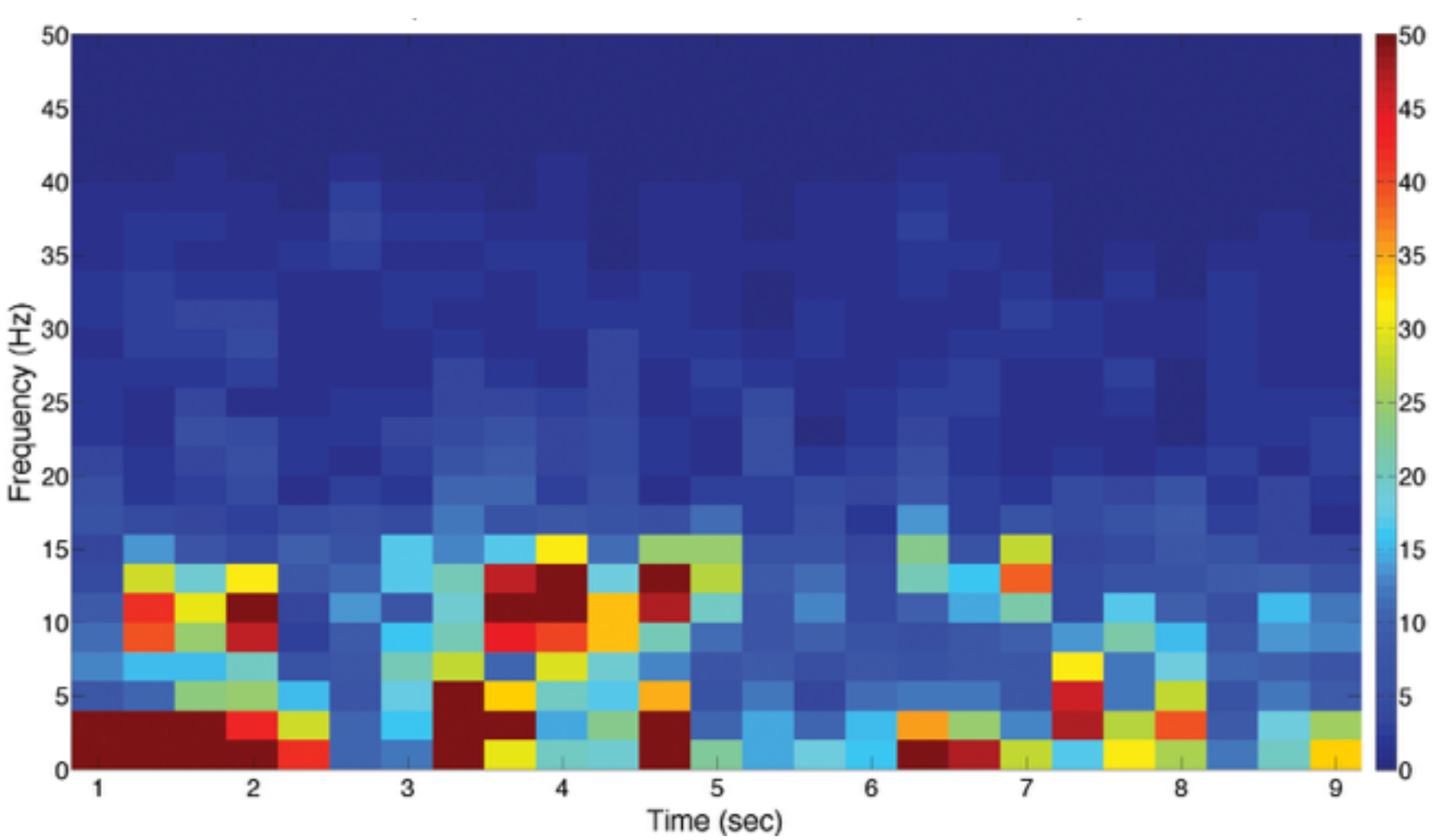
Frequency
Frequency components
Amplitude
Frequency

Time-Frequency Domain







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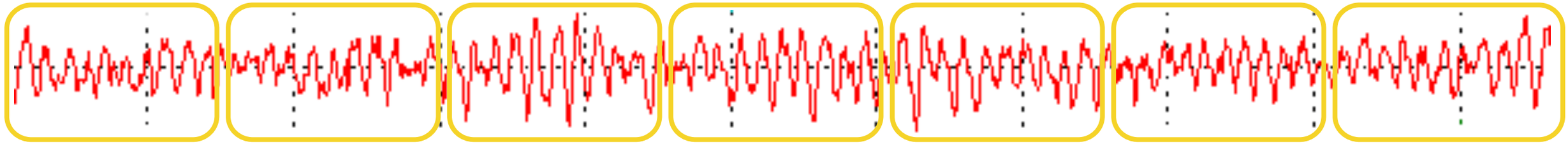
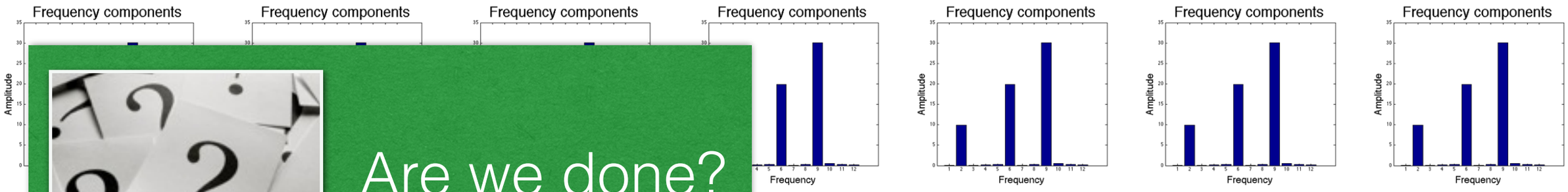
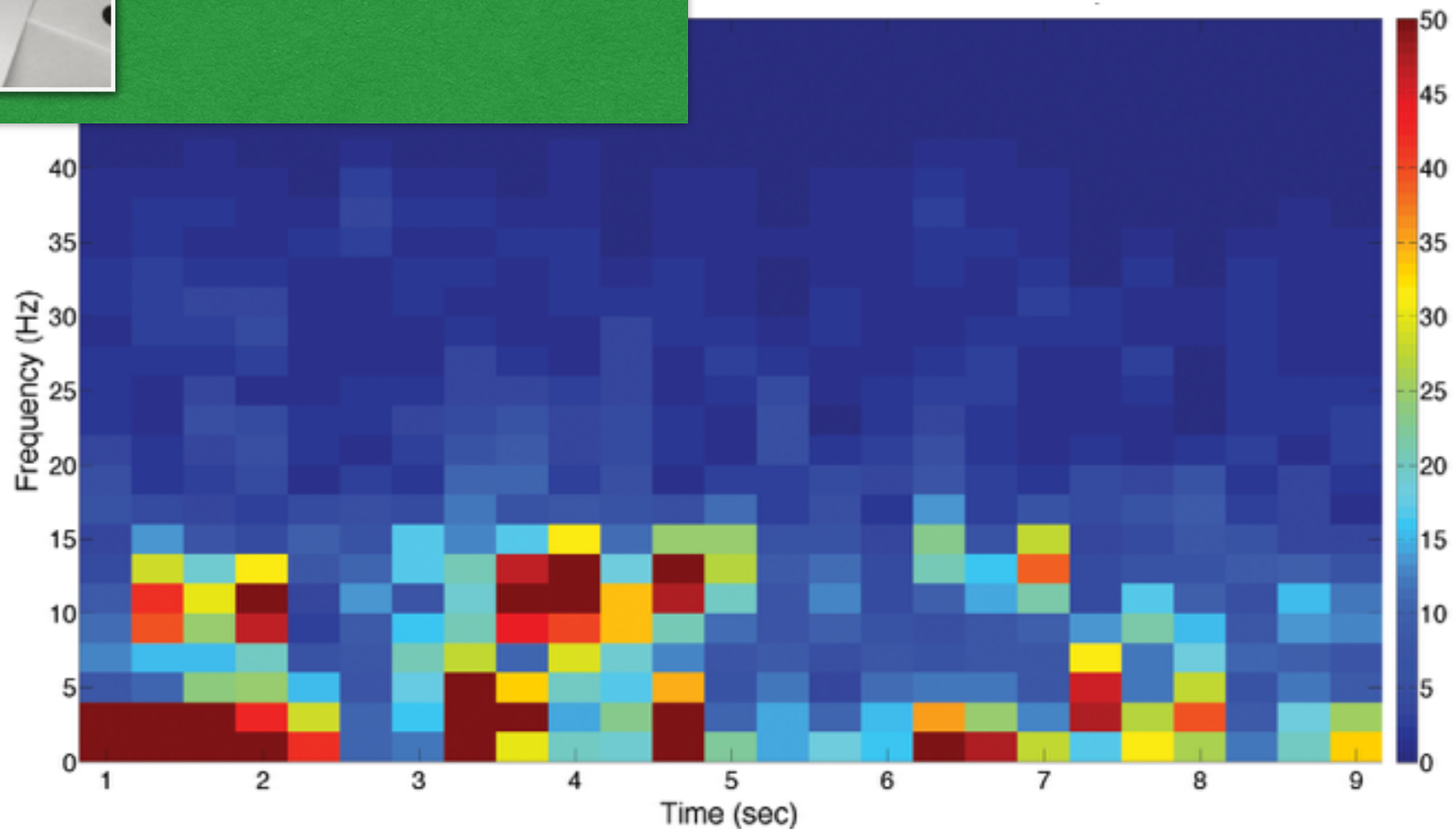




Are we done?



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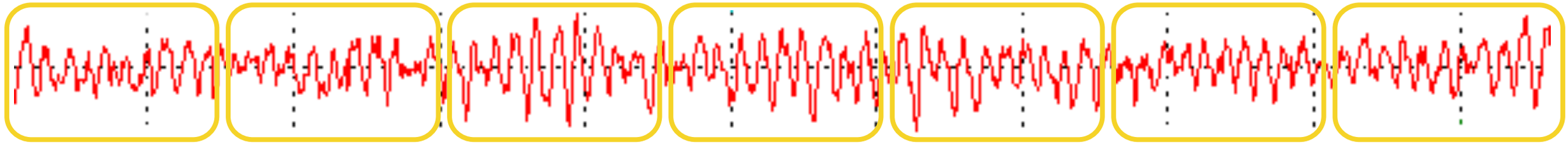
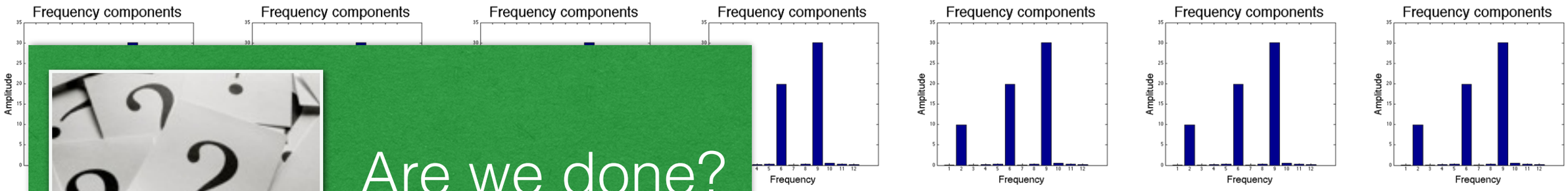
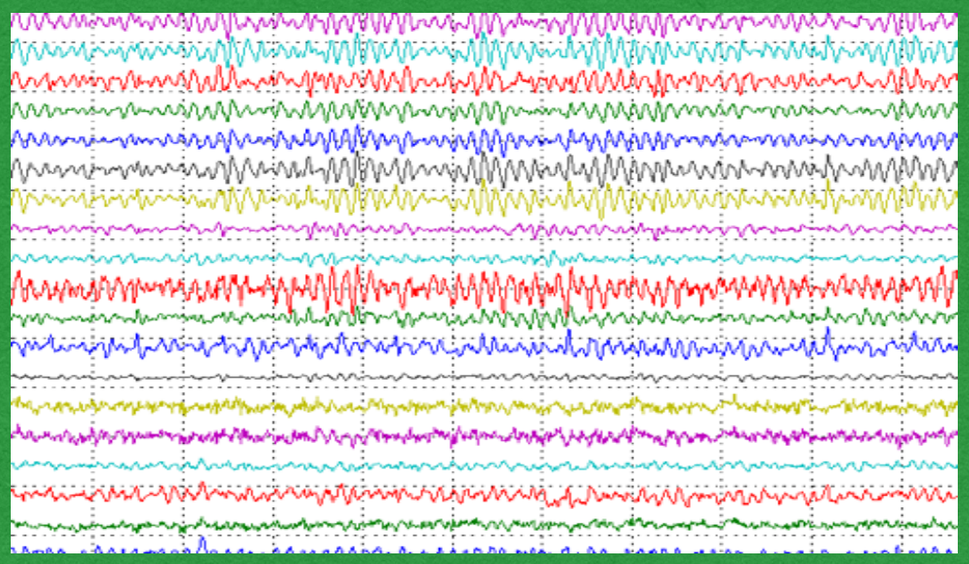
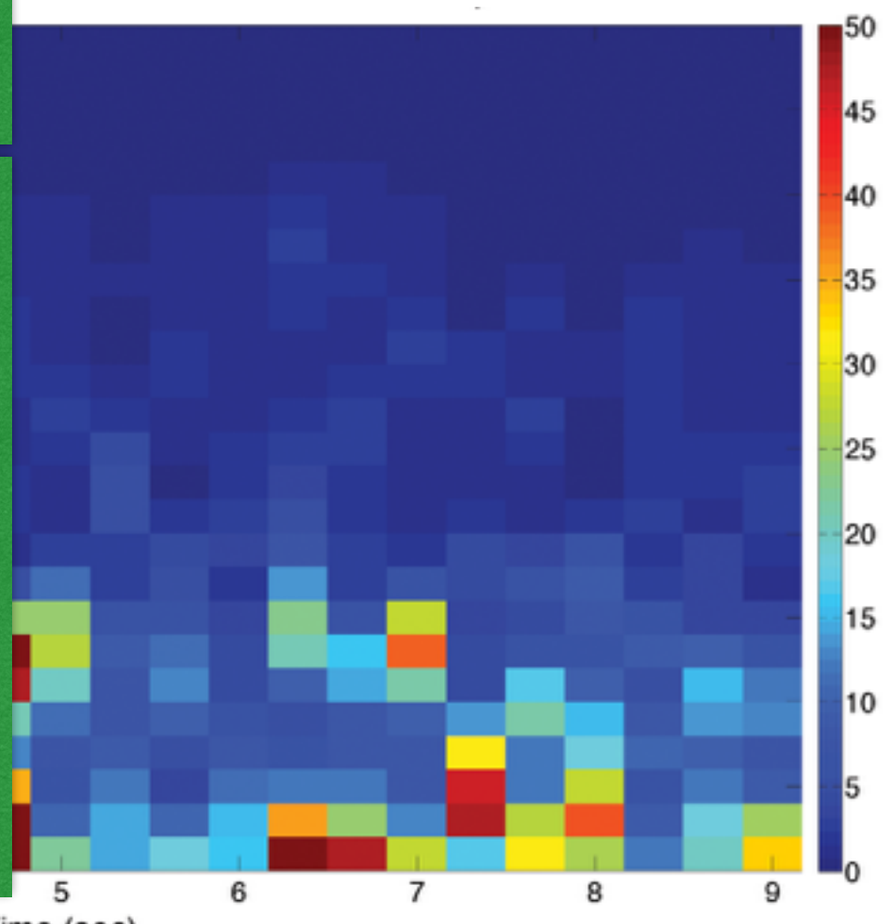




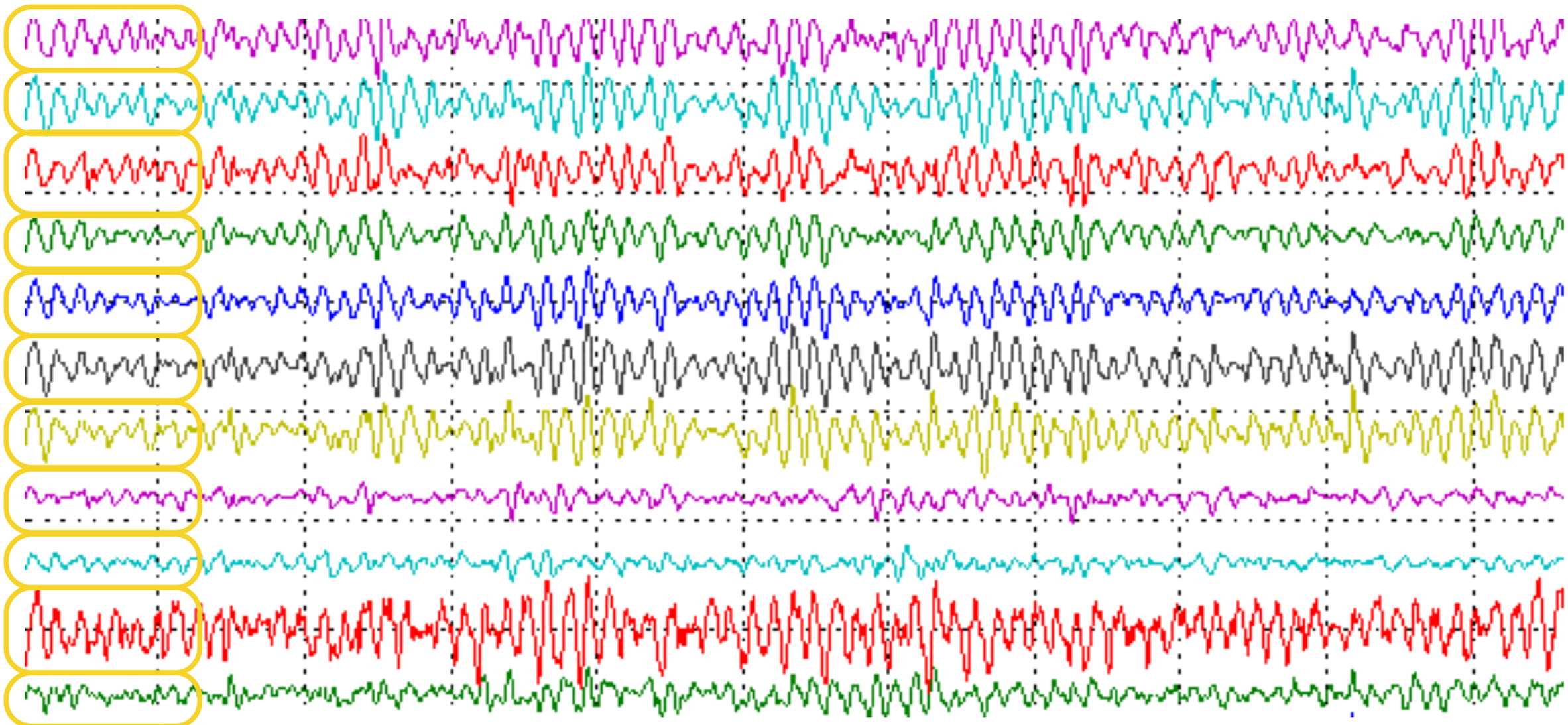
Are we done?

Hint:



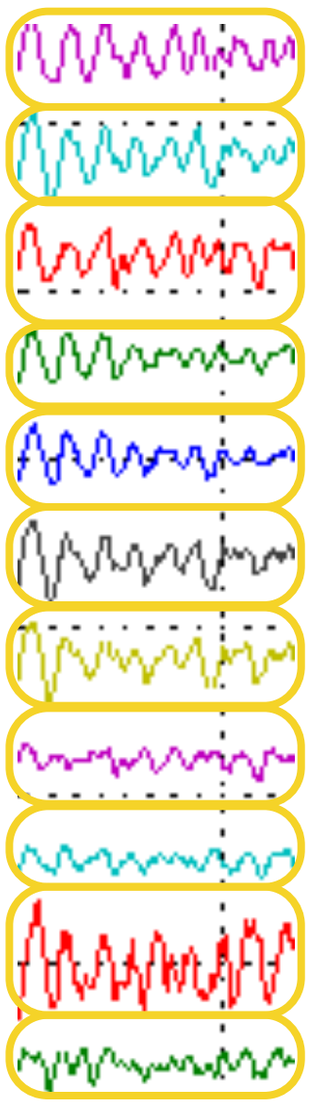


EEG DATA



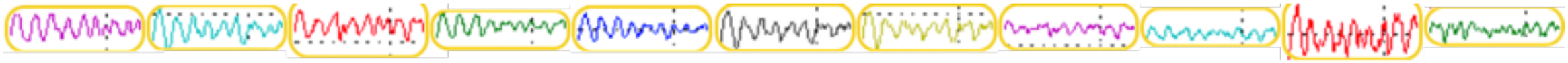
300 MS

EEG DATA



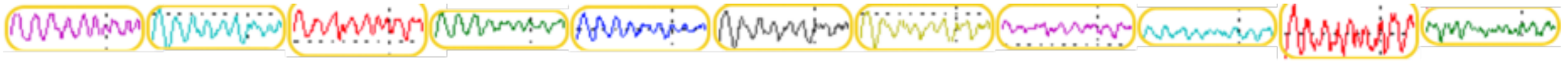
300 MS

EEG DATA

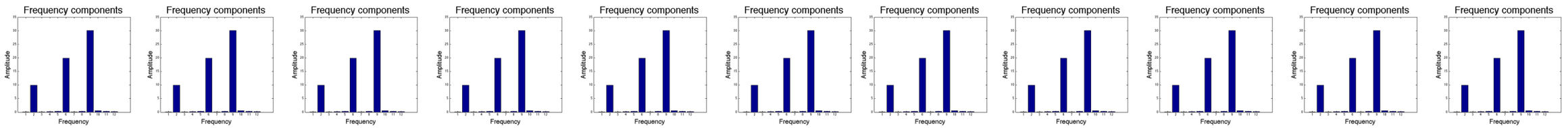


300 MS

EEG DATA



300 MS



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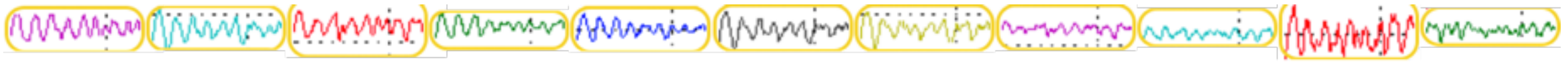
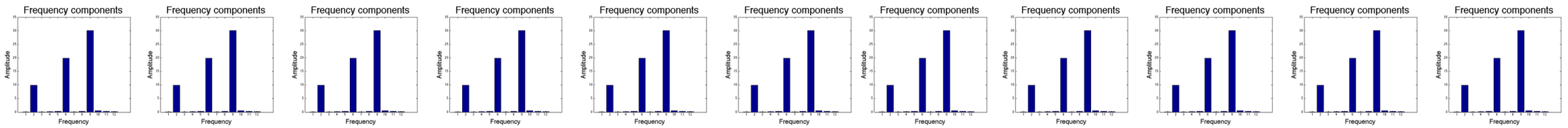
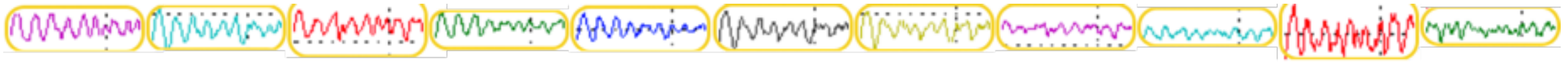


300 MS

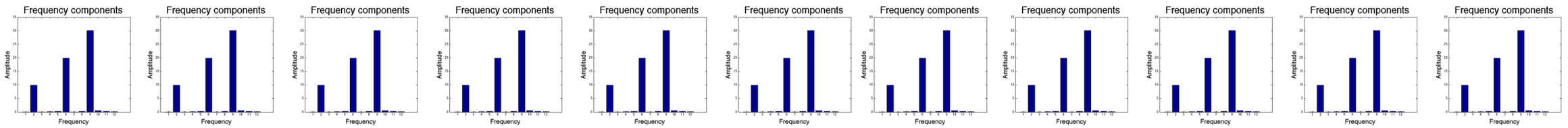


10 channels
50 frequencies
3 seconds of data
300 ms window

EEG DATA



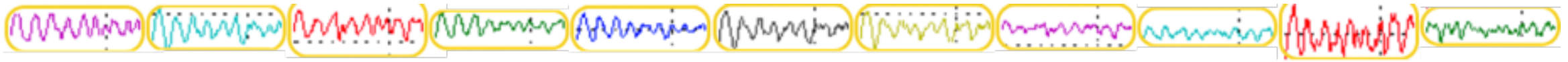
300 MS



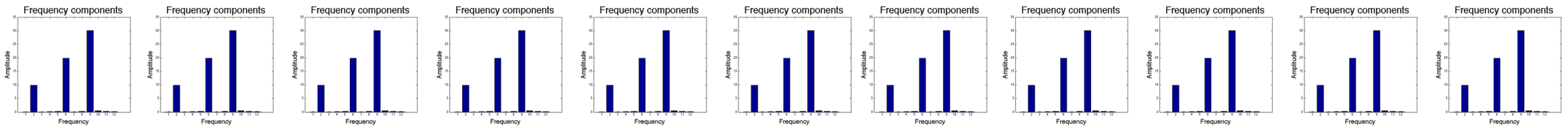
10 channels
50 frequencies
3 seconds of data
300 ms window

- How many numbers to describe 1 reading of 300 ms?

EEG DATA



300 MS



10 channels
50 frequencies
3 seconds of data
300 ms window

- How many numbers to describe 1 reading of 300 ms?
- How many numbers to describe all 3 seconds of data?

SUMMARY

- High temporal resolution
- No surgery!
- Mobile
- Cheap

- Low spatial resolution

Available to **wide audience**, but measurements are **approximate.**

SUMMARY OF NEUROIMAGING TECHNIQUES

Technology	Electrical					Magnetic		Optical
Name	EEG			ECoG	Intracortical	MEG	fMRI	fNIRS
Invasive	✗			✓	✓	✗	✗	✗
Portable	✓			✓	✓	✗	✗	✓
Cost	From $100 to $30,000+			$1000 grid	$2000 per array	$1 mln	$2-3 mln	$200,000
Temporal resolution	50 ms			3 ms	3 ms	50ms	1-2 s	1 s
Spatial resolution	1+ cm			1 mm	0.5 mm - 0.05 mm	5 mm	1 mm voxels	5 mm
	Pattern classification	VEP	ERD/ ERS	P300				
Performance	2 class 90% 3 class 80% 4 class ?	Large number of targets	2 cls 90%	Large number of targets	8 cls 90%	High*	~ same as EEG based	4 cls 90%	2 cls 90%