认知心理学进阶第四讲：磁共振物理

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认知心理学进阶课程

每小组分配10个磁共振成像机时(总价值约7.5万元)，设计功能磁共振成像实验研究某一特定认知心理过程，并撰写项目报告。小组实验方案将酌情择优提供持续支持。

1	认知心理学进阶概论
2	认知实验与认知实验标准工具箱
3	认知实验与PsychoPy程序编制
4	磁共振物理
5	认知心理学实验仪器现场考察
6	磁共振生理（一）
7	磁共振生理（二）
8	磁共振实验设计

9	功能磁共振数据预处理
10	功能磁共振数据Level 1数据分析
11	静息态功能磁共振数据分析
12	功能磁共振数据组分析
13	认知心理学与抑郁症研究
14	认知心理学与深度学习研究
15	认知心理学与经颅磁刺激研究
16	课程汇报考核

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认知心理学进阶课程

组名	姓名	院系
组01	陈君	心理系
组01	刘屹垚	外文系
组01	胡坤鹏	环境学院
组01	张艺缤	电子系
组01	郭生辉	建管系
组01	朱彦熹	外文系
组01	刘品	社科学院
组02	杨泽夏	法学院
组02	周弋楠	未央书院
组02	邓艺萱	社科学院
组02	张奥典	建筑学院
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组02	李佳钰	美术学院
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组03	冯羽墨	新雅书院
组03	于昕彤	日新书院
组03	魏钇钒	生命学院
组03	郭浩然	为先书院
组03	余佳讯	日新书院

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磁共振物理

什么是磁共振成像?

磁共振物理MR Physics

核磁共振的硬件 Hardware

射频系统 RF

梯度系统 Gradient

Sequence　序列

TR　TE

T1　T2　T2*

Excitation

Relaxation

Courtesy of Dr. Joe Yazhuo Kong @ IPCAS MRIRC

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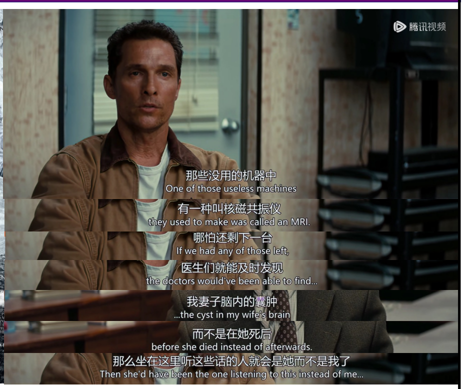
磁共振物理



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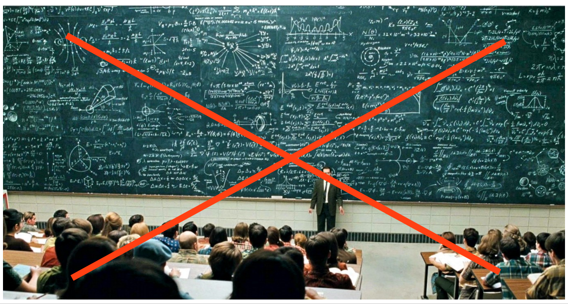
Physics of MRI

Good news…

you don't need to know/understand Quantum Mechanics!



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磁共振成像技术

核磁共振成像

Nuclear Magnetic Resonance Imaging

“核” — 氢原子核^{1}H

人体大约70%是由水组成的
MRI即依赖水中氢原子

Magnetic Field（磁场）
Radio Frequency Wave (RF)（射频）
Nuclei of the tissue generates MR Signal
（组织的原子核产生MR信号）

在对身体没有损害的前提下，快速地获得人体内部结构的高精度立体图像，胎儿也可以使用！

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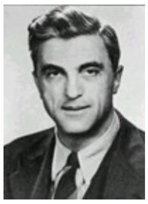
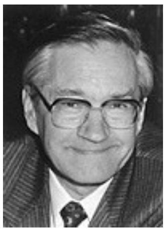


布洛赫(Felix Bloch)

珀赛尔 (Edward Purcell)

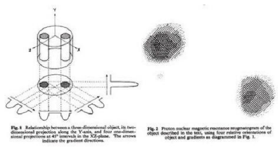
1952年诺贝尔物理学奖：布洛赫(Felix Bloch) & 珀赛尔 (Edward Purcell)
发展了核磁精密测量的新方法及由此所作的发现——核磁共振。

1991年诺贝尔化学奖：
恩斯特*R.R.Ernst*（1933－） 瑞士物理化学家

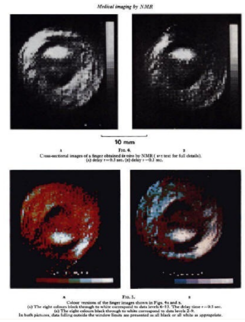


高分辨核磁共振波谱学方面的杰出贡献
- **脉冲傅利叶变换核磁共振谱**
- **二维核磁共振谱**

2003年诺贝尔医学奖：
美国科学家保罗·劳特布尔 (Paul Lauterbur)
英国科学家彼得·曼斯菲尔德(Peter Mansfield)

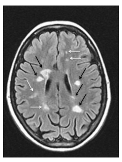
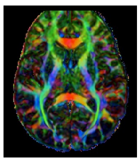
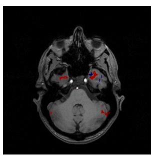
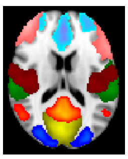
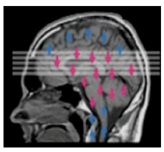


Lauterbur, 1973

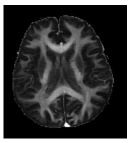


Mansfield, 1977

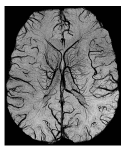
Basic Brain MRI

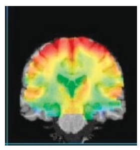
Advanced MRI



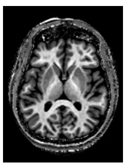
Myelin Water Imaging



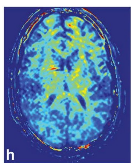
Susceptibility weighted Imaging



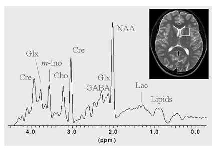
Spectroscopy Imaging



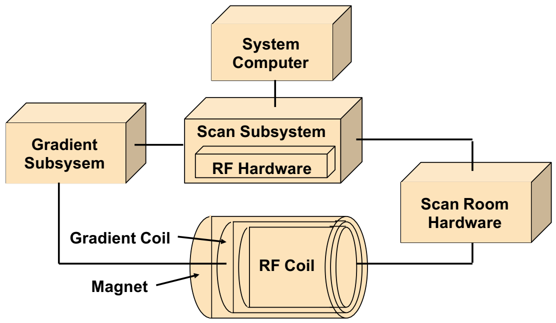
Magnetisation transfer



CEST



MR spectroscopy



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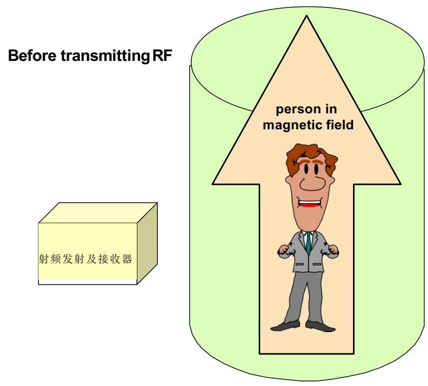

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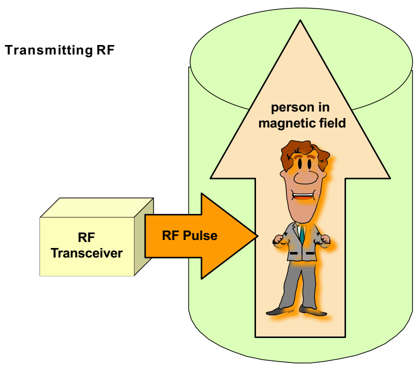

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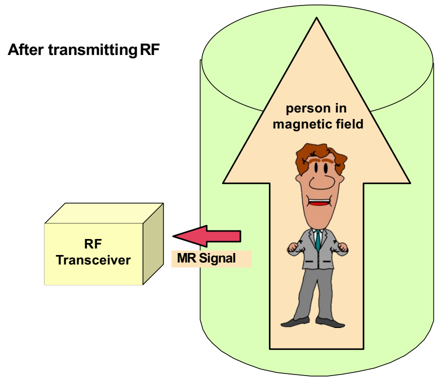

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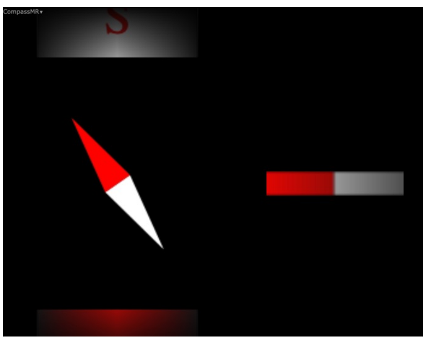
什么是磁共振



http://www.drcmr.dk/JavaCompass/
https://www.youtube.com/watch?v=shB8T8cOeas

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磁共振物理的一些基本概念

- 原子核的自旋和磁矩
- 自旋磁矩在外磁场中的能量状态
- 产生核磁共振的条件
- 拉莫尔方程（Larmor equation）
- 宏观磁矩
- 射频场对宏观磁矩的作用
- 弛豫过程和弛豫时间

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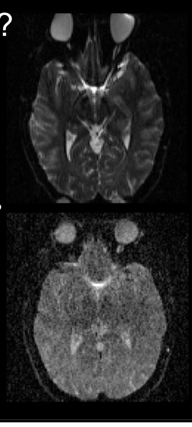
Why learn MRI physics?

Which image is “better”?

- Better signal-to-noise ratio (SNR)?
- Higher resolution?
- Better contrast-to-noise ratio (CNR)?
- Faster to acquire?
- Lower distortion?



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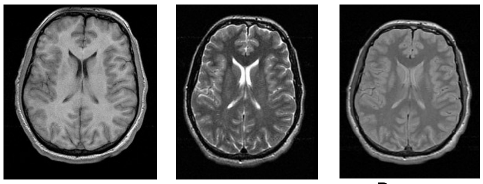
Structural MRI



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The Magnet

Earth’s magnetic field
5×10^{-5} Tesla

Bar magnet
0.01 - 0.1 Tesla

Scrapyard magnet
1 Tesla

Human MRI
0.2 - 11.7Tesla

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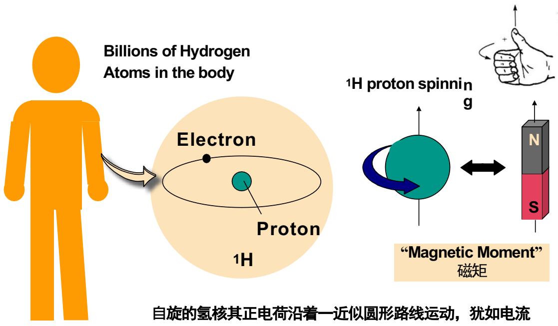

自旋的氢核其正电荷沿着一近似圆形路线运动，犹如电流通过环形线圈一样，从而在其周围产生一磁场。此磁场的大小与方向用磁矩来表示，形成一个微观的磁体偶极子。

具有磁矩的快速自旋核可以看成为极小磁棒

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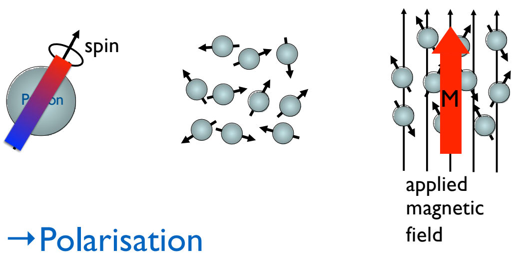
The behavior of magnetic moment of Proton in a magnetic field

（在磁场中质子磁矩的行为）



→Polarisation

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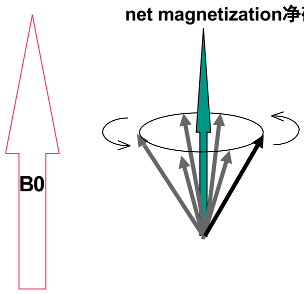
The magnetic field (B0) causes precession of the magnetic moment （磁场导致磁矩的进动）



有序排列的质子呈快速锥形旋转运动，称为进动（Precession）

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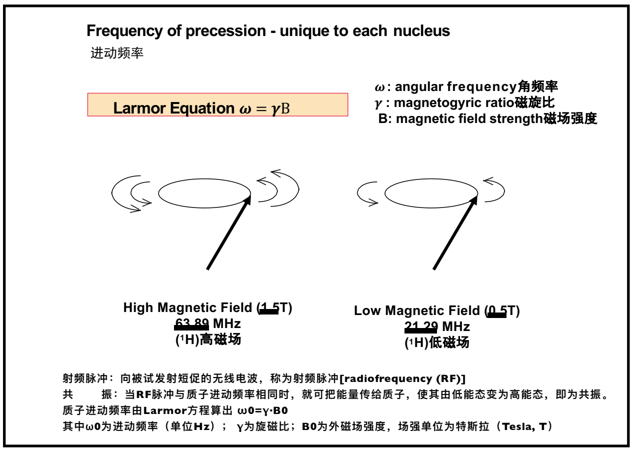

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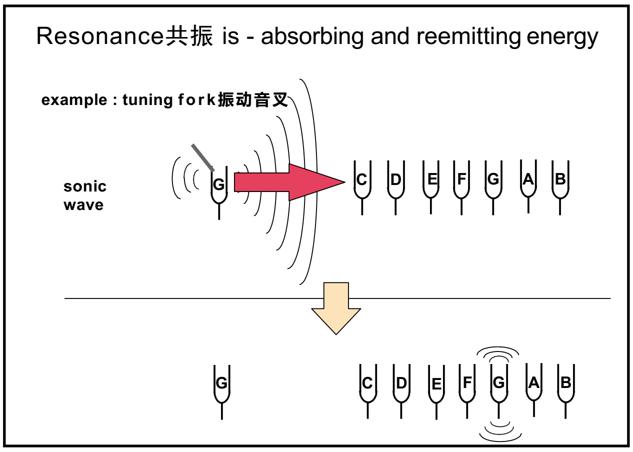

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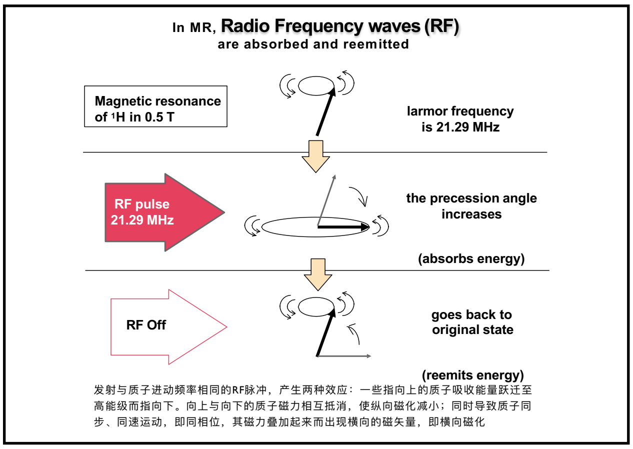

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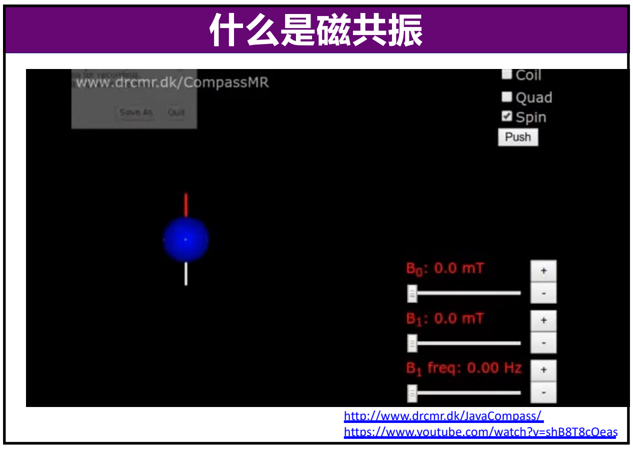

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Compass Needle Analogy

- Some key points here:
  - The main magnetic field (B0) causes the spins (compass needle) to align with it: **Polarisation**
  - The stronger the main magnetic field, the faster the *natural oscillations* of the spins (needle): **Precession**
  - We can knock the spins (needle) out of alignment with the main magnetic field using a weaker oscillating field *only if* the oscillation frequency matches the natural oscillation frequency: **Excitation**
  - Once the spins (needle) are oscillating, we can detect them: **Signal Reception**
  - The spins (needle) will eventually stop oscillating and realign with the main magnetic field: **Relaxation**

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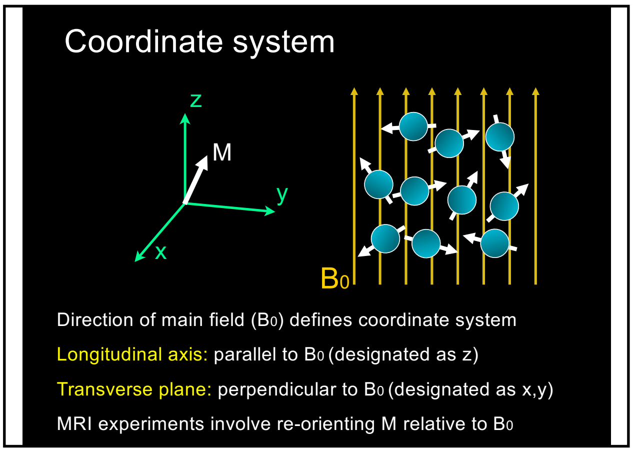

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review

What is needed for resonance?共振需要什么?

- large number of nuclei (with spin and magnetic moment)
  - Hydrogen atoms氢质子子
- a static magnetic field净磁场
  - Magnet磁体
- RF pulse射频脉冲
  - absorb and re-emit energy
    - the “re-emitted energy is the “MR Signal”
    - （再释放的能量是MR信号）

磁共振条件：原子核发生共振吸收时的射频场的角频率等于自旋核在磁场中旋进的角频率(拉莫尔频率$_0$)，这就是磁共振条件。

磁共振：处于恒定外磁场B_0中的自旋核，由于核磁矩取向和旋进引起能级分裂，如果在与外磁场垂直的平面内再加一个旋转的磁场B_1(也称为射频场，记为RF)，只要B_1的能量子恰好等于原子核能级分裂的裂距，即满足拉莫尔公式，原子核就会吸收这个能量，从低能态激发到高能态，这一过程就是核磁共振中的共振吸收。停止RF照射，处于激发态的核磁矩将会回到低能态，同时发射RF，整个吸收和发射的过程称为磁共振。

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RF Coils

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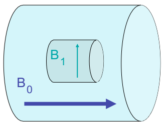
RF Coils

- Generate a magnetic field perpendicular to the main magnetic field of the scanner
- Coil to ‘excite’ the protons (transmit)
- Coil to detect (receive) their resonance
- Can be the same coil, or can be different coils



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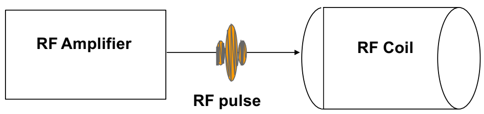
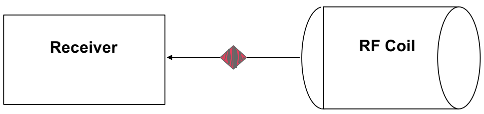
RF Excitation

The actual pulse transmitted to the RF coil is a sinc pulse



After the RF pulse is OFF, the RF coil acts as a receiving coil



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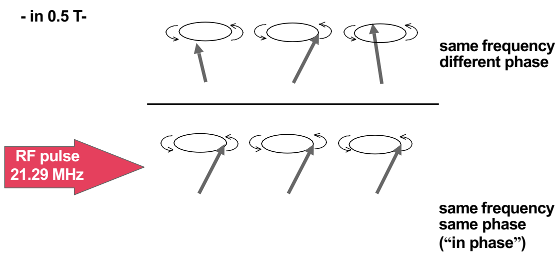
What does the RF pulse do?

1. It makes the nuclei precess **“in phase”**



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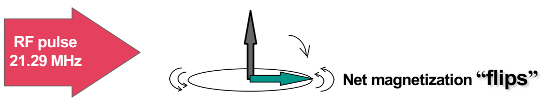
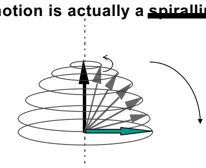
2. It transfers energy to the nuclei



The “flipping” motion is actually a spiralling motion:



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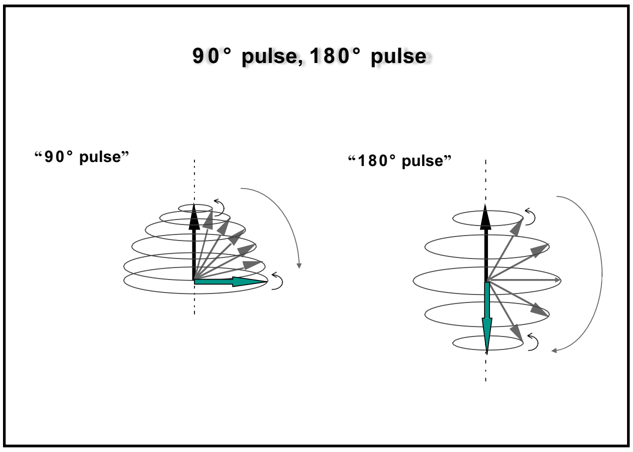

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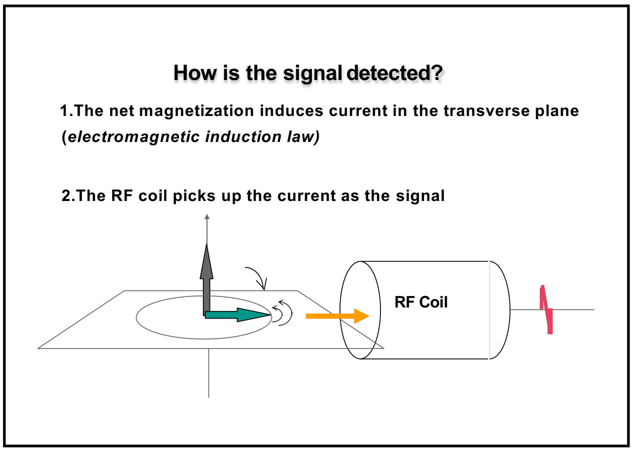

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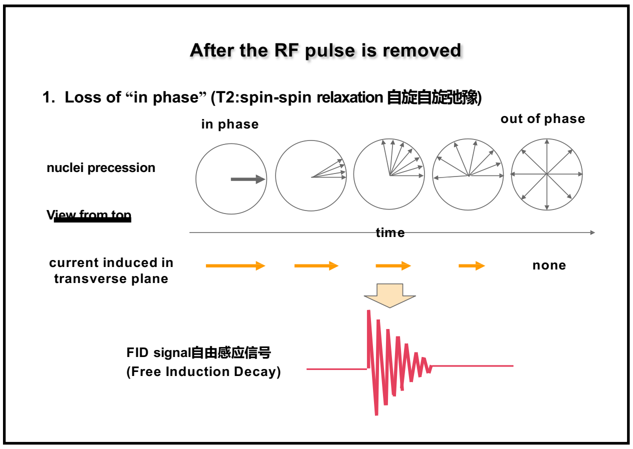

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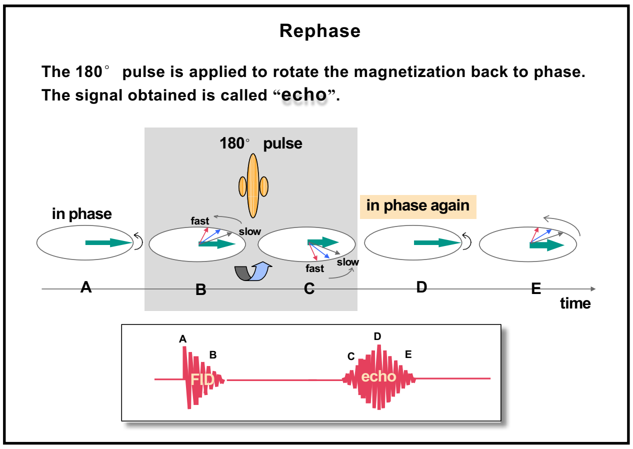

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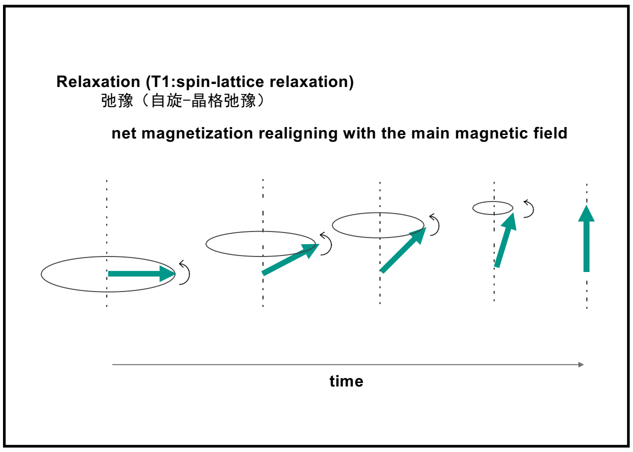

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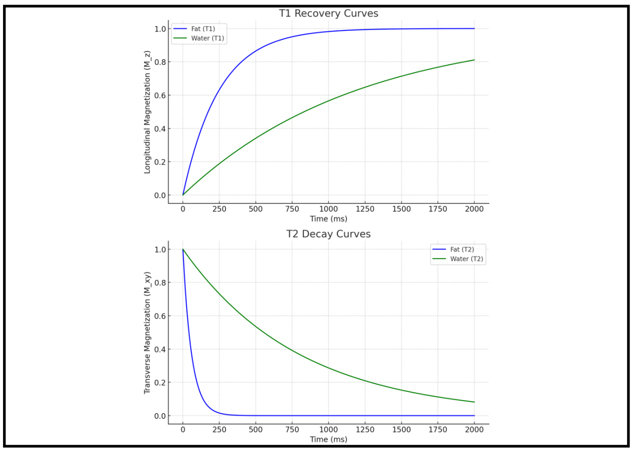

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弛　　　豫　中止RF射频后，由RF所引起的变化恢复到原来的平衡状态。分为纵向弛豫（自旋晶格弛豫）和横向弛豫（自旋自旋弛豫），分别为纵向磁化恢复和横向磁化消失的过程

纵向弛豫时间　纵向磁化由0恢复到原来数值的63%所需的时间，为纵向弛豫时间（longitudinal relaxation time），简称T_1

横向弛豫时间　横向磁化由最大减小到最大值的37%所需的时间，为横向弛豫时间（transverse relaxation time），简称T_2

- **T1**、**T2**是时间常数，不是绝对值。
- **T1**长于**T2** 生物组织的弛豫时间，**T1**为**300ms**～**2000ms**，**T2**为**30ms**～**150ms** 水的**T1**、**T2**都长，而脂肪的**T1**、**T2**均短。
- 病变组织如肿瘤常比周围组织含水量高，故**T1**、**T2**常较长。 **T1**的长短同组织成分、结构和磁环境有关，与外磁场强度也有关。
- **T2**的长短同外磁场和组织内磁场的均匀性有关

组织	T_1	T_2	组织	T_1	T_2
大脑	600	100	脑脊液	1155	145
胼胝体	380	80	头皮	235	60
脑桥	445	75	脊髓	320	80
小脑	585	90			

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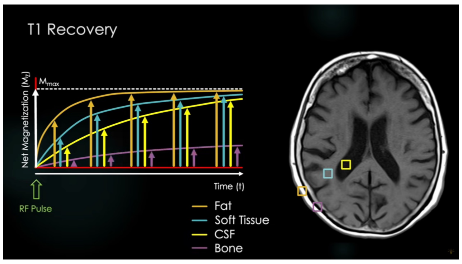

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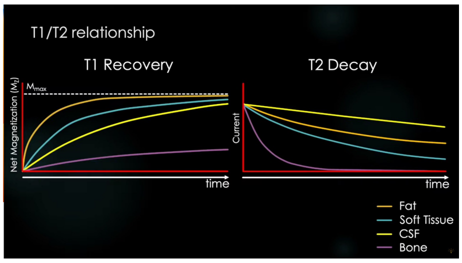

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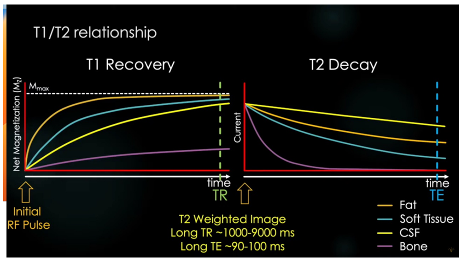

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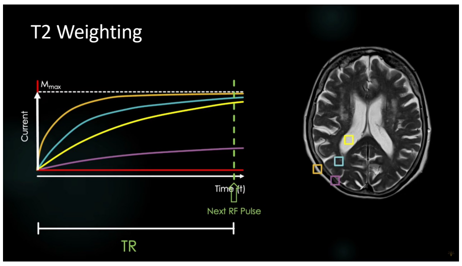

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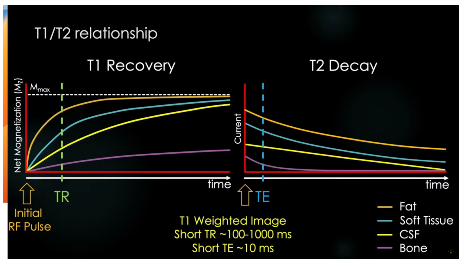

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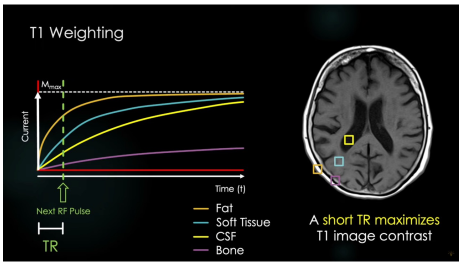

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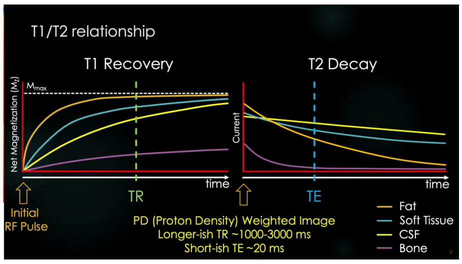

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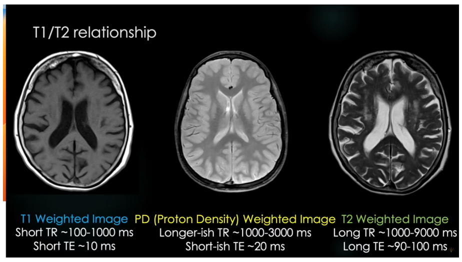

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The RF pulse "flips" the net magnetization vector
射频脉冲翻转净磁化矢量
actually it is a spiralling motion实际上它是螺旋形移动
When the RF coil does not send RF, it acts as a receiving coil 当射频线圈不发放射频脉冲时，它充当接收线圈

"MR signal" is actually the current induced by the magnetization vector
MR信号实际上是由磁化矢量感应的电流

After the RF pulse is turned off, the current induced begins to weaken - the signal begins to decay (FID)
当射频脉冲停止后，感应电流开始变弱—信号开始衰减

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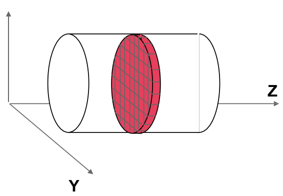
梯度磁场

What are gradient fields for?

Gradient fields are needed for <u>spatial information</u>(空间信息)



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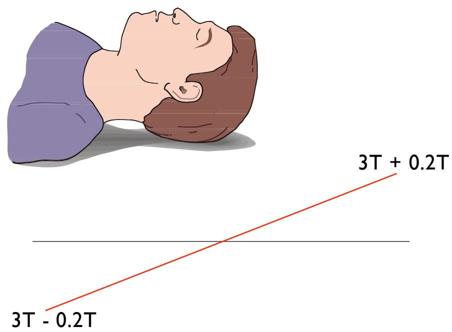
Field Gradients



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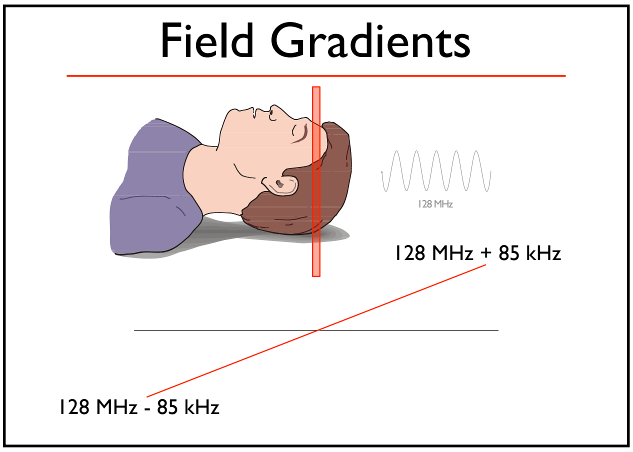

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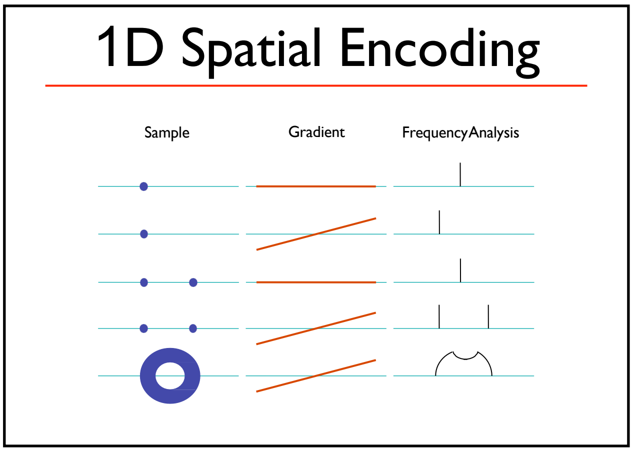

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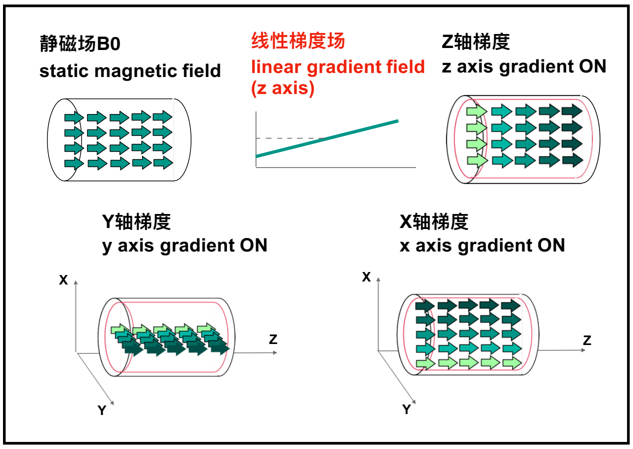

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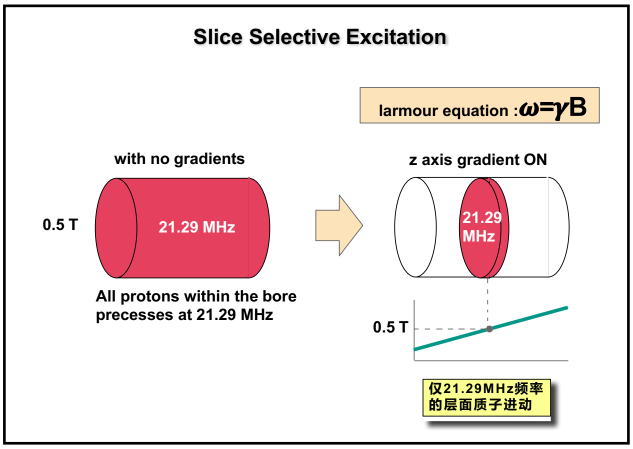

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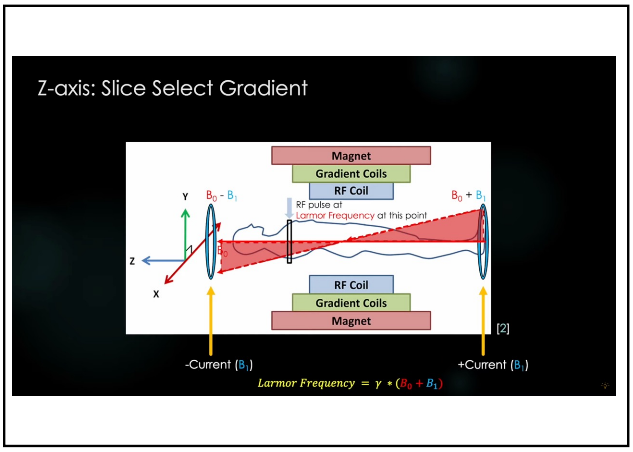

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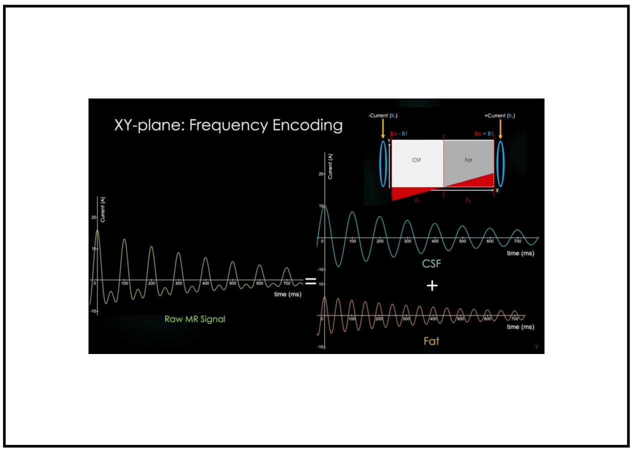

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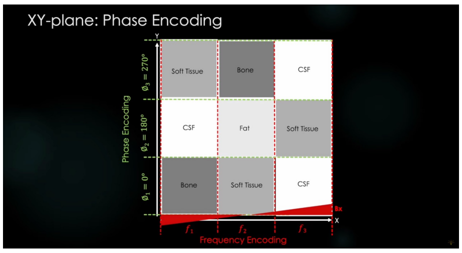

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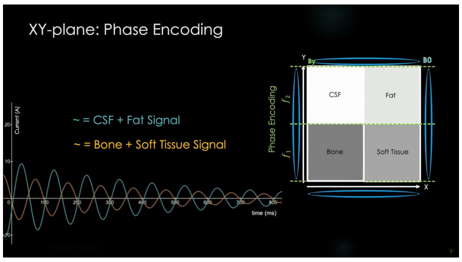

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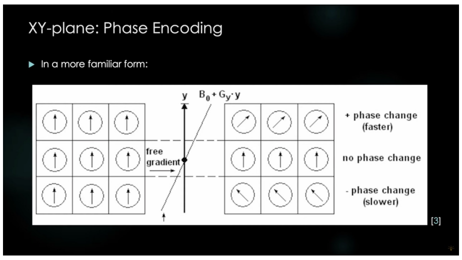

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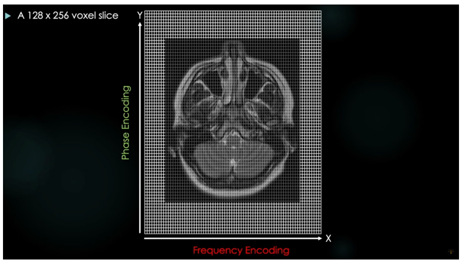

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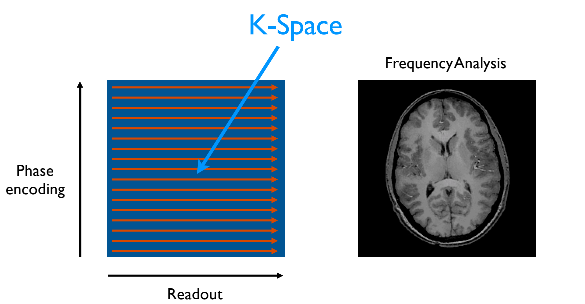
Phase Encoding



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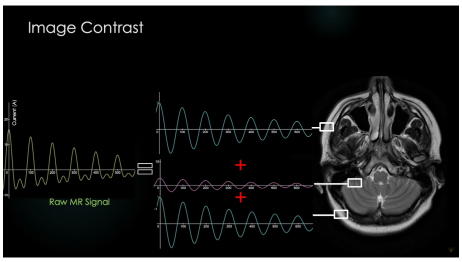

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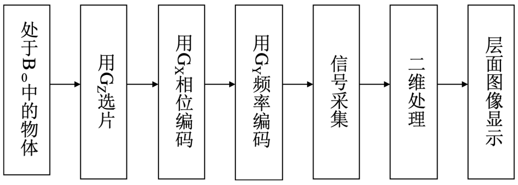
图像重建方法：采集的核磁共振信号，显然带有各体素的x、y、z位置信息。要实现图像重建必须把信号按不同的频率和相位分解使像素与体素信号一一对应。在磁共振成像技术中普遍采用的是傅立叶变换图像重建。



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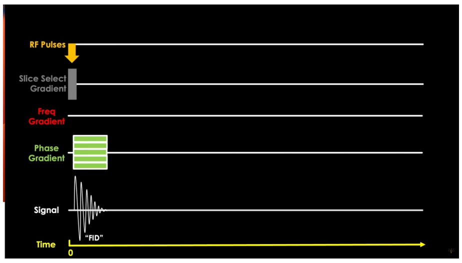

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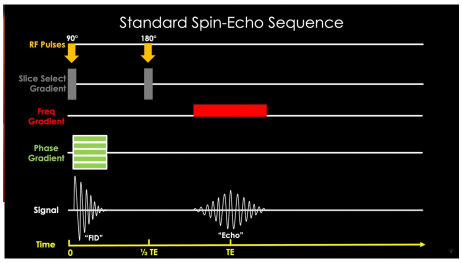

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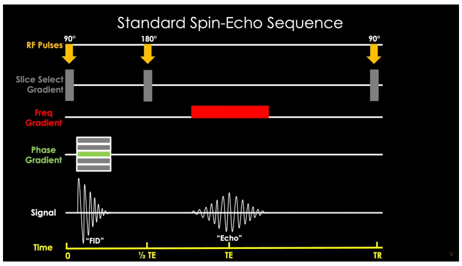

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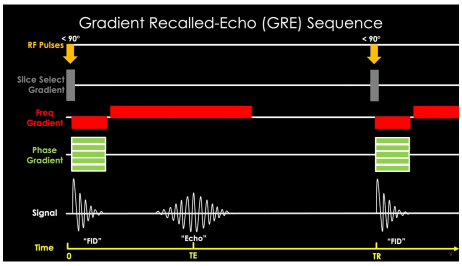

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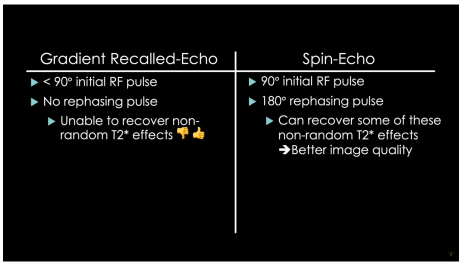

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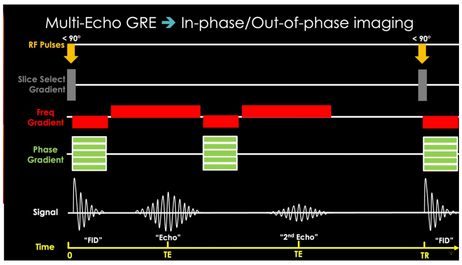

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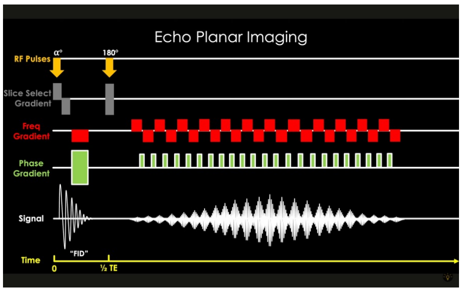

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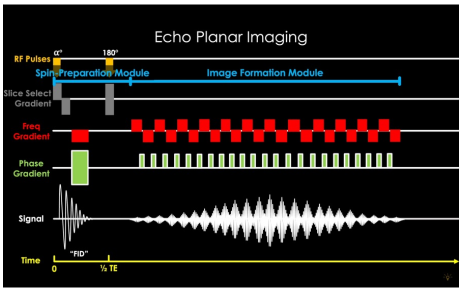

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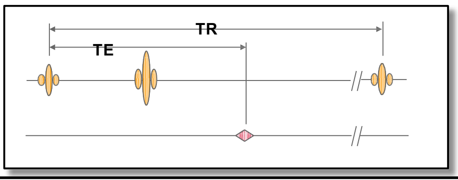
Scan Parameters: **TE** **TR**
扫描参数： **回波时间** **重复时间**

TR (Repetition Time)重复时间
The time interval from the beginning of a pulse sequence until the beginning of a next pulse sequence
一个射频脉冲的开始到下一个射频脉冲的开始的时间间隔
TE (Echo Time)回波时间
The time interval from the first RF pulse of a pulse sequence to the middle of an echo
脉冲序列列的第一个射频脉冲到一个回波的中点的时间间隔



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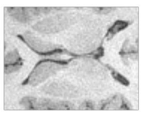
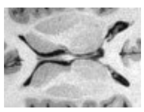
Structural MRI Artefacts

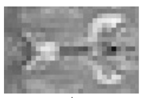
Hardware-related





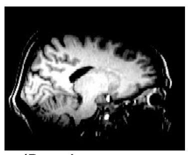
Contrast & Noise
(SNR & CNR)

Resolution &
Partial Voluming



Low-res T_2^*-weighted

- There is always a trade-off in MRI between acquisition time, resolution and noise (Signal to Noise Ratio = SNR)



RF Bias (B_1 inhomogeneity)

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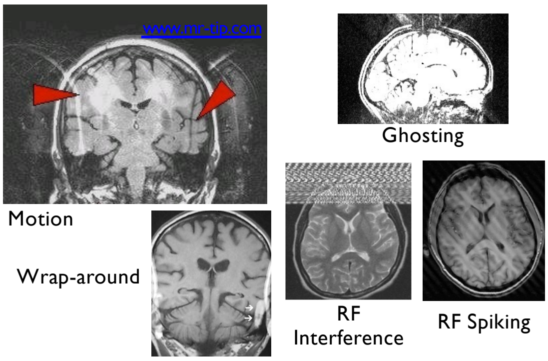
Structural MRI Artefacts



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梯度回波序列

梯度回波序列（gradient echo sequence, GRE）是常用的快速成像序列。空间分辨力和信噪比均较高，可获得准T_1WI、准T_2WI及准PdWI，主要用用于腹部、心血管、与流动液体相关成像及骨关节成像

回波平面成像

回波平面成像（echo planar imaging, EPI）是快速成像技术，获得一个层面可短至20ms，主要用于功能成像fMRI

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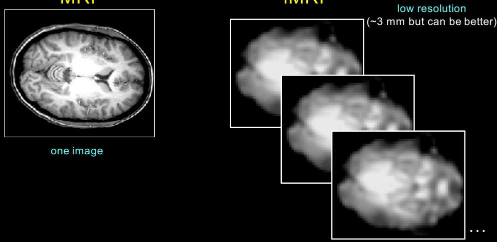
MRI vs. fMRI



fMRI
Blood Oxygenation Level Dependent (BOLD) signal
indirect measure of neural activity

neural activity ➔ blood oxygen ➔ fMRI signal

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Sir Peter Mansfield

1933 – 2017

Let's hear from Prof. Mansfield…

回波平面成像（echo planar imaging, EPI）快速成像技术，获得一个层面可短至20ms，主要用于功能成像fMRI

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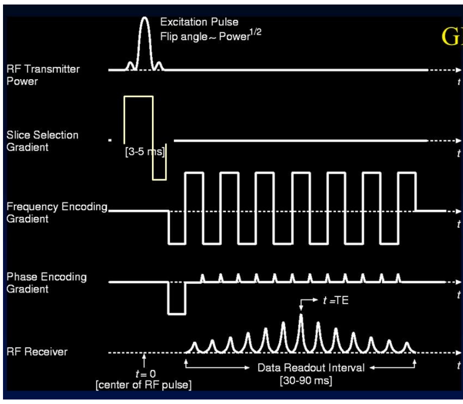

GE-EPI Pulse Sequence

Actually have 64 (or more) freq. encodes in one readout (each one < 1 ms)

[only 13 freq. encodes shown here]

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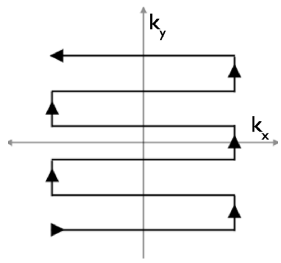
Echo Planar Imaging (EPI)

EPI is far and away the most common method for acquiring FMRI data



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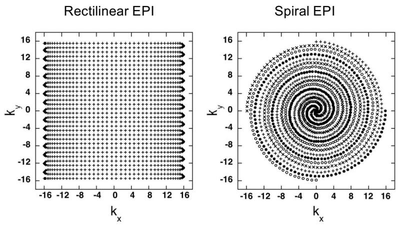
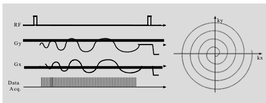
Time & Space: acquisition



Spiral:
快速，梯度变化容易，减少液体流动伪影
但是FSL SPM等主流软件不支持unwarp
不容易做slice timing等



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Why Use EPI?

BOLD effect causes local changes in T2*
- Gradient echo EPI is a T2*-weighted method
- EPI signal contrast is like that of standard GRE

EPI is much faster than line-by-line GRE
- Haemodynamic response changes occur in seconds
- EPI can acquire whole-brain data in seconds rather than minutes to to better track BOLD changes

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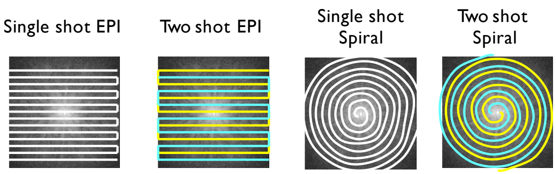

Echo-Planar Imaging EPI
- sample k-space in a linear zig-zag trajectory

spiral imaging
- sample k-space in a spiral trajectory

single shot imaging
- sample k-space with one trajectory

multi-shot imaging
- sample k-space with multiple (typically 2 or 4) trajectories
- Improve spatial resolution
- Reduce artifacts

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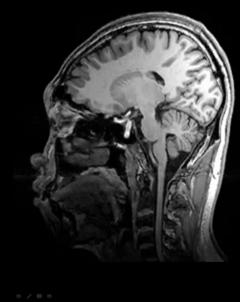
回波平面成像（echo planar imaging, EPI）快速成像技术，获得一个层面可短至20ms，主要用于功能成像fMRI



Ascending

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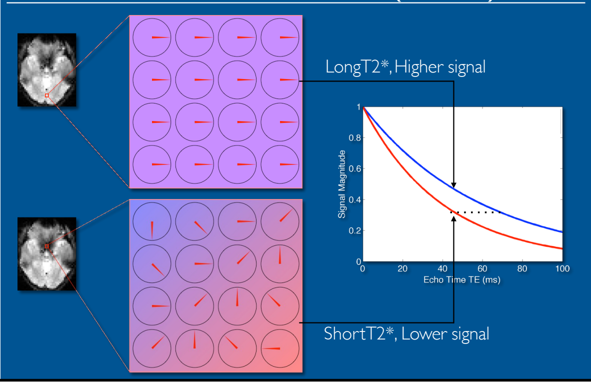
The Gradient Echo (GRE)



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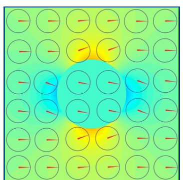
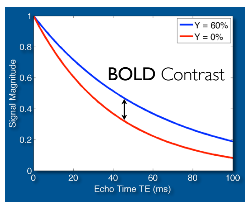
BOLD Signal Contrast

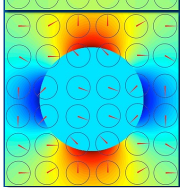
Blood Oxygenation Level Dependent



Y = 60%
Low inhomogeneity
Longer T2*
Higher GRE signal



Y = 0%
High inhomogeneity
Shorter T2*
Lower GRE signal



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BOLD Signal Contrast

- BOLD contrast comes from signal fluctuations due to changingT2*
- T2* changes with the oxygenation state nearby blood
- ∴ BOLD signal reflects blood oxygenation

- What about the neurons?
  Neuro-vascular coupling

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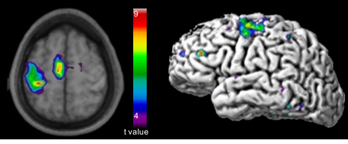
Functional MRI (fMRI)

- indirect detection of neuronal activity
- BOLD: **B**lood **O**xygenation **L**evel **D**ependent
  - magnetic properties of hemoglobin
    - deoxyhemoglobin is like a *contrast agent*
- dynamically monitor changes in [dHb] changes and correlate with tasks or stimuli



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感谢各位同学！

敬请批评指正！

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