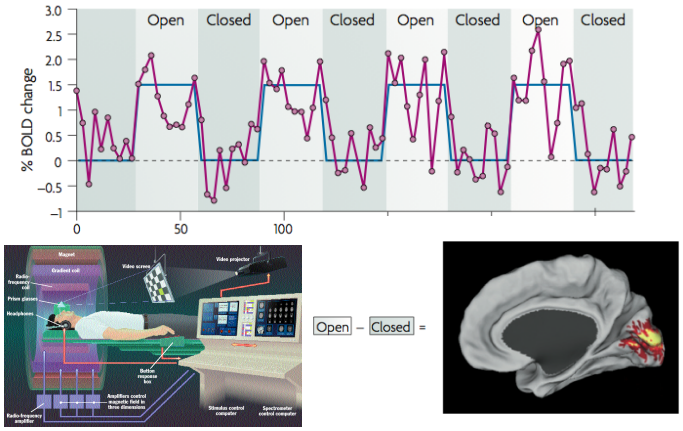
Bioengineering 280A
Principles of Biomedical Imaging

Fall Quarter 2015
MRI Lecture 9

Task-Related BOLD fMRI



http://defiant.ssc.uwo.ca/Jody_web/fmri4dummies.htm

Fox and Raichle 2007

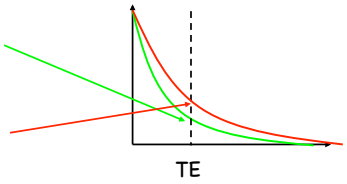
BOLD Signal Change

Baseline Signal

$$S_B = M_0 \exp\left(-TE \cdot R^*_{2,B}\right)$$

Activation Signal

$$S_A = M_0 \exp\left(-TE \cdot R^*_{2,A}\right)$$



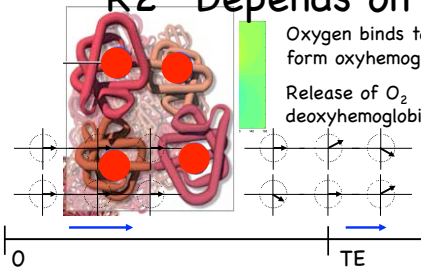
$$\frac{\Delta BOLD}{BOLD_0} = \frac{S_A - S_B}{S_B}$$

$$\approx -TE \cdot \Delta R^*_2$$

R2* Depends on dHB

Oxygen binds to the iron atoms to form oxyhemoglobin HbO_2

Release of O_2 to tissue results in deoxyhemoglobin $dHBO_2$



Some dHB, Some dephasing

More dHB, More dephasing, Decrease in MR signal.
Higher R_2^*

Blood Flow and Oxygen Metabolism

$[dHb]_{venous} = CMRO_2/CBF$

$CBF\ [O_2]_{arterial}$ → Cerebral Blood Flow

Oxygen extraction fraction (OEF)

$CMRO_2$

Cerebral Metabolic Rate of Oxygen

↑ CBF → ↓ $[dHB]_{venous}$

↑ $CMRO_2$ → ↑ $[dHB]_{venous}$

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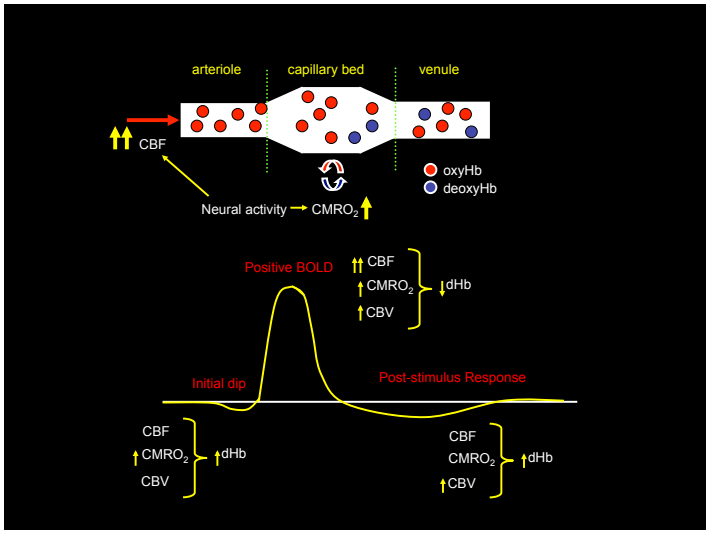

Functional MRI

Large-amplitude, spatially correlated fluctuations in BOLD fMRI signals during extended rest and early sleep stages

Masaki Fukunaga[a,*], Silvina G. Horovitz[a], Peter van Gelderen[a], Jacco A. de Zwart[a], J. Martijn Jansma[a], Vasiliki N. Ikonomidou[a], Renxin Chu[a], Roel H.R. Deckers[a], David A. Leopold[b], Jeff H. Duyn[a]

PubMed

3: Grill HJ, Skibicka KP, Hayes MR.

Imaging obesity: fMRI, food reward, and feeding.

Cell Metab. 2007 Dec;6(6):423-5.

PMID: 18054310 [PubMed - indexed for MEDLINE]

See Genius. No items found.

Your search for *donut fmri* retrieved no results.

However, a search for *donut fmri* retrieved the following items.

Neural Activation Patterns of Methamphetamine-Dependent Subjects During Decision Making Predict Relapse

Martin P. Paulus, MD; Susan F. Tapert, PhD; Mary A. Schuckit, MD

Acute effects of alcohol on neural correlates of episodic memory encoding

Hedvig Söderlund,[a,*] Cheryl L. Grady,[a,b,c] Craig Easdon,[a] and Endel Tulving[a,b]

Marketing actions can modulate neural representations of experienced pleasantness

Hilke Plassmann*, John O'Doherty*, Baba Shiv†, and Antonio Rangel*‡

Mapping a multidimensional emotion in response to television commercials

Jon D. Morris [1 2 *], Nelson A. Klahr [2 3], Feng Shen [1], Jorge Villegas [1], Paul Wright [2 3], Guojun He [2 3], Yijun Liu [2 3 *]

Distinguishing specific sexual and general emotional effects in fMRI—Subcortical and cortical arousal during erotic picture viewing

Martin Walter,[a,*] Felix Bermpohl,[b] Harold Mouras,[c] Kolja Schiltz,[a,d] Claus Tempelmann,[d] Michael Rotte,[d] Hans Jochen Heinze,[d] Bernhard Bogerts,[a] and Georg Northoff[a]

Hippocampal Activation for Autobiographical Memories over the Entire Lifetime in Healthy Aged Subjects: An fMRI Study

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Cabernet and fMRI

1050–1054 | PNAS | January 22, 2008 | vol. 105 | no. 3

Marketing actions can modulate neural representations of experienced pleasantness

Hilke Plassmann*, John O'Doherty*, Baba Shiv†, and Antonio Rangel*‡

*Division of the Humanities and Social Sciences, California Institute of Technology, MC 228-77, Pasadena, CA 91125; and †Stanford Graduate School of Business, Stanford University, 518 Memorial Way, Littlefield L383, Stanford, CA94305

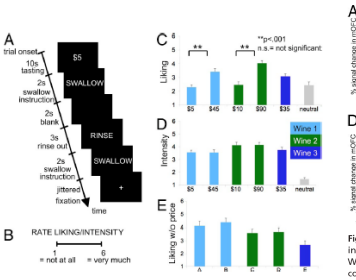

Fig. 1. Experimental design and behavioral results. (*A*) Time course for a typical trial. (*B*) Reported pleasantness and intensity ratings scales. (*C*) Reported pleasantness for the wines during the cued price trials. (*D*) Taste intensity ratings for the wines during the cued price trials. (*E*) Reported pleasantness for the wines obtained during a postexperimental session without price cues.

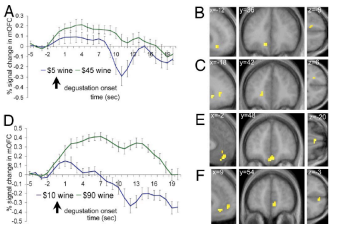

Fig. 2. The effect of price on each wine. (*A*) Wine 1: averaged time courses in the medial OFC voxels shown in *B* (error bars denote standard errors). (*B*) Wine 1: activity in the mOFC was higher for the high- ($45) than the low-price condition ($5). Activation maps are shown at a threshold of $P < 0.001$ uncorrected and with an extend threshold of five voxels. (*C*) Wine 1: activity in the vmPFC was also selected by the same contrast. (*D*) Wine 2: averaged time courses in the medial OFC voxels shown in *E*. (*E*) Wine 2: activity in the mOFC was higher for the high- ($90) than for the low-price condition ($10). (*F*) Wine 2: activity in the vmPFC was higher for the same contrast.

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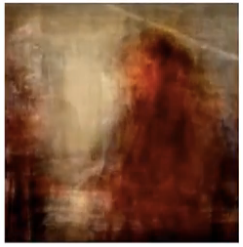
Vision Reconstruction

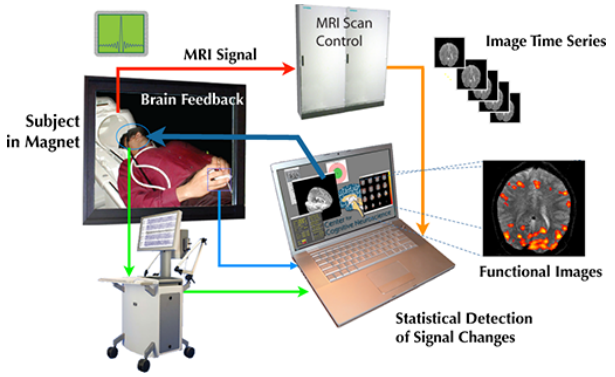
Presented clip

Clip reconstructed from brain activity



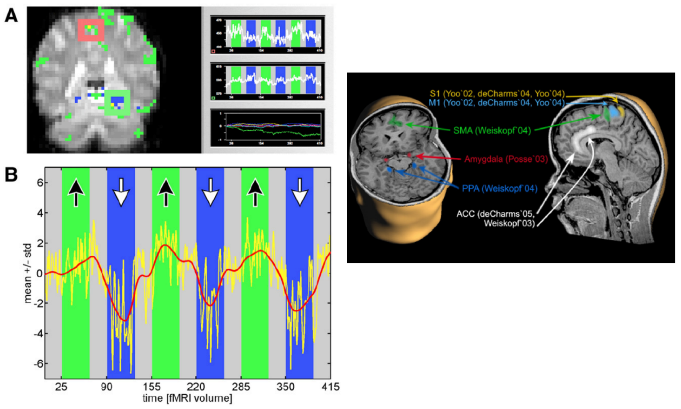
http://www.youtube.com/watch?v=6FsH7RK1S2E

Real-Time fMRI



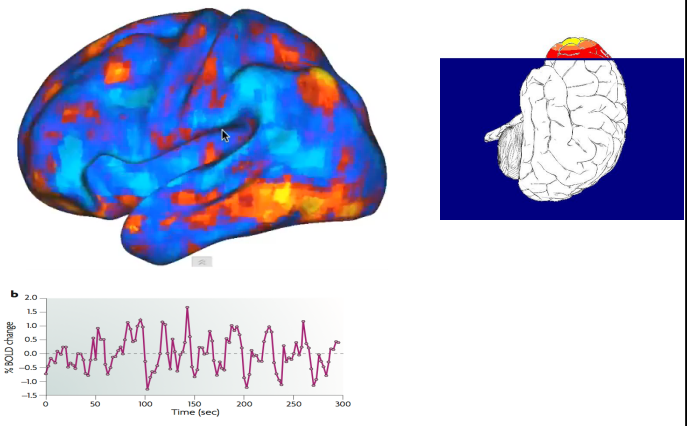
http://www.brainmapping.org/MarkCohen/research/RTfMRI.html

Real-time fMRI



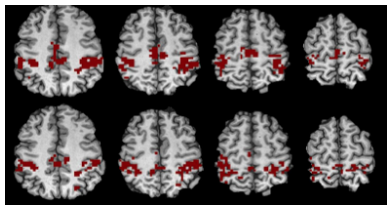
Weiskopf et al. Magn. Reson. Imaging, 2007

Resting-State fMRI



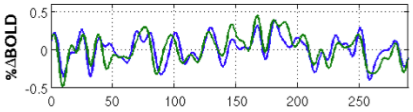
Fox and Raichle 2007, http://www.youtube.com/watch?v=VaQ66lDZ-08&feature=plcp

Resting-State BOLD Connectivity



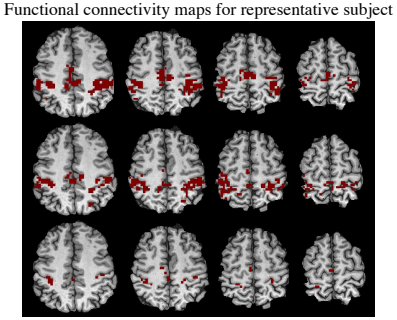
Task-Related
Motor Activation Map

Resting State Correlation Map



Resting State fMRI Signals From Left and Right Motor Cortices

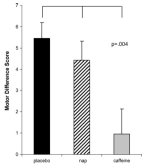
Functional connectivity maps for representative subject



Activation Map

Rest

Rest



Rack-Gomer et al 2008;
Mednick et al 2008

Default Mode and Attention Networks

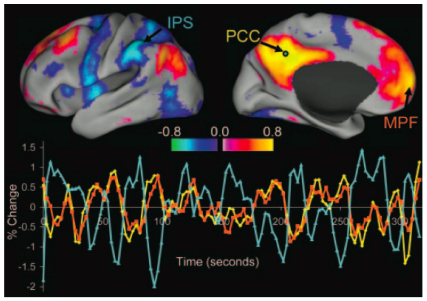
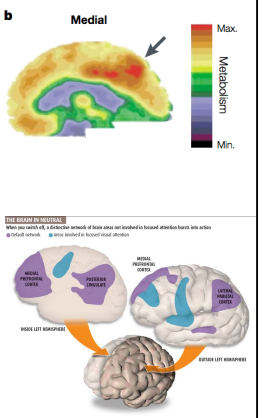


Fig. 1. Intrinsic correlations between a seed region in the PCC and all other voxels in the brain for a single subject during resting fixation. The spatial distribution of correlation coefficients shows both correlations (positive values) and anticorrelations (negative values), thresholded at $R = 0.3$. The time course for a single run is shown for the seed region (PCC, yellow), a region positively correlated with this seed region in the MPF (orange), and a region negatively correlated with the seed region in the IPS (blue).

Gusnard et al, Nat Rev. Neuro, 2001; Fox et al, PNAS 2005



http://www.newscientist.com/data/images/archive/2681/26811501.jpg

Functional Brain Architecture

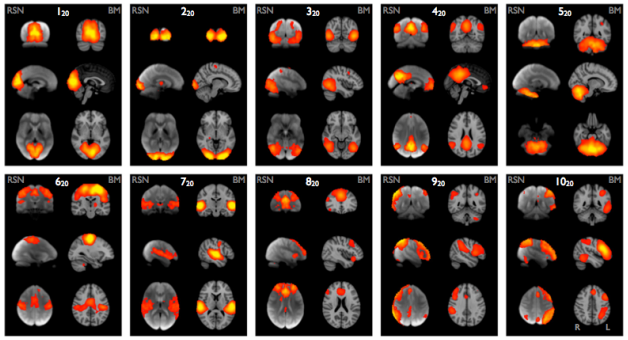
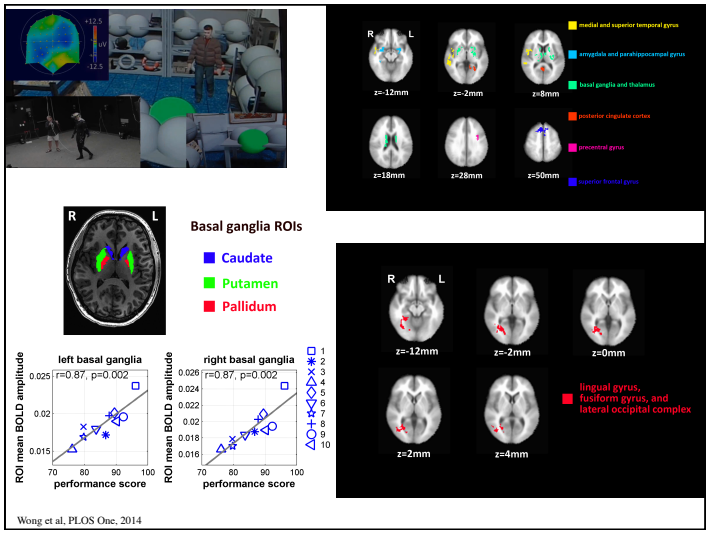
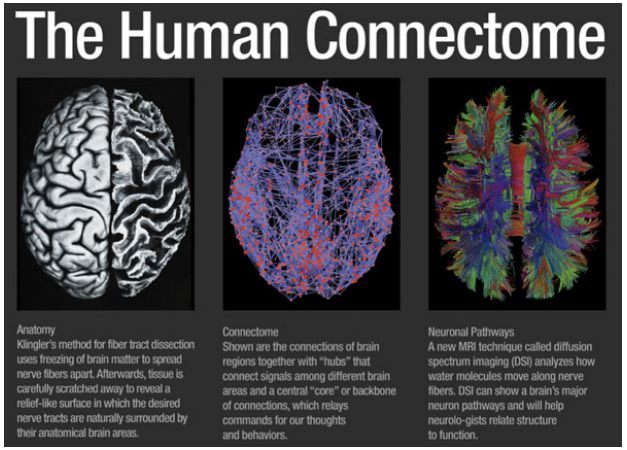


Fig. 1. Ten well-matched pairs of networks from the 20-component analysis of the 29,671-subject BrainMap activation database and (a completely separate analysis of) the 36-subject resting FMRI dataset. This figure shows the 3 most informative orthogonal slices for each pair. (Left column of each pair) Resting FMRI data, shown superimposed on the mean FMRI image from all subjects. (Right column of each pair) Corresponding network from BrainMap, shown superimposed on the MNI152 standard space template image. The networks were paired automatically by using spatial cross-correlation, with mean $r = 0.53$ (0.25:0.79); the weakest of these correlations thus has a significance of $P < 10^{-5}$ (corrected). All ICA spatial maps were converted to z statistic images via a normalized mixture-model fit, and then thresholded at $Z = 3$.

Smith et al, PNAS 2009

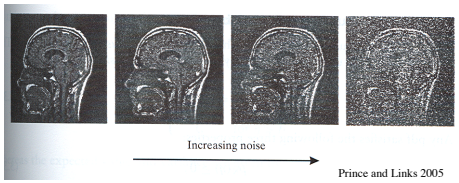


Wong et al, PLOS One, 2014



http://scimaps.org/maps/map/the_human_connectome_115/

Noise and SNR

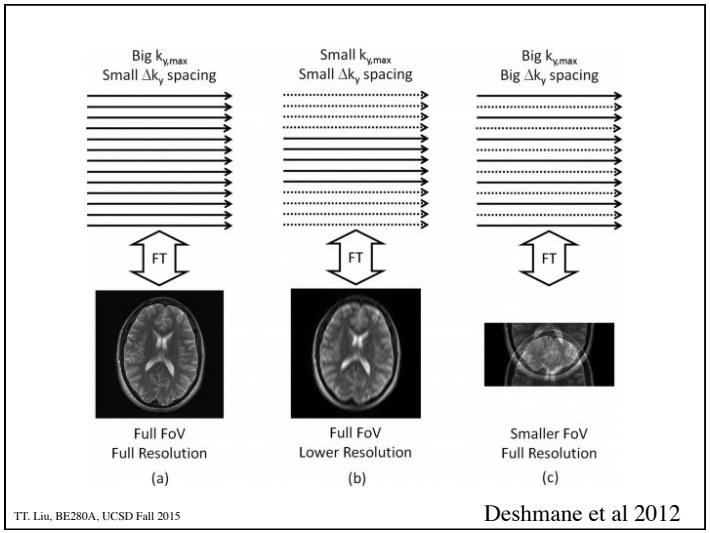


Prince and Links 2005

Figure 3.10
The effect of noise on image quality: image quality decreases rapidly with increasing noise contamination.

$$SNR \propto \frac{Signal}{\sigma_n} \propto \sqrt{Measurement\ Time} \cdot Voxel\ Volume \cdot f(\rho, T_1, T_2)$$

Consider going from 2 mm isotropic resolution to 1 mm isotropic resolution. Volume goes down by a factor of 8. To maintain the same SNR we would need to scan 64 times as long! (This assumes noise is dominated by thermal noise. In some cases (e.g. fMRI), physiological noise dominates for many typical protocols and the decrease in SNR is not necessarily as steep).



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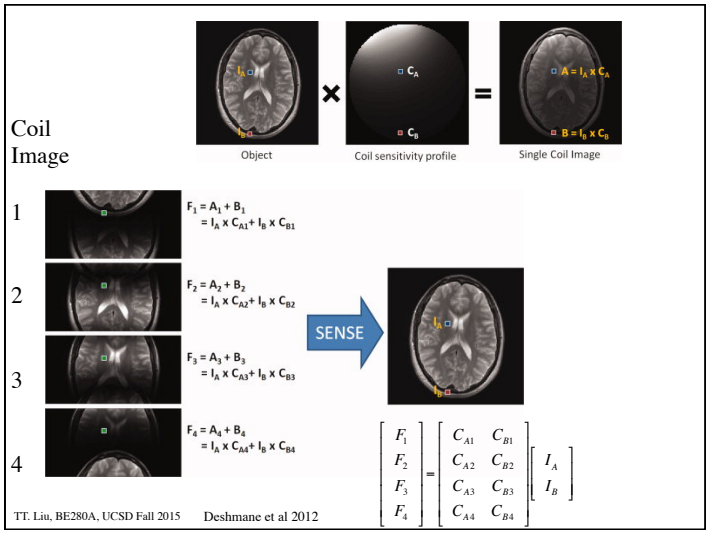
Deshmane et al 2012



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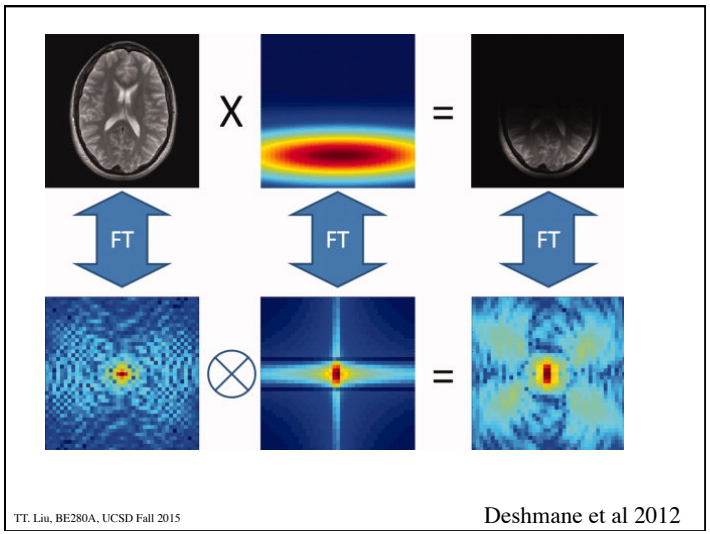
Deshmane et al 2012



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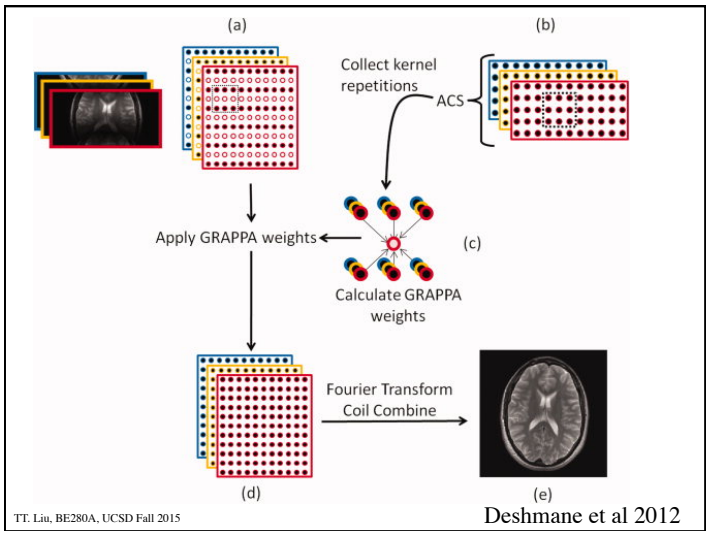
Deshmane et al 2012



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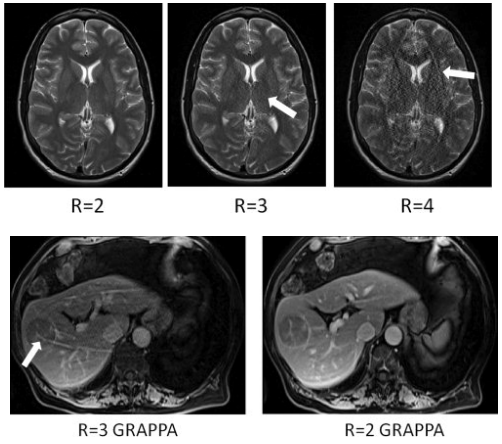
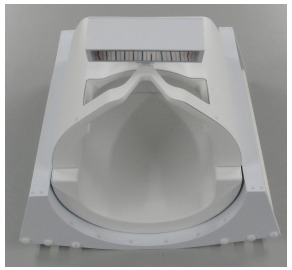
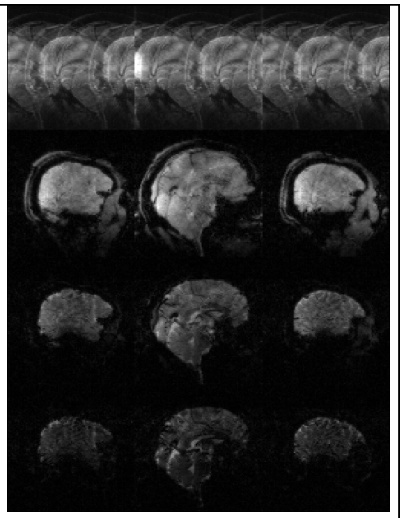
Deshmane et al 2012



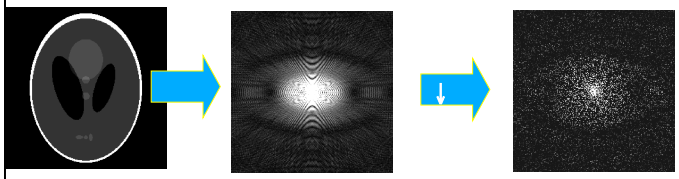
Deshmane et al 2012



Nova 32 channel

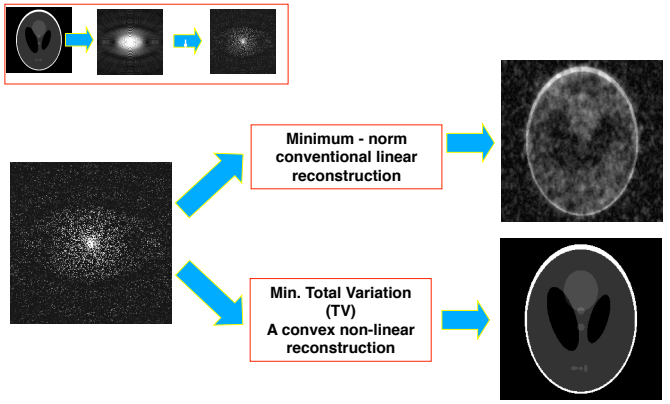


Compressed Sensing



Slide Credit: http://www.stanford.edu/~mlustig/

Compressed Sensing

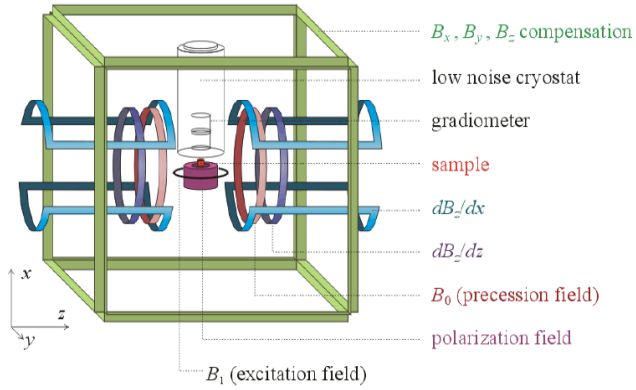


Slide Credit: http://www.stanford.edu/~mlustig/

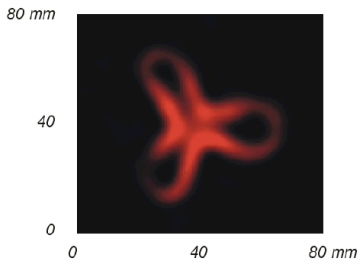
Timeline

Michael Crichton, 1999

"Most people", Gordon said, "don't realize that the ordinary hospital MRI works by changing the quantum state of atoms in your body ... But the ordinary MRI does this with a very powerful magnetic field - say 1.5 tesla, about twenty-five thousand times as strong as the earth's magnetic field. We don't need that. We use Superconducting QUantum Interference Devices, or SQUIDs, that are so sensitive they can measure resonance just from the earth's magnetic field. We don't have any magnets in there".

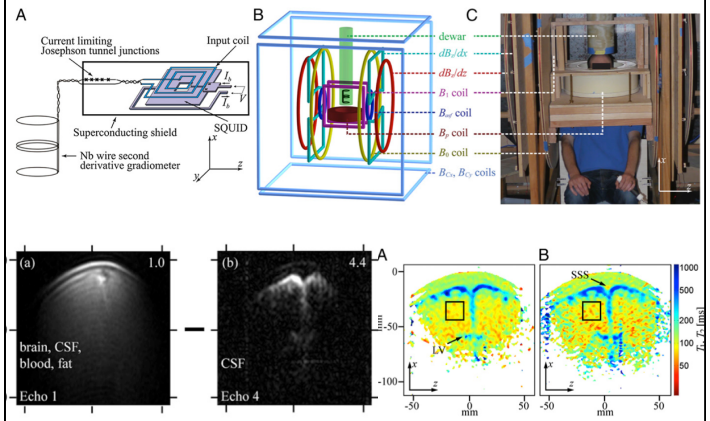


J. Clarke, UC Berkeley



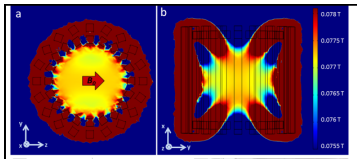
B0 = 132μT
G = 100μT/m
48 projections
1.5 min. acquisition

J. Clarke, UC Berkeley

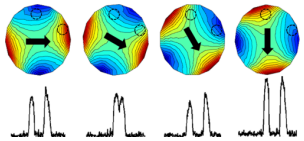


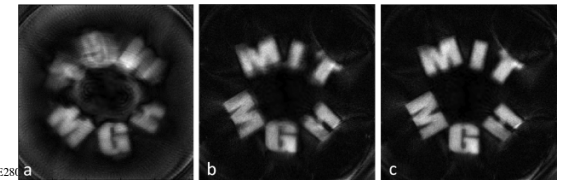
MRI of the human brain at 130 microtesla

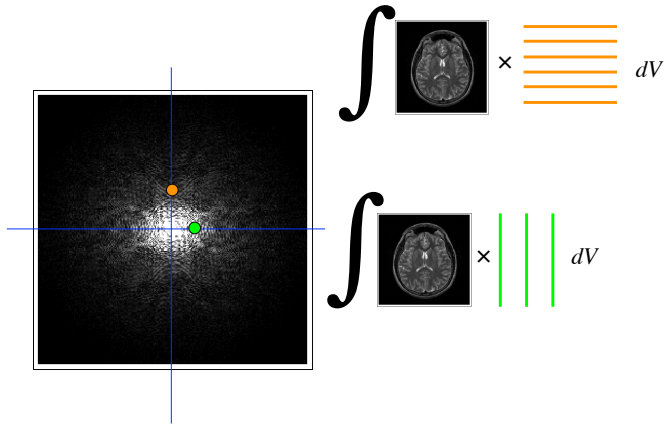
Ben Inglis[a], Kai Buckenmaier[b,c], Paul SanGiorgio[b,c,1], Anders F. Pedersen[b], Matthew A. Nichols[b,2], and John Clarke[b,c,3]

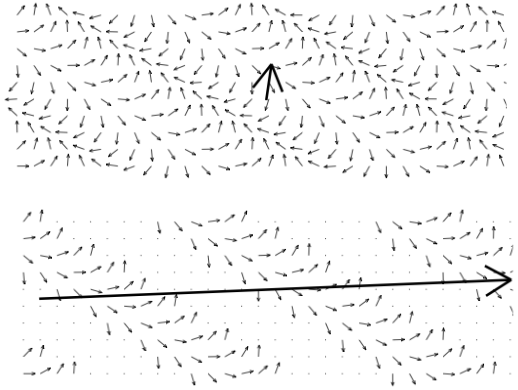


Two-dimensional imaging in a lightweight portable MRI scanner without gradient coils
Cooley et al, MRM 2014



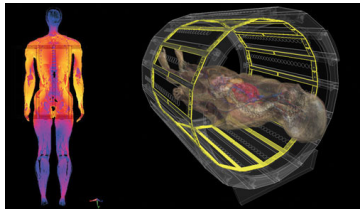




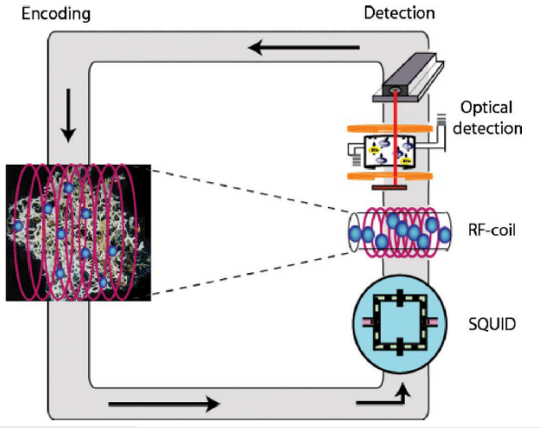


Hanson 2009

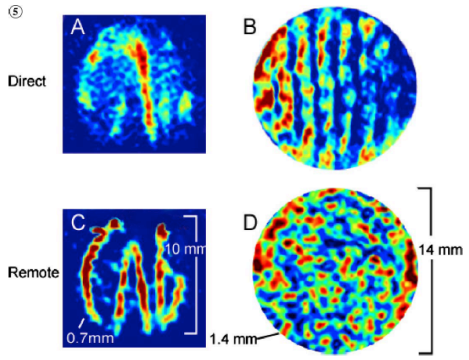
Integration of the signal



http://www.microwavejournal.com/legacy_assets/images/7842_Figure2.jpg
http://www.healthcare.philips.com/pwc_hc/main/shared/Assets/Images/MRI/coils/oa_coils_main_en.jpg

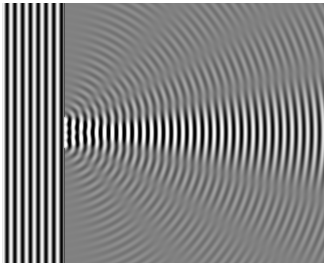


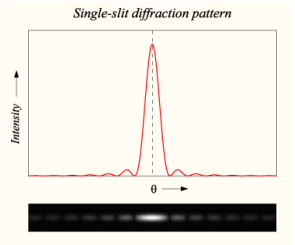
Seeley et al, JMR 2004



Seeley et al, JMR 2004

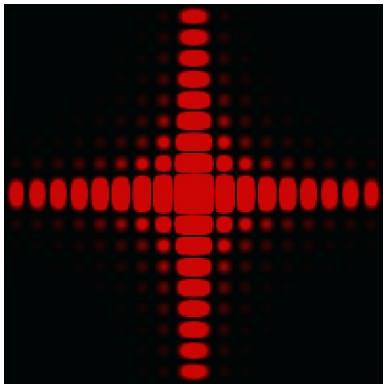
Ultrasound and Fourier Transforms





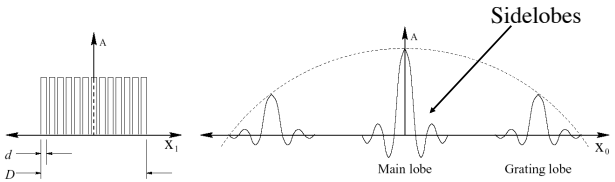
Sources:Mayo Clinic and wikipedia

Square Aperture Diffraction



Source:wikipedia

Example

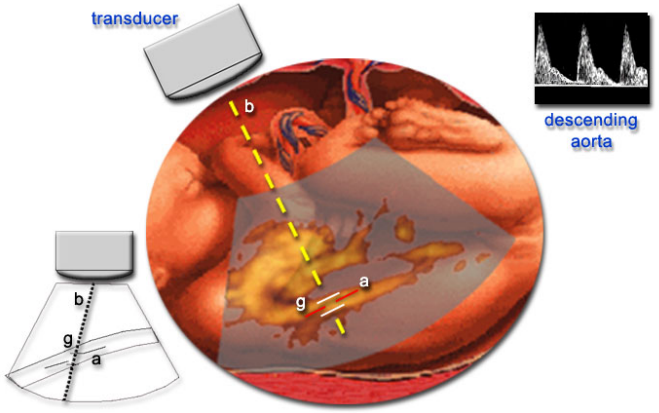


$$rect\left(\frac{x}{D}\right)\left[rect\left(\frac{x}{d}\right)*\frac{1}{d}comb\left(\frac{x}{d}\right)\right] \Leftrightarrow D\sin c(Dk_x)*\left[d\sin c(dk_x)comb(dk_x)\right]$$

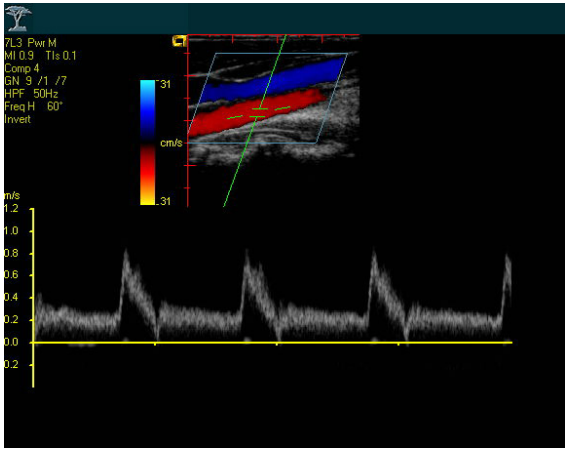
Question: What should we do to reduce the sidelobes?

Anderson and Trahey 2000

PW Doppler



http://www.centrus.com.br/DiplomaFMF/SeriesFMF/doppler/capitulos-htmlchapter_01.htm



Siemens Medical Systems; jnormal common carotid artery

Aliasing

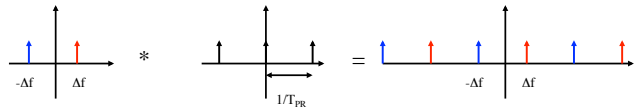
Measure Doppler shifts at a specified range

For unambiguous range, one pulse at a time.

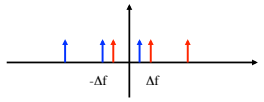
$T_{PR} = \frac{2r_{max}}{c}$ (e.g. 200 usec for 15 cm depth)

To avoid aliasing require

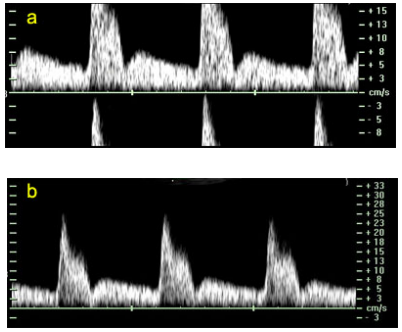
$\frac{1}{T_{PR}} > 2\Delta f_{max}$



Aliased

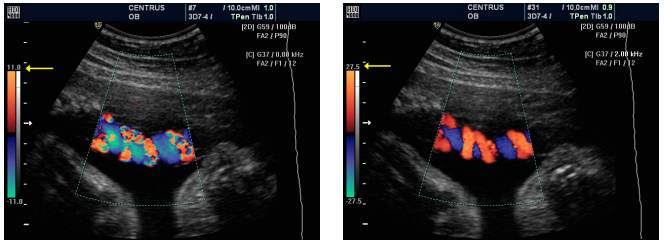


Aliasing



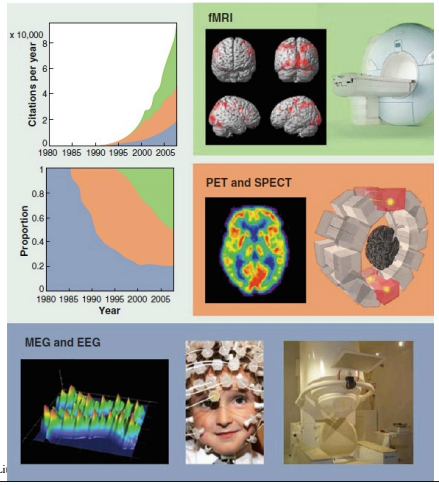
http://www.centrus.com.br/DiplomaFMF/SeriesFMF/doppler/capitulos-htmlchapter_01.htm

Aliasing



http://www.centrus.com.br/DiplomaFMF/SeriesFMF/doppler/capitulos-htmlchapter_01.htm

Functional NeuroImaging



NIRS

Friston, 2010, Science

Photoacoustic Imaging