EE 369C LECTURE 10

PARALLEL MRI

COMPUTING GRAPPA WEIGHTS

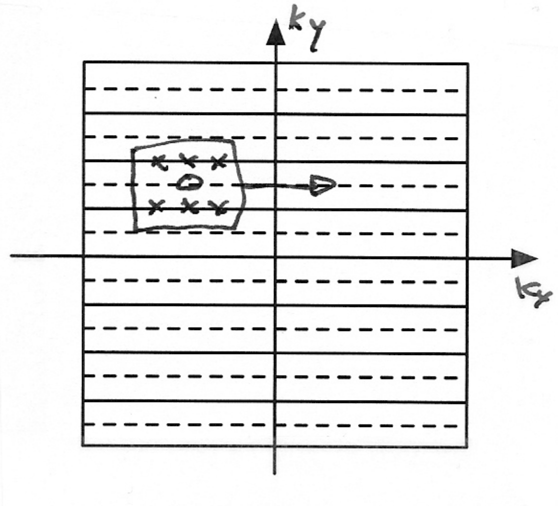
SPIRiT

COIL COMPRESSION

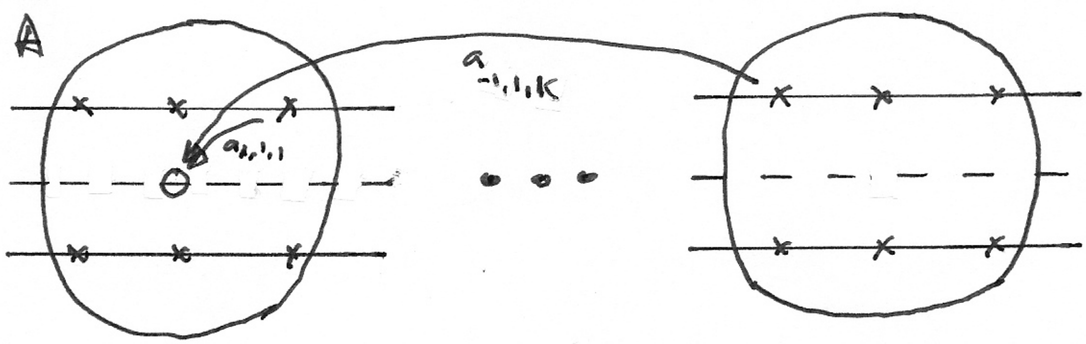
ASSIGNMENT

READ LUSTIG SPIRiT PAPER

GRAPPA



FILL IN MISSING K-SPACE DATA FROM NEIGHBORING SAMPLES



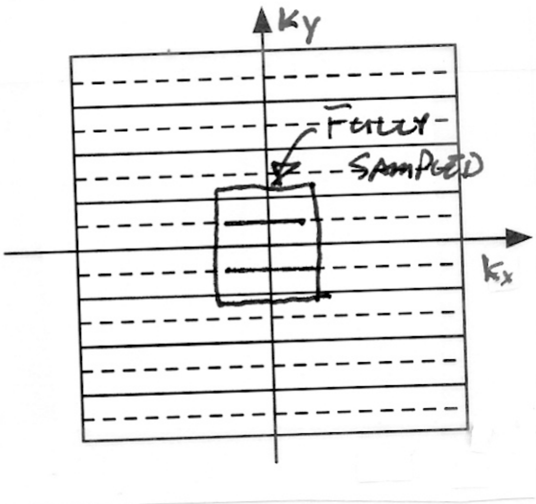
COIL 1 COIL K

MISSING DATA IS LINEAR COMBINATION OF ALL NEIGHBORHOOD POINTS, FROM ALL COILS

$$\hat{M}_k(k_x, k_y) = \sum_{i,j,k} a_{i,j,k} M_k(k_x + i\Delta k, k_y + j\Delta k)$$

HOW DO WE FIND $a_{i,j,k}$?

AUTOCALIBRATION

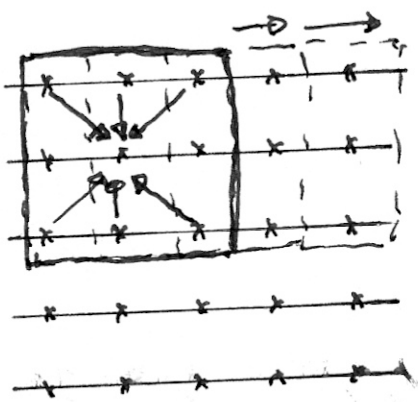


ASSUME THERE IS A REGION WHERE WE ARE FULLY SAMPLED

WE HAVE SAMPLES OF WHAT THE GRAPPA SYNTHESIS EQUATION SHOULD PRODUCE

INVERT THIS TO SOLVE FOR GRAPPA WEIGHTS

CALIBRATION AREA HAS TO BE LARGER THAN THE GRAPPA KERNEL



EACH SHIFT OF KERNEL GIVES ANOTHER EQUATION

HERE 3x3 KERNEL, 5x5 CALIBRATION AREA GIVES 3x3=9 EQUATIONS

WRITE AS A MATRIX EQUATION

$$\underbrace{\underline{M}_{K,C}}_{\text{CALIBRATION DATA}} = \underbrace{M_A}_{\text{NEIGHBORHOOD SAMPLES ALL COILS}} \overbrace{\underline{g}_K}^{\text{GRAPPA COEFFICIENTS}}$$

GRAPPA WEIGHTS ARE

$$\underline{a}_k = \left(M_A^* M_A + \lambda I\right)^{-1} M_A^* \underline{m}_{k,c}$$

WHERE λ IS AN OPTIONAL REGULARIZATION PARAMETER.

REPEAT FOR <u>EACH</u> <u>COIL</u>.

<u>GRAPPA ALGORITHM</u>

COMPUTE GRAPPA WEIGHTS FROM CALIBRATION REGION

COMPUTE MISSING K-SPACE DATA USING THE GRAPPA WEIGHTS

RECONSTRUCT INDIVIDUAL COIL IMAGES

COMBINE COIL IMAGES

<u>GRAPPA ISSUES</u>

CALIBRATION REGION SIZE

GRAPPA KERNEL SIZE

SAMPLE GEOMETRY DEPENDENCE

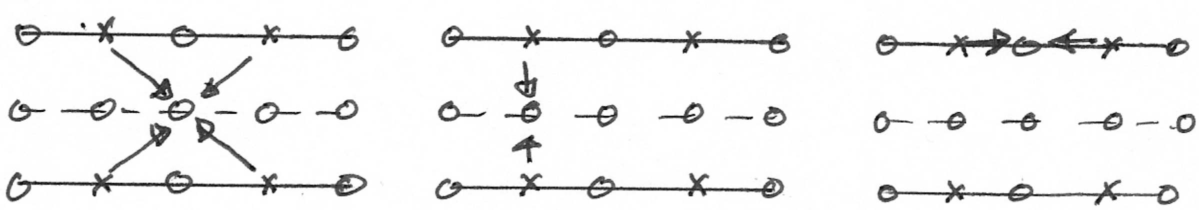
SAMPLE GEOMETRY DEPENDENCE

GRAPPA WEIGHTS DEPEND ON WHICH SAMPLES ARE ACQUIRED, AND WHICH ARE ESTIMATED

SIMPLE FOR SKIPPED LINES

SAME WEIGHTS WORK EVERYWHERE

HARDER FOR 2x2 ACCELERATION



EACH GEOMETRY HAS ITS OWN SET OF WEIGHTS

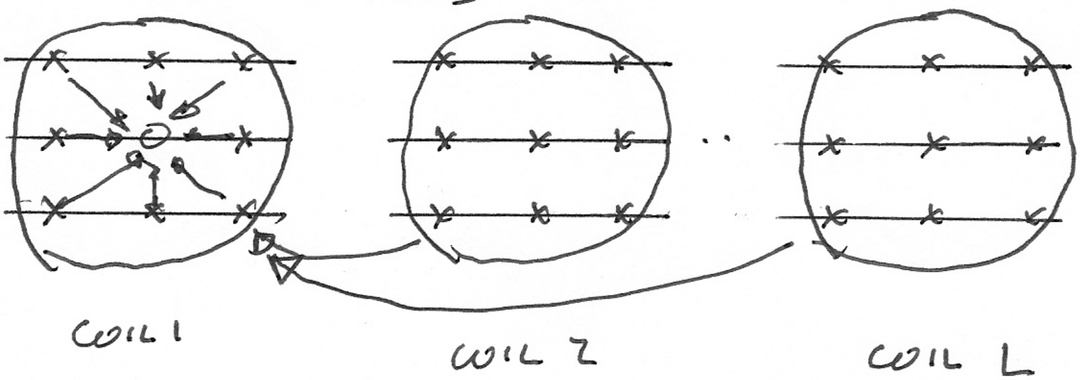
RAPIDLY GETS CONFUSING

FOR IRREGULAR SAMPLING (NON-CARTESIAN, RANDOM)

BECOMES UNMANAGEABLE!

ALTERNATIVE PERSPECTIVE

ASSUME I KNOW THE FINAL RECONSTRUCTION AND I TRY TO ESTIMATE A SAMPLE FROM ITS NEIGHBORS



I SHOULD GET MY ORIGINAL RECONSTRUCTION

THE FULL GRAPPA OPERATOR SHOULD DO NOTHING IF I APPLY IT TO THE CORRECT RECONSTRUCTION!

THE FINAL RECONSTRUCTION SHOULD BE <u>CONSISTENT</u> WITH THE FULL GRAPPA OPERATOR.

SPIRIT BASIC IDEA

1) CALIBRATE ON ENTIRE NEIGHBORHOOD, KNOWN OR UNKNOWN
2) FILL IN KNOWN DATA, ZERO OTHERWISE
3) APPLY KERNEL TO ESTIMATE ALL DATA
4) RESTORE KNOWN DATA
5) ITERATE 3+4 UNTIL DATA STOPS CHANGING

THIS IS A "PROJECTION ONTO CONVEX SETS"

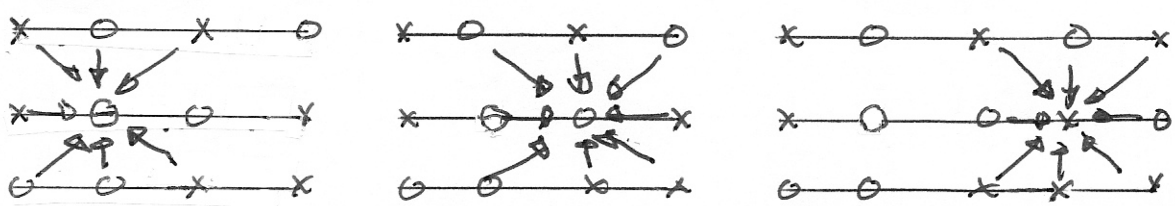
OR POCS TYPE ALGORITHM

ALTERNATELY ENFORCES TWO CONSTRAINTS

CONSISTENCY WITH ACQUIRED DATA

CONSISTENCY WITH KERNEL

SAME WEIGHTS FOR ANY GEOMETRY



ZERO VALUES SLOWLY FILL IN

ADVANTAGES

ONLY ONE SET OF WEIGHTS

WORKS FOR ANY SAMPLE GEOMETRY

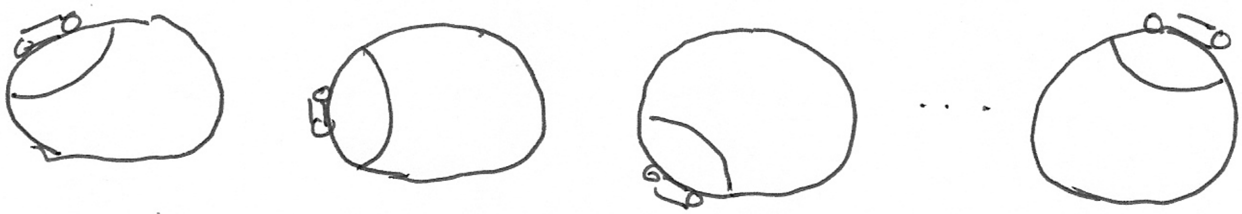
EFFECTIVELY A LARGER KERNEL

DISADVANTAGE

ITERATIVE RECON

EIGEN COILS AND COIL COMPRESSION

ARRAY COIL SENSITIVITIES



COIL 1   COIL 2   COIL 3   ...   COIL L

EACH COIL SEES A LOCAL REGION

NOT CLEAR HOW MUCH ACCELERATION IS POSSIBLE

g-FACTOR HITS A WALL AT 3-4 IN 1D, WHY?

WHAT IS THE FUNDAMENTAL DIMENSIONALITY OF RF ENCODING

EIGEN COILS

MAKE A MATRIX OF VECTORIZED SENSITIVITY MAPS

$$C = \begin{pmatrix} \vdots & \vdots & & \vdots \\ c_1(\underline{x}) & c_2(\underline{x}) & \cdots & c_L(\underline{x}) \\ \vdots & \vdots & & \vdots \end{pmatrix}$$

THE MATRIX C^*C SHOWS THE CORRELATION BETWEEN CHANNELS

COMPUTE THE EIGEN DECOMPOSITION OF C^*C

$$C^*C = B D B^*$$

WHERE B IS A UNITARY MATRIX OF EIGENVECTORS AND

$$D = \begin{pmatrix} \lambda_1 & & 0 \\ & \ddots & \\ 0 & & \lambda_L \end{pmatrix}$$

IS A DIAGONAL MATRIX OF EIGENVALUES

THEN

$$B^* C^* \underbrace{C B}_{C'} = D$$

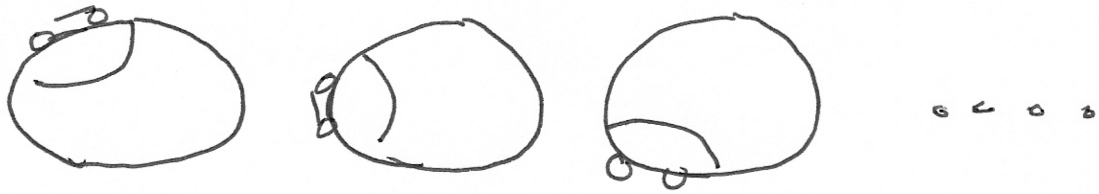
LET

$$\underbrace{C'}_{\text{EIGEN COILS}} = \underbrace{C}_{\text{COILS}} \underbrace{B}_{\text{UNITARY ROTATION}}$$

THE λ_i TELL YOU HOW MUCH ENERGY IS IN EACH EIGEN COIL CHANNEL

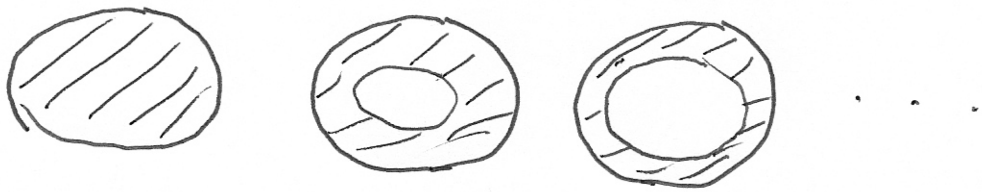
THESE DROP OFF RAPIDLY. THIS TELLS YOU HOW MANY INDEPENDENT CHANNELS YOU HAVE WHERE THAT ADDITIONAL INFORMATION IS

ORIGINAL CHANNELS



COIL 1 COIL 2 COIL 3

EIGEN CHANNELS

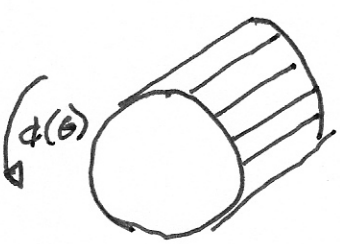


UNIFORM 1ST MODE 2ND MODE

CHANNELS GET:

- CLOSER TO EDGE
- LOWER MAXIMUM
- INCREASING NUMBER OF CYCLES OF PHASE

LOOKS LIKE THE MODES OF A BIRDCAGE RF COIL



UNIFORM - DRIVE IN PHASE
1ST MODE - ONE CYCLE OF PHASE
2ND MODE - TWO CYCLES OF PHASE
⋮

YOU CAN DO PARALLEL IMAGING THIS WAY!

EIGEN COILS SHOW YOU SOMETHING FUNDAMENTAL ABOUT THE ELECTROMAGNETICS

COIL COMPRESSION

USE THE EIGENCOIL BASIS TO REDUCE THE SIZE OF YOUR PARALLEL IMAGING RECON

IF M IS A MATRIX OF THE VECTORIZED ALIASED DATA, COMPUTE

$$m' = mB$$

THIS IS THE DATA ROTATED INTO THE EIGEN COIL SPACE.

ONLY KEEP THE COLUMNS OF m' THAT HAVE SIGNIFICANT EIGEN COILS

RECONSTRUCT USING EIGENCOILS C'.