WARPS

$$I(\underline{x} + \underbrace{\underline{w}(\underline{x})}_{\text{displacement}}) \approx \underbrace{B(\underline{x})}_{\text{base image}}$$

How to think about warp?

- For each location in base image ($\underline{x}$), reach out to $\underline{x} + \underline{w}(\underline{x})$ to grab $I()$ and bring that value back
- It's <u>not</u> that $\underline{x}+\underline{w}(\underline{x})$ says where to put $I(\underline{x})$, it's that it says where to get the value that belongs at $\underline{x}$
- This is what 3dQwarp computes & what 3dNwarpApply does with a warp

Programs

- 3dQwarp
- 3dNwarpApply
  - can auto-catenate warps & matrices
- 3dNwarpCat – catenation
- 3dNwarpCalc – more complex calculations
- 3dNwarpFuncs – functions of a warp, like volume distortion at each voxel

UNWARPING

① Via Field Map

EPI distorted in phase encoding "y" direction

$$I(\underbrace{x, y + c\lambda(x,y)}_{\text{warping}}) = \underbrace{\frac{1}{1 + c\frac{\partial\lambda(x,y)}{\partial y}}}_{\text{scale}} \underbrace{M_\perp(x,y)}_{\text{true image}}$$

$\lambda(x,y)$ = frequency shift (say in Hz)

c = constant

$= \tau \cdot FOV_y$

? → τ = time between k_y lines (eg., ≈ 300 μsec)

0018, 1310, 1312 → FOV_y = Field of view in y-direction (e.g. ≈ 240 mm)

so $c \approx 3 \cdot 10^{-4}s \cdot 2.4 \cdot 10^2 mm = 0.072$ mm/Hz

Measured field map

ⓐ Is it undistorted (measured by GRE) or distorted itself (measure by EPI) } determines if we have $\lambda(x,y)$ or a distorted $\lambda(x,y)$)

ⓑ contains a lot of noise <u>and</u> is unreliable near edges of brain - where most distortion is

ⓒ <u>so</u> needs to be smoothed and extended outside brain where it was measured

→ How to do (c) properly is the issue!

Given c and (c), 3dNwarpApply can transform a dataset.

UNWARPING

② Blip ~ up/down (or left/right)

EPI pairs with scan 1 way $(c > 0)$
and the other way $(c < 0)$

$$I_p(x, y + c\lambda(x,y)) \approx M(x,y)$$
$$I_m(x, y - c\lambda(x,y)) \approx M(x,y)$$

} unknown "true" image

So use 3dQwarp with the "-plusminus" option to match find

$$I_p(\underline{x} + \underline{w}(\underline{x})) \approx I_m(\underline{x} - \underline{w}(\underline{x}))$$

instead of the usual

$$I(\underline{x} + \underline{w}(\underline{x})) \approx B(\underline{x})$$

Then can use the "meet in the middle" warp $\underline{w}(\underline{x})$ to warp all blip up EPIs to the middle (and $-w(x)$ to warp all blip dow EPIs)

Properly done, blip up/down should scan both k_x & k_y backwards, and excite with opposite k_z gradients. Then all 3D distortions are reversed & 3dQwarp is reasonable

Advantages over fieldmap:

- no need to find (or fit) c or $\langle c \rangle$ [or even phase encode dir
- 3D adjustment