False Sense of EPI-to-Structural Alignment with Common Cross-Modality Registration Methods

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The Problem

- Aligning EPI volumes to T$_1$-weighted volumes using Mutual Information (MI) or Correlation Ratio (CR) as the cost functional can produce registrations that ***look good but are actually bad***
- Brain outlines from the two volumes might match well, but this ***can be very misleading***:
  - Interior structures (ventricles, fissures, sulci) that are visible in both types of images often are displaced 5 mm — or more
- This is ***not a software issue***: **AFNI** (3dAllineate), **SPM** (COREG), and **FSL** (FLIRT) all often fail to give good anatomical matchings, upon close visual inspection
- **Sample Images**:
  - T$_1$-weighted volumes as the grayscale background, each one registered to the EPI volume with a distinct method
  - EPI volume is edge-detected and only its edges are shown in the color overlay
  - Two implementations of MI (**AFNI/3dAllineate** & **SPM/COREG**)
  - Two implementations of CR (**AFNI/3dAllineate** & **FSL/FLIRT**)
  - Our new **LPC** cost functional (**AFNI/align_epi_anat.py**)

• EPI interior edges track structural edges only with LPC

Local Pearson Correlation Cost Functional (LPC)

• Weighted correlation $r(\mathbf{x})$ calculated over neighborhood $N(\mathbf{x})$ of any point $\mathbf{x}$; then $r(\mathbf{x})$'s are nonlinearly combined to give final cost:

$$W(\mathbf{x}) = \sum_{\mathbf{y}\in N(\mathbf{x})} w(\mathbf{y}) \quad \text{[local sum of weights]}$$

$$M(\mathbf{x};F) = \frac{1}{W(\mathbf{x})} \sum_{\mathbf{y}\in N(\mathbf{x})} w(\mathbf{y})\cdot F(\mathbf{y}) \quad \text{[local weighted mean of volume } F\text{]}$$

$$Q(\mathbf{x};F,G) = \sum_{\mathbf{y}\in N(\mathbf{x})} w(\mathbf{y})\cdot[F(\mathbf{y})-M(\mathbf{x};F)]\cdot[G(\mathbf{y})-M(\mathbf{x};G)] \quad \text{[local scalar product of } F \text{ \& } G\text{]}$$

$$r(\mathbf{x}) = \frac{Q(\mathbf{x};E,S)}{[Q(\mathbf{x};E,E)\cdot Q(\mathbf{x};S,S)]^{1/2}} \quad \text{[local weighted correlation coefficient]}$$

$$C_{\text{LPC}}[E,S] = \sum_{\mathbf{x}\in P} W(\mathbf{x})\cdot s(r(\mathbf{x}))\cdot|s(r(\mathbf{x}))| \Big/ \sum_{\mathbf{x}\in P} W(\mathbf{x}) \quad \text{[combined correlation coefficients]}$$

• where: $E(\mathbf{x})$=EPI; $S(\mathbf{x})$=T$_1$; $s(r)=\tanh^{-1}(r)$; $N(\mathbf{x})$=Kepler's rhombic dodecahdron centered at $\mathbf{x}$; P=FCC space-filling lattice of rhombic dodecahdra covering the brain volume; and $W(\mathbf{x})$=weight proportional to $E(\mathbf{x})$ to accentuate matching of CSF (bright in EPI, dark in T$_1$); the algorithm looks for the *most negative correlation* by minimizing $C_{\text{LPC}}[E(\mathbf{x}),S(\mathbf{T}(\mathbf{x},\theta))]$ over affine transformations $\mathbf{T}(\bullet)$

• CSF (usually) tracks ventricles, fissures, sulci fairly well in EPI; LPC produces a robust match between those central *and* cortical anatomical structures visible in both EPI and structural volumes

• Computing correlations locally and then combining protects against shading artifacts and signal dropouts

Conclusions

- **Accurate and truly "robust" alignment of structural and EPI volumes requires a modality-specific cost functional**
- **And requires visual inspection of results, especially if you are relying on the function-to-structure correspondence:**
  - **projection to cortical surface models; surgical planning**

Assessment Methodology

- Three raters (blinded to method and presentation order) each scored each of 27 {EPI,T$_1$} volume pairs for alignment on a 4 point scale (from awful to excellent), for 8 different registration methods/tools:
  - **1**=awful **2**=errors > 5 mm **3**=errors 2..5 mm **4**=errors 0..2 mm
  - while viewing edge-enhanced images, in all three planes, overlaid in color and/or flickering between viewing *E* and *S*
  - Sample datasets at 1.5 and 3.0 Tesla, from diverse sites
  - Raters agreed remarkably well (Spearman correlations≈0.8)
  - Contigency table statistics confirms the obvious: **LPC wins**