Today

- Combining Results
  - Across conditions, across Subjects
- Spatial Modeling & Inference
  - Multiple comparisons problem
- SPM introduction

Combining Results

- Often have results we want to combine
  - Same subject, different contrasts
  - Same subject, different acquisition
  - Same subject, different days
  - Different subjects
- How to integrate these results?
- Two fundamentally different approaches
  - Fixed Effects
  - Mixed/Random Effects
    - "Random Effects" has become standard, though strictly it is a Mixed Effects model

Combining Results: Fixed Effects

- Fixed effects test an intersection of null hypotheses
  - $\mathcal{H}_0$: The effect zero in *all* sessions
  - $\mathcal{H}_0$: The effect zero in *all* subjects
- Fixed effects hypotheses are easily tested
  - Chuck all the data into SPM
  - Test the grand hypothesis
    - Example: 4 subjects, each with 2 conditions

The contrast of interest is then

Combining Results: Fixed Effects

- "Grand" model approach not perfect
  - Can be huge, slow analysis
    - Thousands of scans!
    - Tons of disk space
  - Assumes homogeneous variance across subjects
- But can be very sensitive

Combining Results: Fixed Effects Shortcomings

- Doesn't account for intersubject variability in response
  - Significance can be due to a single subject
- Susceptible to hypothesis testing facility
  - Given enough data, you'll *always* reject the null!
  - Do you ever really believe "$\mathcal{H}_0$: Effect is $0.000000000000\bar{0}$" ?

Combining Results: Conjunction of Contrasts

- Tries to address weakness of fixed effects approach
- Standard fixed effects approach can be driven by one "best" subject/contrast/effect
- SPM's Conjunction
  - Take the *minimum* of multiple statistics
  - Then only can see effect if *all* large
- Example
  - 4 subjects, each with 2 conditions
  - Create 4 contrasts, one for each subject
  - "Conjunction" of the four is just minimum of four statistic images

X:Conj

Combining Results: Conjunction of Contrasts

- SPM Conjunction
  - ⇀ Random field theory requires individual contrasts to be orthogonal
  - ⇀ Two contrasts orthogonal if *inner product* is zero
  - ⇀ These are orthogonal: [-1 1 0 0] & [0 0 -1 1]
  - ⇀ These are not: [0 -1 1 0] & [0 0 -1 1]

X:Conj

Combining Results: Contrast Masking

- Can combine contrast/statistic images with masks
- Example... Two factor study
  - ⇀ Faces vs Places (A1 vs A2)
  - ⇀ Familiar vs Unfamiliar (B1 vs B2)
  - ⇀ In SPM

    [A1 A2 B1 B3]

X:Msk

Combining Results: Contrast Masking

- To view familiarity effect *but only* where there was a Faces effect...
  - ⇀ Select “Familiar-Unfamiliar” in contrast manager
  - ⇀ “Yes” to “mask with other contrast”
    - – Specify “Faces-Places” contrast
  - ⇀ Set “uncorrected mask p-value”
    - – e.g. 0.001
  - ⇀ Select “inclusive” mask
    - – Want to see voxels where Faces-Places $>$ threshold
  - ⇀ *et voila*
- Subsequent inferences don’t account for masking
  - ⇀ But masking only could increase significance

X:Msk

Combining Results: Random Effects

- What is a “random effect”?
  - ⇀ Well, have one already

    $$Y = X\beta + \epsilon$$

- Random effect models treat *response magnitude* as random
  - ⇀ So far $X\beta$, i.e. $c\beta$ has been *fixed*!
  - ⇀ Only randomness is residual or measurement error

Combining Results: Visualizing Random Effects

Fixed Effect	Random Effects

Combining Results: Understanding Random Effects

- With fixed effects
  - ⇀ Combining over subjects, only question is

    “Is average response large relative to scan-to-scan variability”
- With random effects
  - ⇀ Combining over subjects, question is

    “Is average response large relative to scan-to-scan *and* subject-to-subject variability”

Combining Results: Understanding Random Effects

- Fixed Effects Model & Null Hypothesis
  - ⇀ $Y(t) = \mu + \alpha f(t) + \epsilon(t)$
  - ⇀ Fixed, known: $f(t)$
  - ⇀ Fixed, unknown: μ, α
  - ⇀ Random: $\epsilon(t)$
  - ⇀ Dist^n assumption: $\epsilon(t) \sim \mathcal{N}(0, \sigma^2)$
  - ⇀ $\mathcal{H}_0$: $\mu = 0$

    Mean of each subject's response is zero

Combining Results: Understanding Random Effects

- Random Effects Model & Null Hypothesis
  - ⇀ $Y_i(t) = \mu_i + \alpha_i f(t) + \epsilon_i(t)$
  - ⇀ Fixed, known: $f(t)$
  - ⇀ Fixed, unknown: μ_i
  - ⇀ Random: $\alpha_i, \epsilon_i(t)$
  - ⇀ Dist^n assumption: $\epsilon_i(t) \sim \mathcal{N}(0, \sigma^2)$

    $\alpha_i \sim \mathcal{N}(\theta, \tau^2)$

    $\epsilon_i(t), \alpha_i$ independent
  - ⇀ $\mathcal{H}_0$: $\theta = 0$

    Mean of the *population* of the subject's response is zero

Combining Results: Random Effects in SPM

- SPM only fits fixed effects models
  - ⇀ In general, random effects models can't be fit with least squares
  - ⇀ Generally requires iterative fitting
- One special *very useful* case
  - ⇀ Assume each subject has same experimental design
    - – Same number of scans, same design matrix
  - ⇀ Assume each subject's residual error (σ^2) is the same
  - ⇀ Fit each subject, create a contrast for each
  - ⇀ Compute a one sample t test on contrast images
- This approach implements random effects inference!

Combining Results: Random Effects in SPM — Details

- Fit "first level" models
  - ⇀ Analyze each subject, one by one
  - ⇀ Hint: Use very systematic naming structure, like

    `ProjNm/ANALYSES/SubXXXX/ModelNm`

    Where `ModelNm` should be informative, like `NoDerivRTcov`

    if you wanted to indicate that this model had no temporal derivative but included a response time covariate

Combining Results: Random Effects in SPM — Details

- Create contrasts
  - ⇀ For each subject, create contrasts
  - ⇀ Hint: Figure out contrasts of interest ahead of time; enter all contrasts at once and use exact same contrast order for all subjects
- Analyze contrast images
  - ⇀ Analysis consists of one (contrast) image per subject
  - ⇀ with 1-, 2-sample t-test, or correlation
  - ⇀ Hint: A natural naming convention is

    `ProjNm/ANALYSES/RFX/ModelNm`

    Where `ModelNm` should reflect the contrast tested and perhaps suffixed with the number of subjects used, e.g. `ItemRecog_12`

Combining Results: Random Effects in SPM

- What if not all subjects have same design matrix
  - ⇀ An issue of a balanced design
    - – If not too unbalanced, probably OK
  - ⇀ If way unbalanced, probably way dodgy

Combining Results: Random Effects in SPM

- Example
  - Places vs Faces
  - After study, subjects asked to score familiarity of images
  - Result used to define dichotomous Familiar/Nonfamiliar factor
  - Interest is in Places-Faces only for Familiar stimuli
  - Problem!
    - If some subjects find only 10% familiar, and other find 90% there will be horrible imbalance in the design matrix
    - Put another way, some subjects will be able to offer 90% of their data to the contrast, others only 10%

X:UnblRFX

Combining Results: Conclusion

- Fixed effects inference
  - Evidence of effect seen in cohort
- Fixed effects inference
  - Evidence of effect in population (sampled)