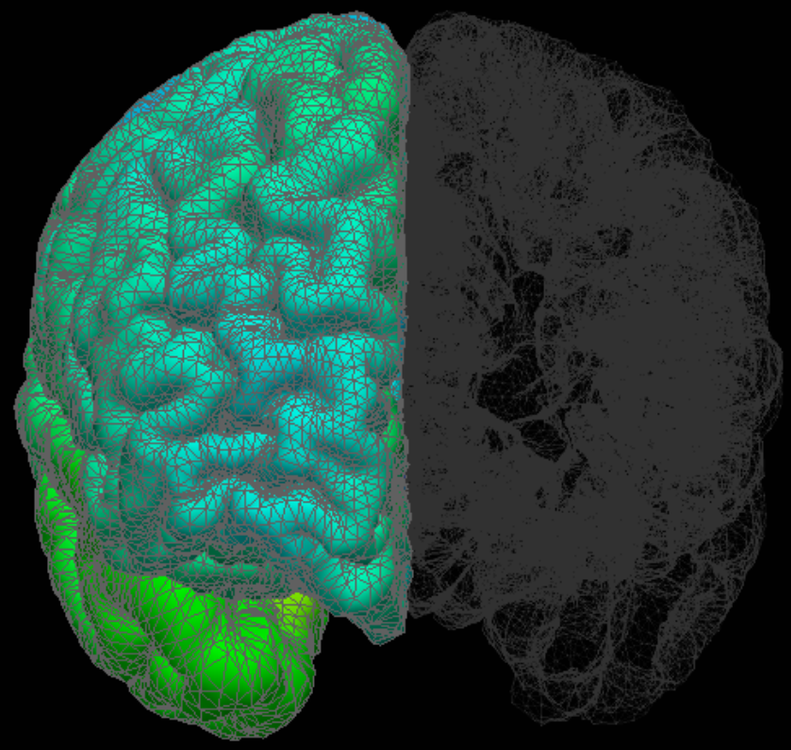


SURFACE- AND VOLUME-BASED STATISTICAL ANALYSIS WITH SURFSTAT

Boris Bernhardt, PhD

MULTIMODAL IMAGING AND CONNECTOME ANALYSIS LAB

mica-mni.github.io

SESSION OUTLINE

PART 1 (20-30 MINS)

SOME CONCEPTS

&

WALKTHROUGH

PART 2 (20 MINS)

HANDS-ON IN MATLAB

WHAT CAN YOU DO WITH SURFSTAT

READING AND DISPLAYING SURFACE AND VOLUMETRIC DATA

UNIVARIATE AND MULTIVARIATE STATISTICAL ANALYSIS

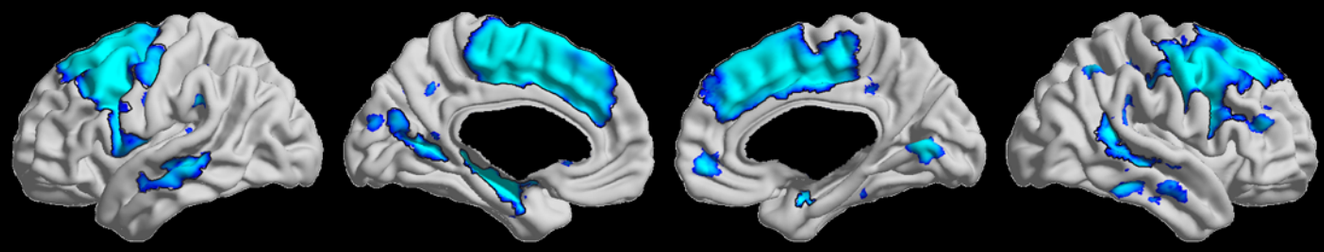
GLMs AND LMEs IN A UNIFIED FRAMEWORK

MODEL-FORMULA PARADIGM - NO DESIGN MATRICES NEEDED

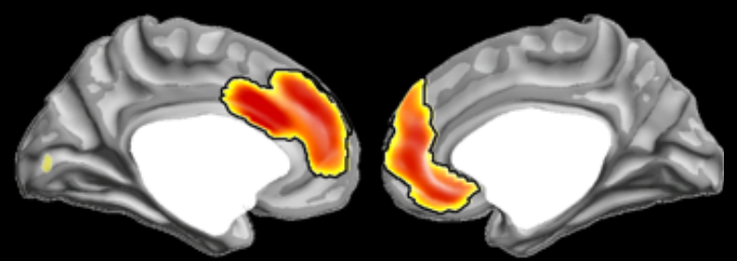
MULTIPLE COMPARISONS PROCEDURES: BONFERRONI, FDR, RFT

POWERFUL VISUALIZATIONS

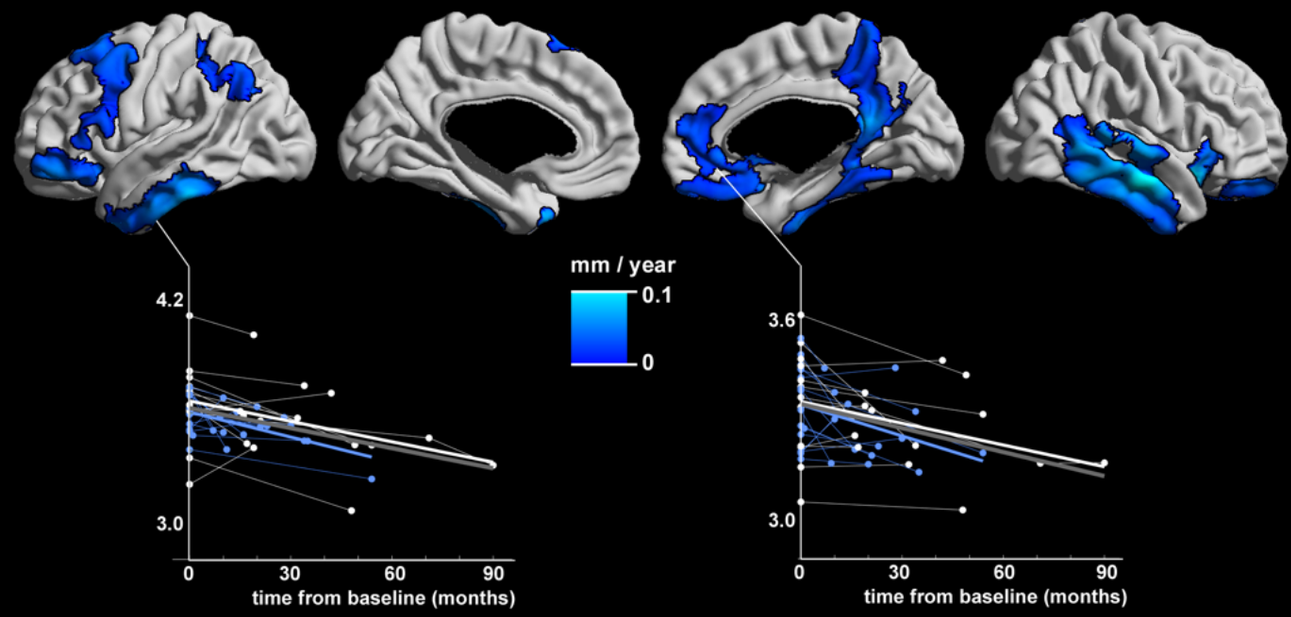
GROUP COMPARISONS



CORRELATIONS



LONGITUDINAL ANALYSES



GENERAL WORKFLOW OF ANALYSIS

LAUNCH MATLAB

LOAD TOOLBOX

READ ANALYSIS SPREADSHEET (EXCEL)

READ SURFACE FEATURES AND TEMPLATE MESH

PERFORM STATISTICAL ANALYSIS

MODEL FITTING

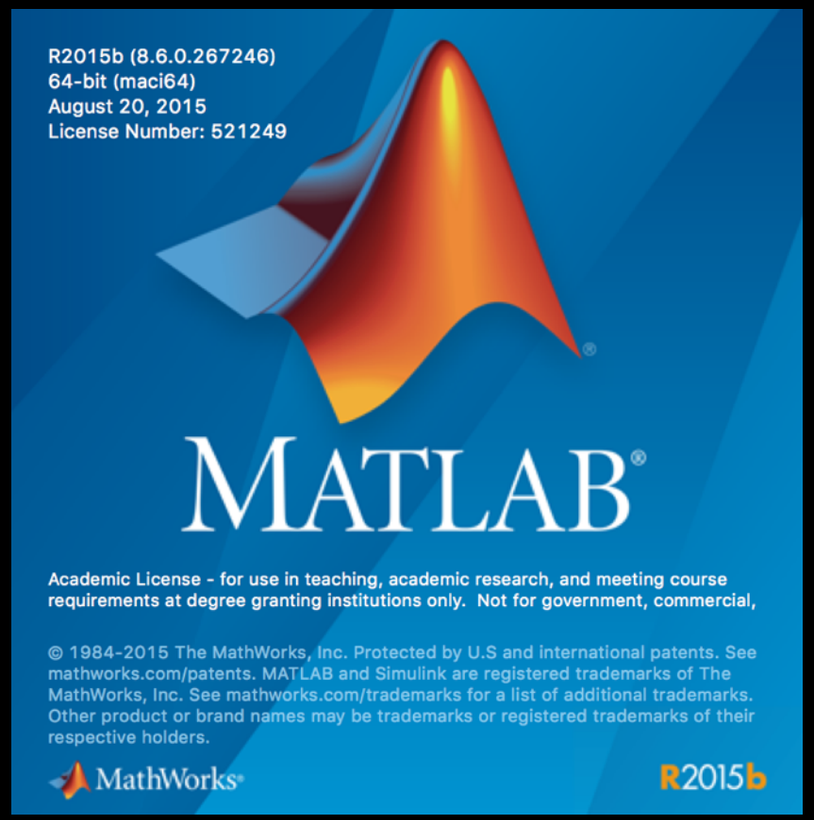
CONTRAST ESTIMATION

MULTIPLE COMPARISONS CORRECTION

DISPLAY RESULTS

TO GET STARTED

LAUNCH MATLAB



SET PATH AND LOAD TOOLBOX

your path

```
%% 0. define directory and add toolbox
P='/data/noel/noel10/workshop/users/boris/Day2_1400_Bernhardt_MRIStats/surfstat_tutorial/';
addpath([P 'surfstat'])
```

LOAD SURFACES (GITHUB)

```
%% 1. Load the surface data
SP = SurfStatAvSurf({[P 'fsaverage5/lh.pial'],[P 'fsaverage5/rh.pial']})
SW = SurfStatAvSurf({[P 'fsaverage5/lh.white'],[P 'fsaverage5/rh.white']})

% generate a mid thickness surface
SM.coord = (SP.coord + SW.coord)./2;
SM.tri   = SP.tri;
```

```
boris@bicvm10:/data/noel/noel10/workshop/users/boris/Day2_1400_Bernhardt_MRIStats/surfstat_tutorial$ l
s -1
fsaverage5/
myStudy.csv
surfstat/
surfstat_example.m
thickness/
```

WHAT ARE THESE SURFACES

```
>> SW

SW =

      tri: [40960x3 int32]
    coord: [3x20484 double]
```

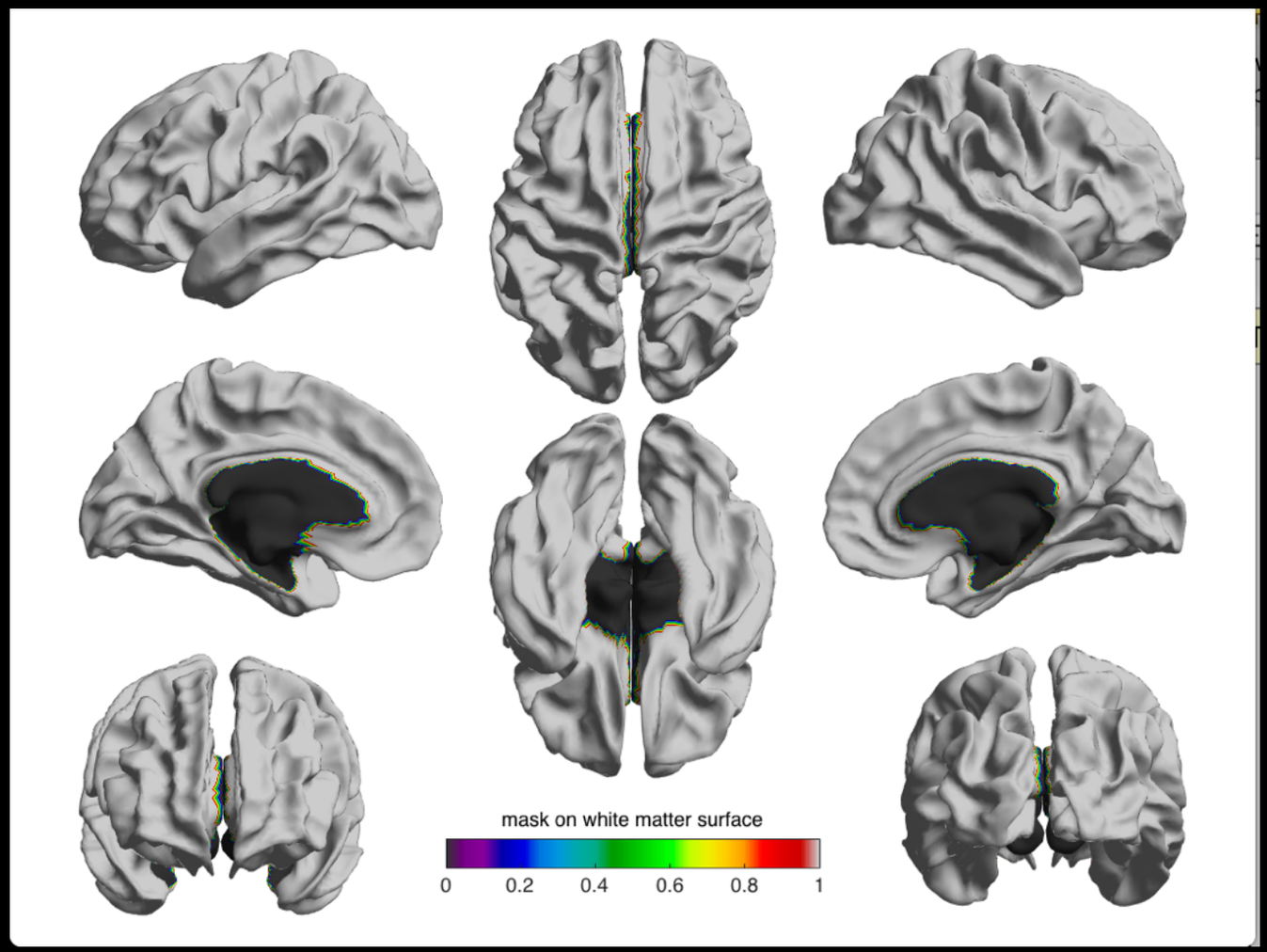
SOME USEFUL FEATURES

```
%% 2. load brain mask and some useful surface features
load([P 'fsaverage5/mask.mat']),
load([P 'fsaverage5/curv.mat'])
```

FIRST DISPLAY

```
%% 3. Display what we have been loading

% first the brain mask
f=figure,
SurfStatViewData(double(mask),SW,'mask on white matter surface')
```

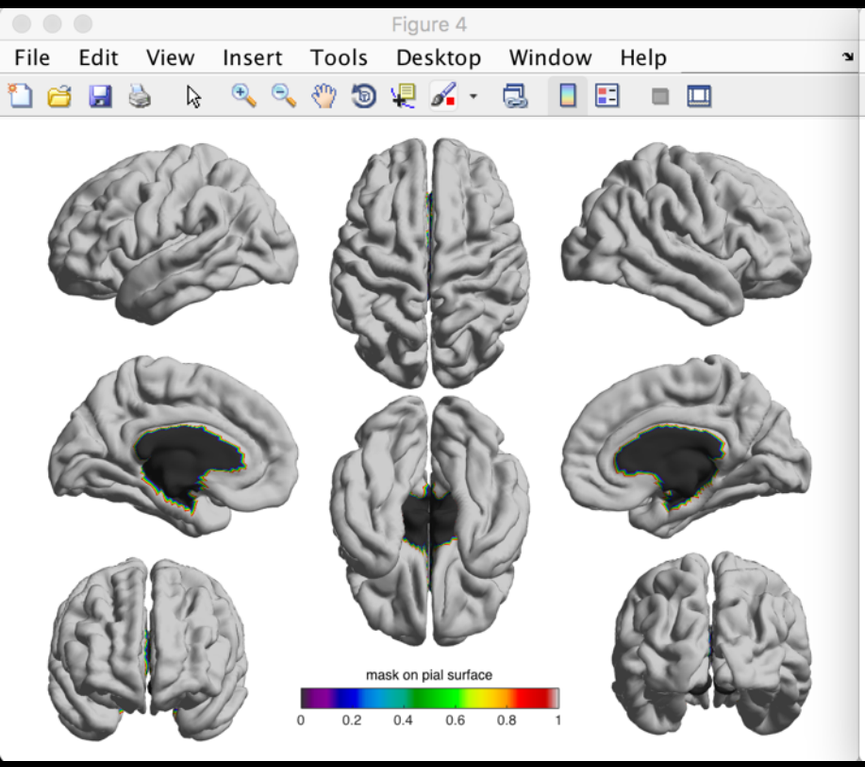
BRAIN MASK

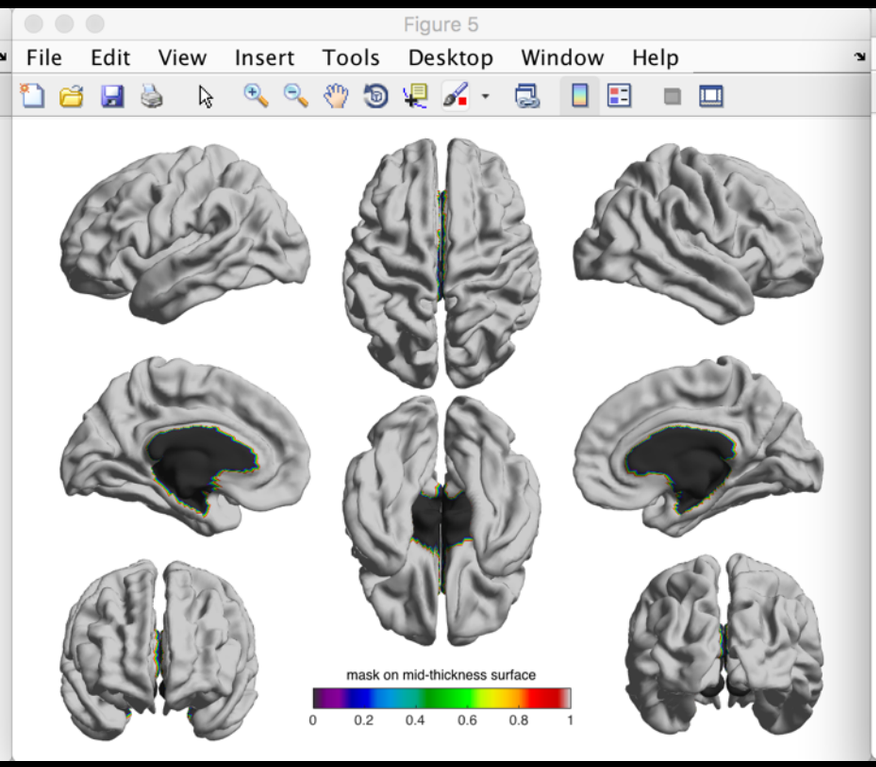


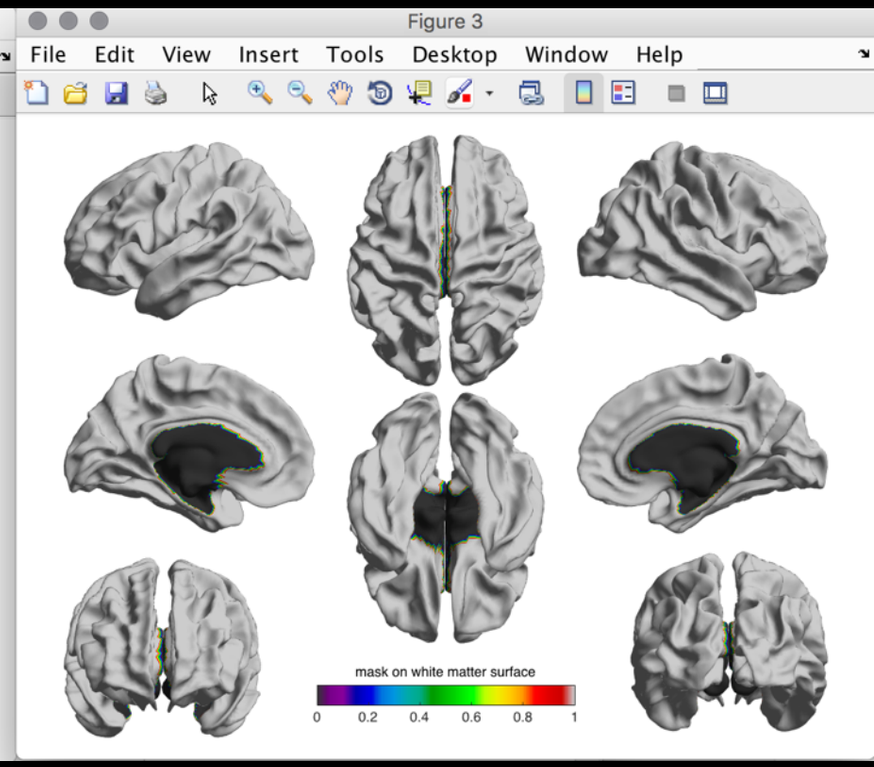
ON DIFFERENT SURFACES

```
%% 3. Display what we have been loading

% first the brain mask
f=figure,
SurfStatViewData(double(mask),SW,'mask on white matter surface')

f=figure,
SurfStatViewData(double(mask),SP, 'mask on pial surface')

f=figure,
SurfStatViewData(double(mask),SM, 'mask on mid-thickness surface')
```

ON DIFFERENT SURFACES



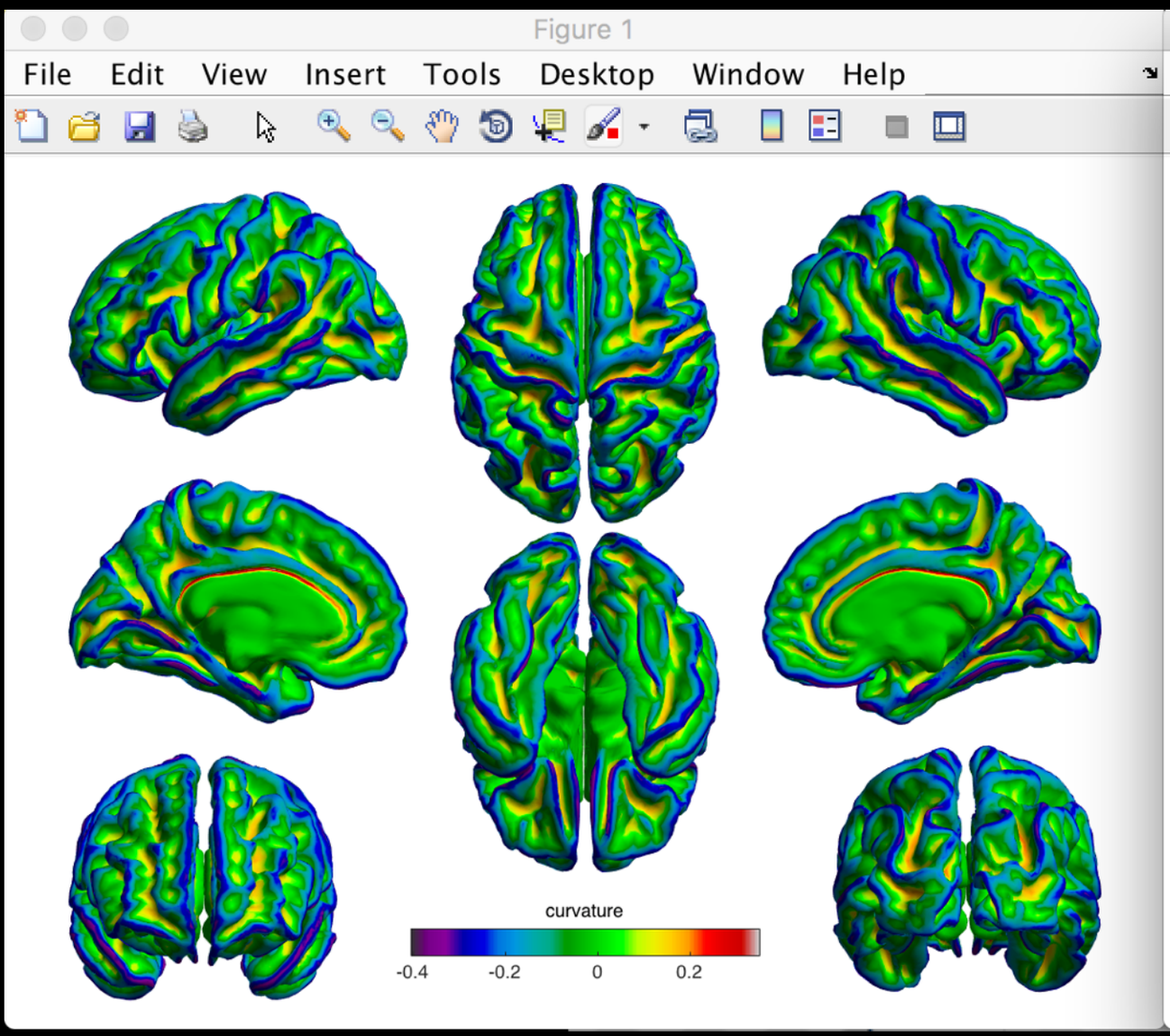


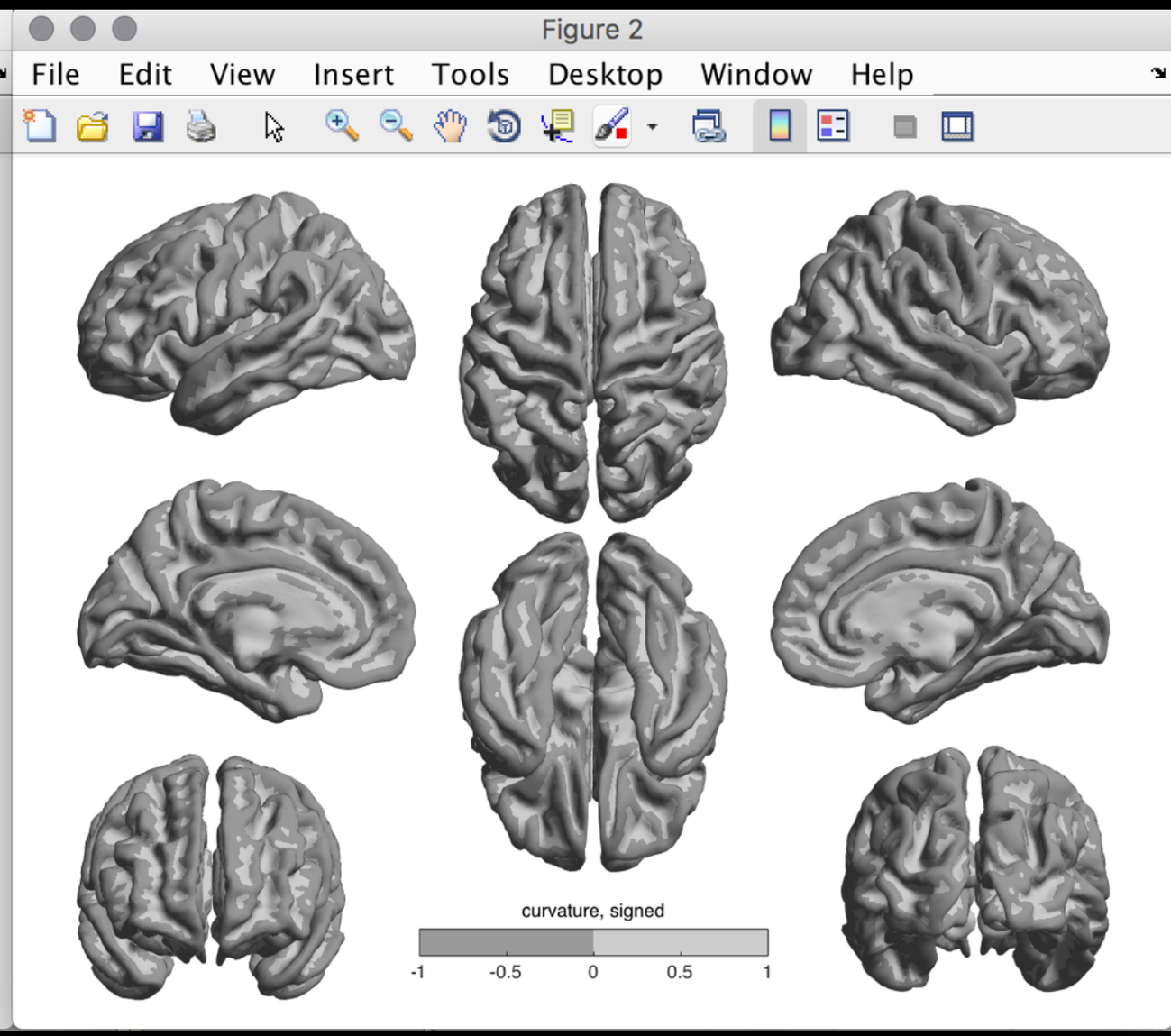


WE CAN ALSO DISPLAY OTHER DATA

```
%% then the curvature data
f=figure,
SurfStatViewData(curv, SM, 'curvature')

% and now a binarized colormap
f=figure,
SurfStatViewData(sign(curv), SM, 'curvature, signed')
colormap([0.6 .6 .6; .8 .8 .8])
```

WE CAN ALSO DISPLAY OTHER DATA

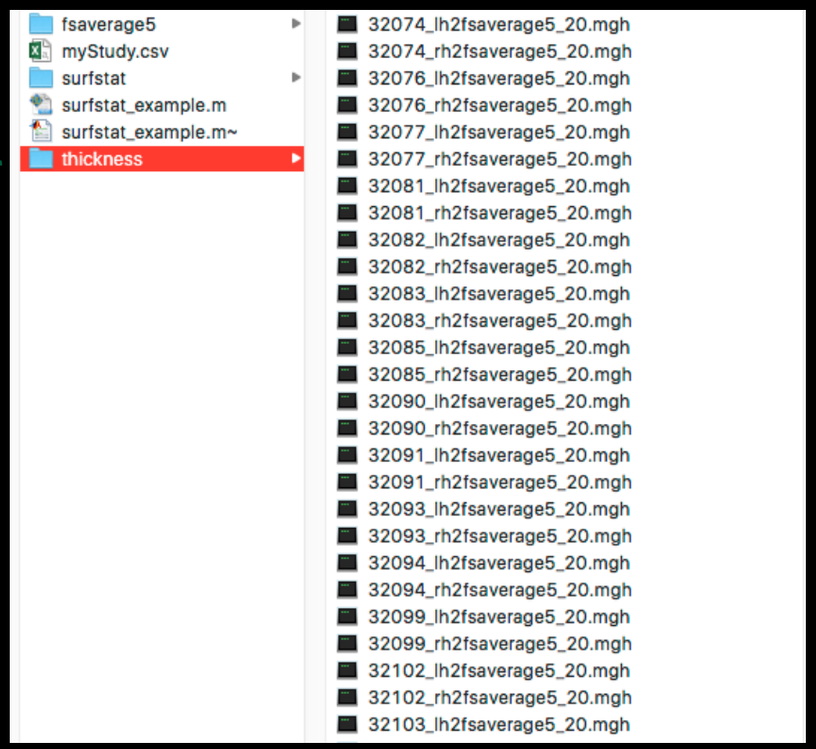




NOW ITS TIME TO LOAD THE DATA OF THE INDIVIDUAL SUBJECTS

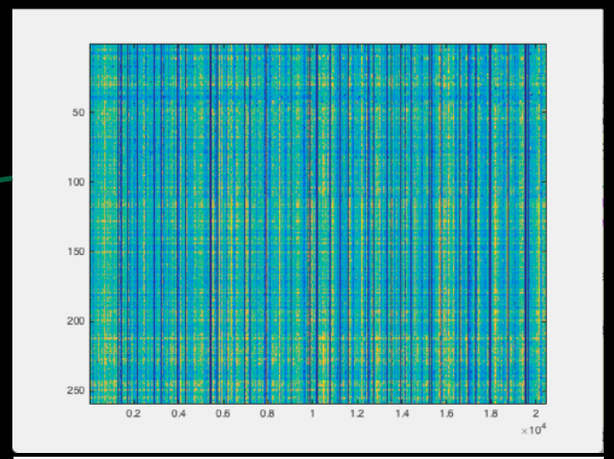
```
%%  4. ready for some analysis: load the spreadsheet
% load csv file that contains our participant ids, groups and IVs
fid      = fopen([P 'myStudy.csv']); % final group
C        = textscan(fid,'%s%s%n%s%n','Delimiter',',',...
                    'headerLines',1,'CollectOutput',1);
fclose(fid);

% we have to do a little bit of recoding
ID       = C{1}(:,1);
GR       = C{1}(:,2);
AGE      = C{2};
HAND     = C{3};
IQ       = C{4};
```

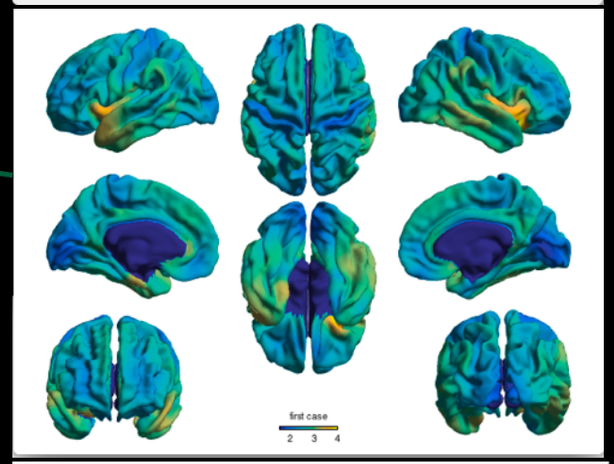
```
%% 4b. Load the thickness data
% generate the file names
left     = strcat(P, 'thickness/', ID, '_lh2fsaverage5_20.mgh');
right    = strcat(P, 'thickness/', ID, '_rh2fsaverage5_20.mgh');

% load data into a matrix
T        = SurfStatReadData([left, right]);
```

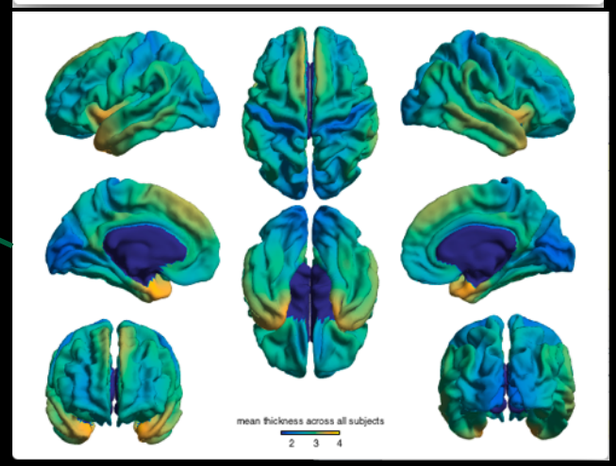


LETS VERIFY WHAT WE JUST LOADED

```
%% lets verify
f=figure,
    imagesc(T,[1.5 4])
    colormap(parula)

f=figure,
    SurfStatViewData(T(1,:),SM, 'first case')
    SurfStatColLim([1.5 4])
    colormap(parula)

f=figure,
    SurfStatViewData(mean(T,1),SM, 'mean thickness across all subjects')
    SurfStatColLim([1.5 4])
    colormap(parula)
```







NOW WE CAN FINALLY BUILD THE FIRST LINEAR MODELS

t-tests, correlations, partial correlations, ANOVAs, MANOVAs,…

are just specific instances of the linear model of the form

$$Y \sim \beta_0 + \beta_1 * x_1 + \beta_1 * x_1 + \beta_3 * x_1 \times x_2 \ldots + \varepsilon$$

DATA

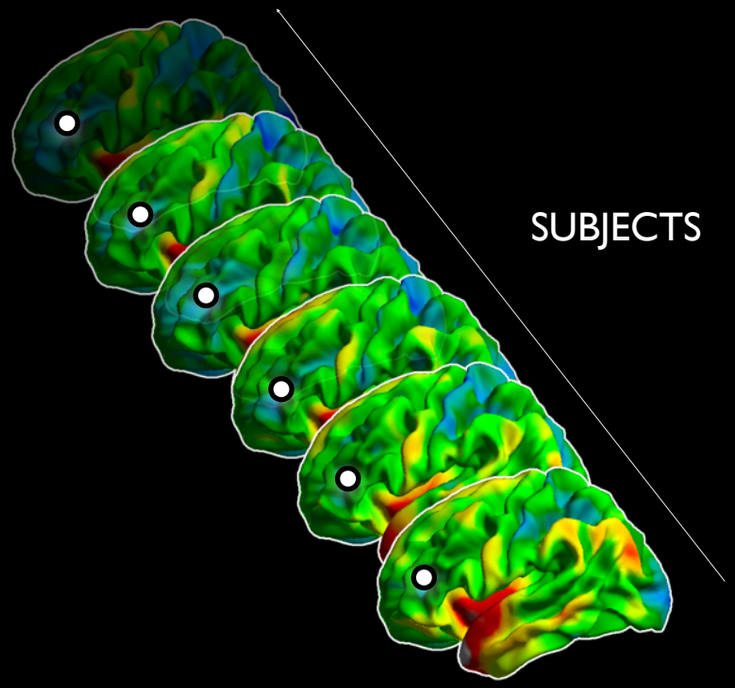
INTERCEPT

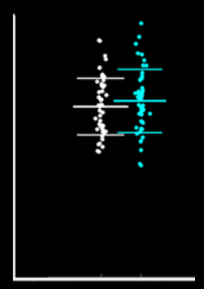
SIMPLE EFFECTS

INTERACTIONS

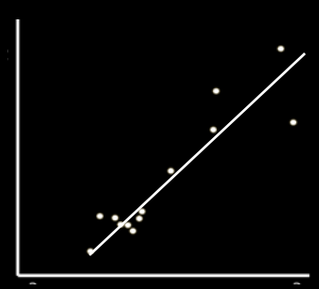
NOW WE CAN FINALLY BUILD THE FIRST LINEAR MODELS

CROSS-SECTIONAL ANALYSES

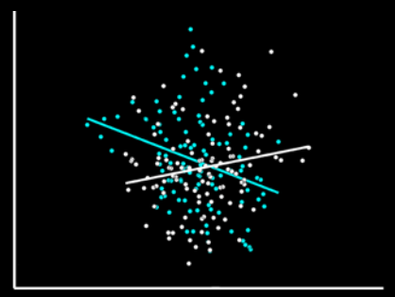




Y=1+G

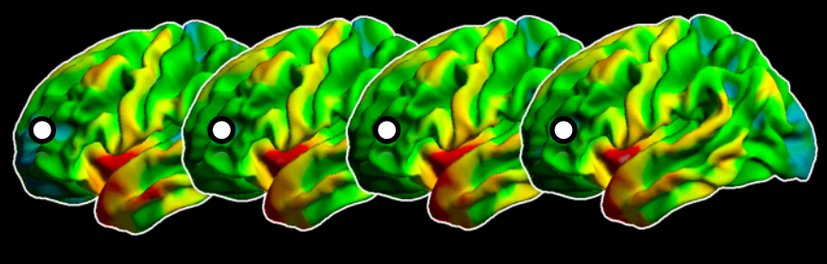


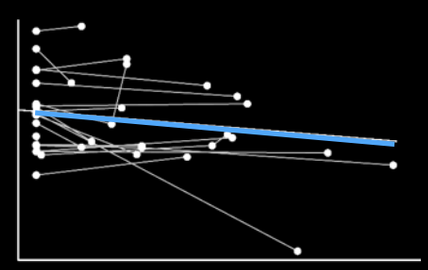
Y=1+A



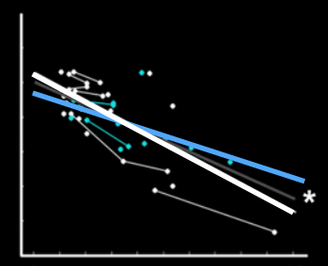
Y=1+G+A+G×A

LONGITUDINAL ASSESSMENTS





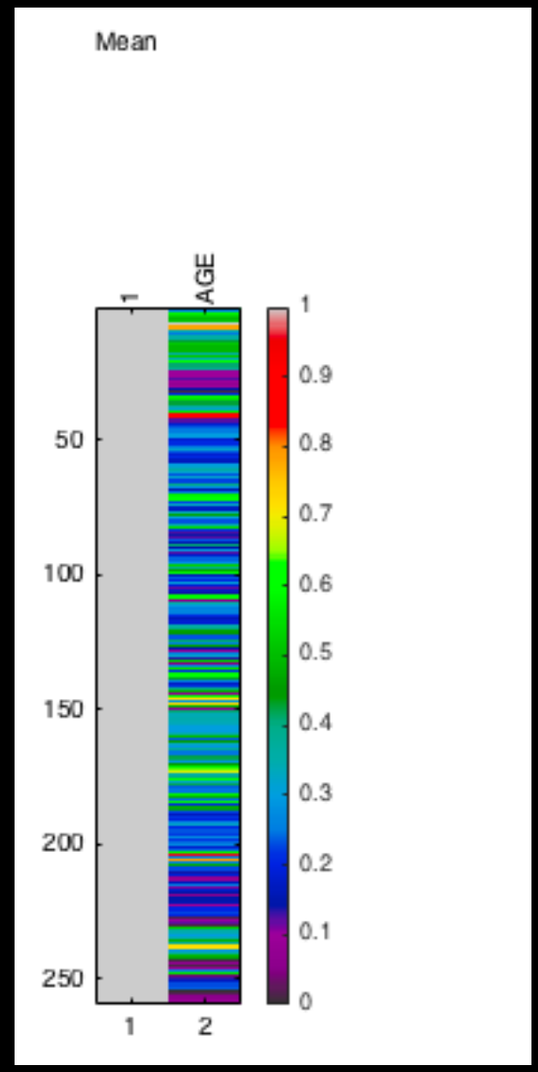
Y=1+r(S)+ISI



Y=1+r(S)+ISI+G+ISI×G

NOW WE CAN FINALLY BUILD THE FIRST LINEAR MODELS

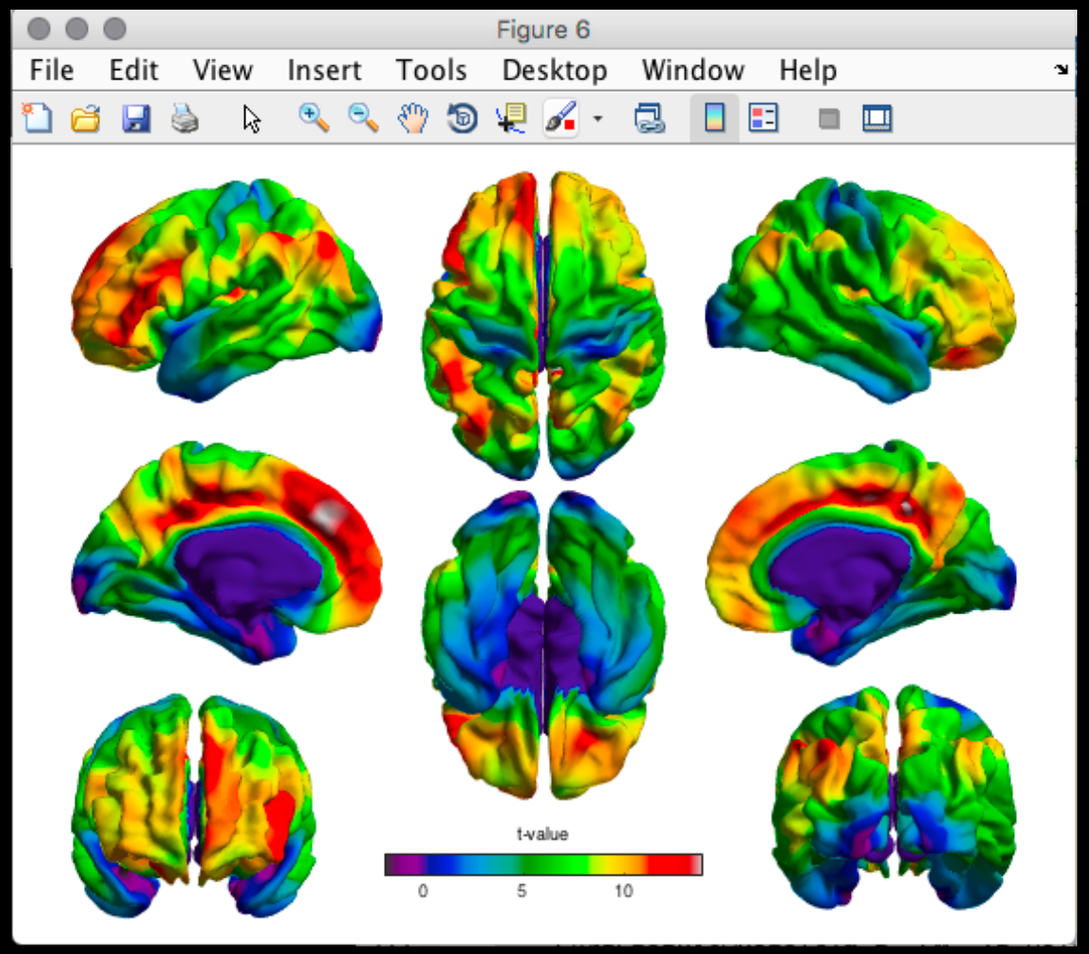
```
%% now we can finally do a firs models: lets look at effects of age

% first code some variables of interest
AGE_term  = term(AGE);

% then build a model
M = 1 + AGE_term;
f=figure, image(M)

% estimaste the model parameter s
slm = SurfStatLinMod(T, M, SW);

% specifiy contrast
slm = SurfStatT(slm, -AGE)
```



NOW WE CAN FINALLY BUILD THE FIRST LINEAR MODELS

```
slm =

       X: [259x2 double]
      df: 257
    coef: [2x20484 double]
     SSE: [1x20484 double]
     tri: [40960x3 int32]
    resl: [61440x1 double]
       c: [-2.9671e-14 -1.0000]
       k: 1
      ef: [1x20484 double]
      sd: [1x20484 double]
       t: [1x20484 double]
```

```
% display t-value
f=figure
    SurfStatViewData(slm.t, SM, 't-value')
```

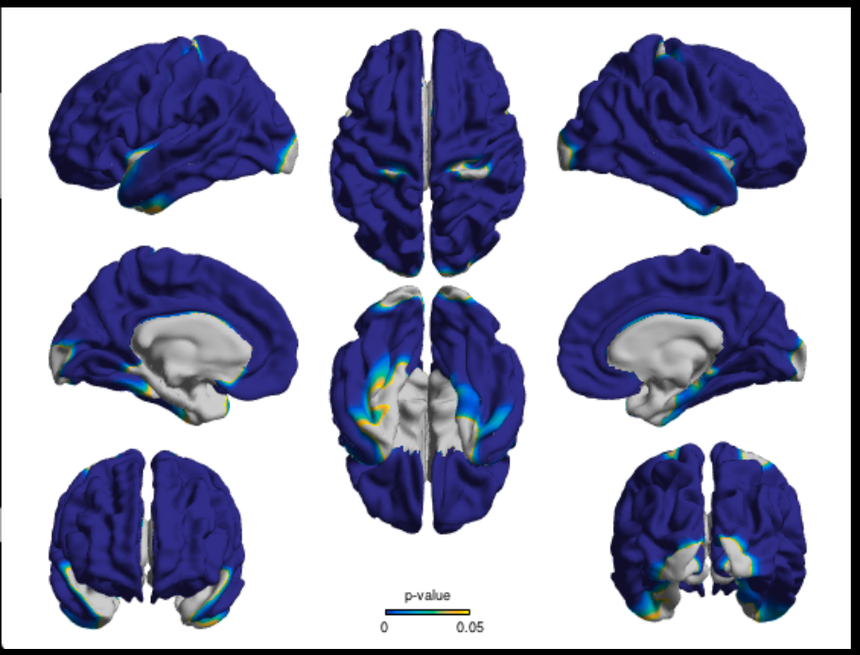


AND CORRECT FOR MULTIPLE COMPARISONS

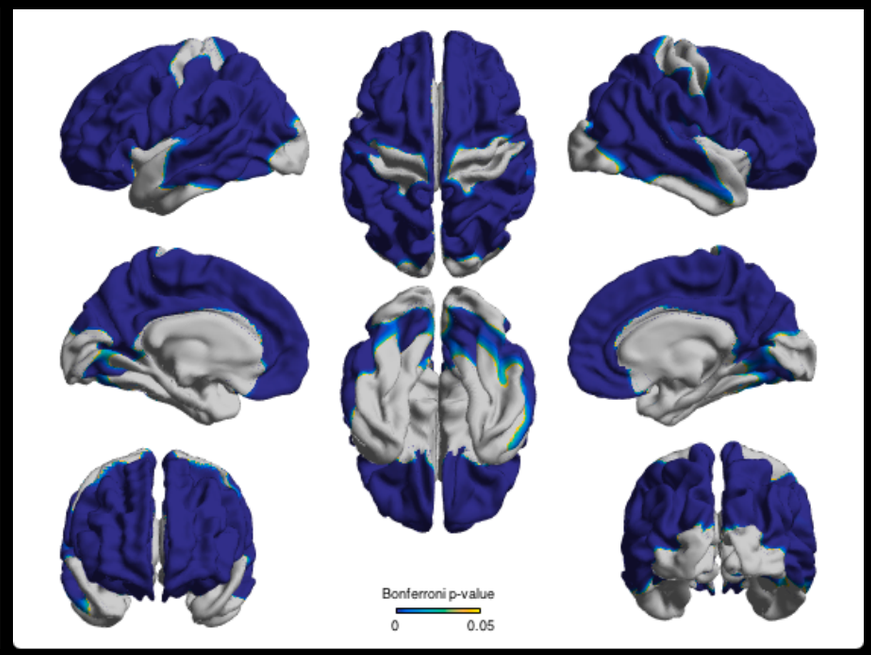
```
% multiple comparison correction: none
p = 1-tcdf(slm.t,slm.df);
f=figure
    SurfStatViewData(p, SM, 'p-value')
    SurfStatColLim([0 0.05])
    colormap([parula; .8 .8 .8])

% multiple comparison correction: Bonferroni
p = 1-tcdf(slm.t,slm.df);
p = p*size(p,2);
f=figure
    SurfStatViewData(p, SM, 'Bonferroni p-value')
    SurfStatColLim([0 0.05])
    colormap([parula; .8 .8 .8])

% multiple comparions using fdr
qval = SurfStatQ(slm,mask);
f=figure
    SurfStatView(qval, SM, 'fdr')

% multiple comparions using random field theory
pval = SurfStatP(slm,mask);
f=figure
    SurfStatView(pval, SM, 'rft')
```

AND CORRECT FOR MULTIPLE COMPARISONS

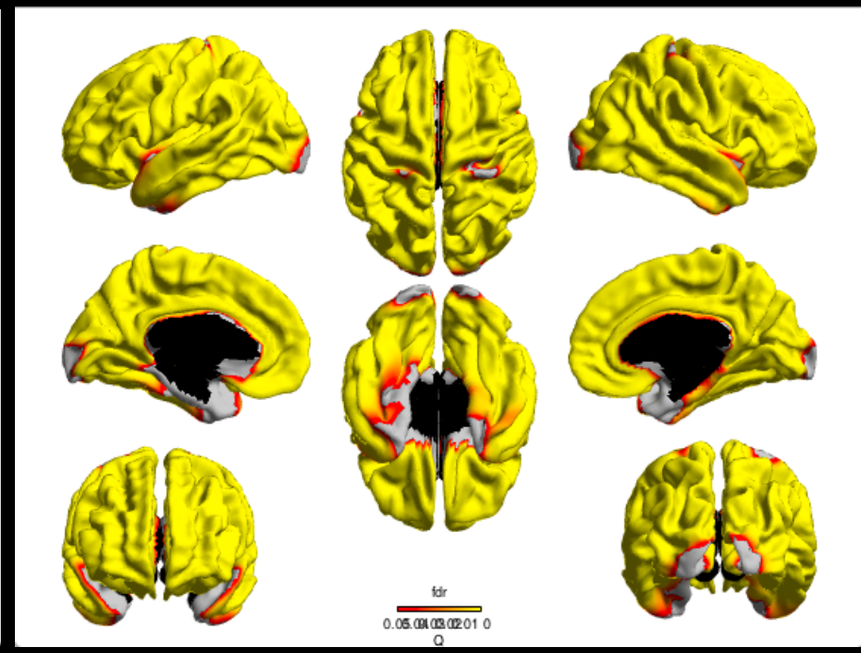
uncorrected



Bonferroni



FDR



SIMPLE LINEAR MODELS CONTINUED

Different models and contrasts are possible

```
A = term(AGE); G = term(GR);

M = 1 + G

slm = SurfStatLinMod(T, M, SW)

slm = SurfStatT(slm, G.Group1-G.Group2)
```

is a model that assesses group differences

$y = \beta_0 + \beta_1 * G + \varepsilon$

SIMPLE LINEAR MODELS CONTINUED

Different models and contrasts are possible

```
A = term(AGE); G = term(GR);

M = 1 + A + G

slm = SurfStatLinMod(T, M, SW)

slm = SurfStatT(slm, G.Group1-G.Group2)
```

is a model that assesses group differences, controlling for age

$$y = \beta_0 + \beta_1 * A + \beta_2 * G + \varepsilon$$

SIMPLE LINEAR MODELS CONTINUED

Different models and contrasts are possible

```
A = term(AGE); G = term(GR);

M = 1 + A + G

slm = SurfStatLinMod(T, M, SW)

slm = SurfStatT(slm, -AGE)
```

is the same model but assesses age effects, controlling for group

$$y = \beta_0 + \beta_1 * A + \beta_2 * G + \varepsilon$$

SIMPLE LINEAR MODELS CONTINUED

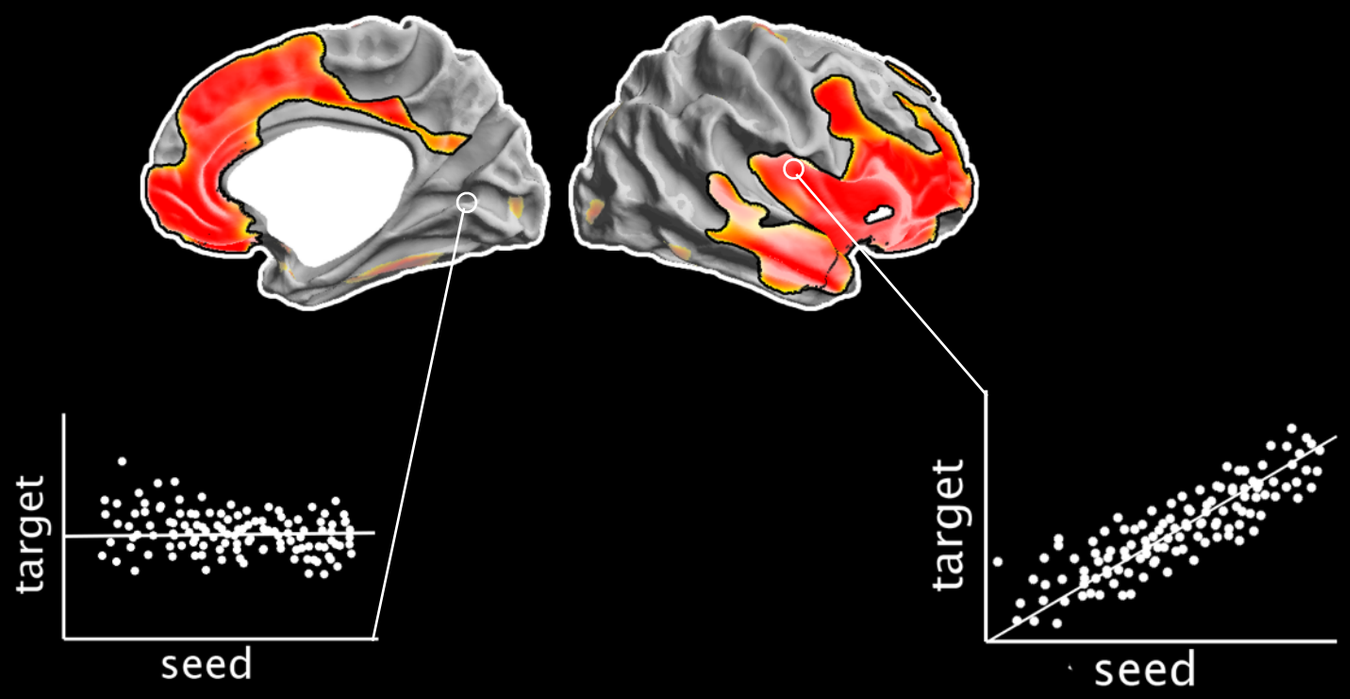
Different models and contrasts are possible

```
A = term(AGE); G = term(GR);

M = 1 + A + G + A*G

slm = SurfStatLinMod(T, M, SW)

slm = SurfStatT(slm, (-AGE.*G.Group2)- (-AGE.*G.Group1))
```

interaction model, assumes different age effect across groups

$y = \beta_0 + \beta_1 * A + \beta_2 * G + \beta_3 * GxA + \varepsilon$

STRUCTURAL COVARIANCE ANALYSIS



Lerch et al. (2006) NeuroImage

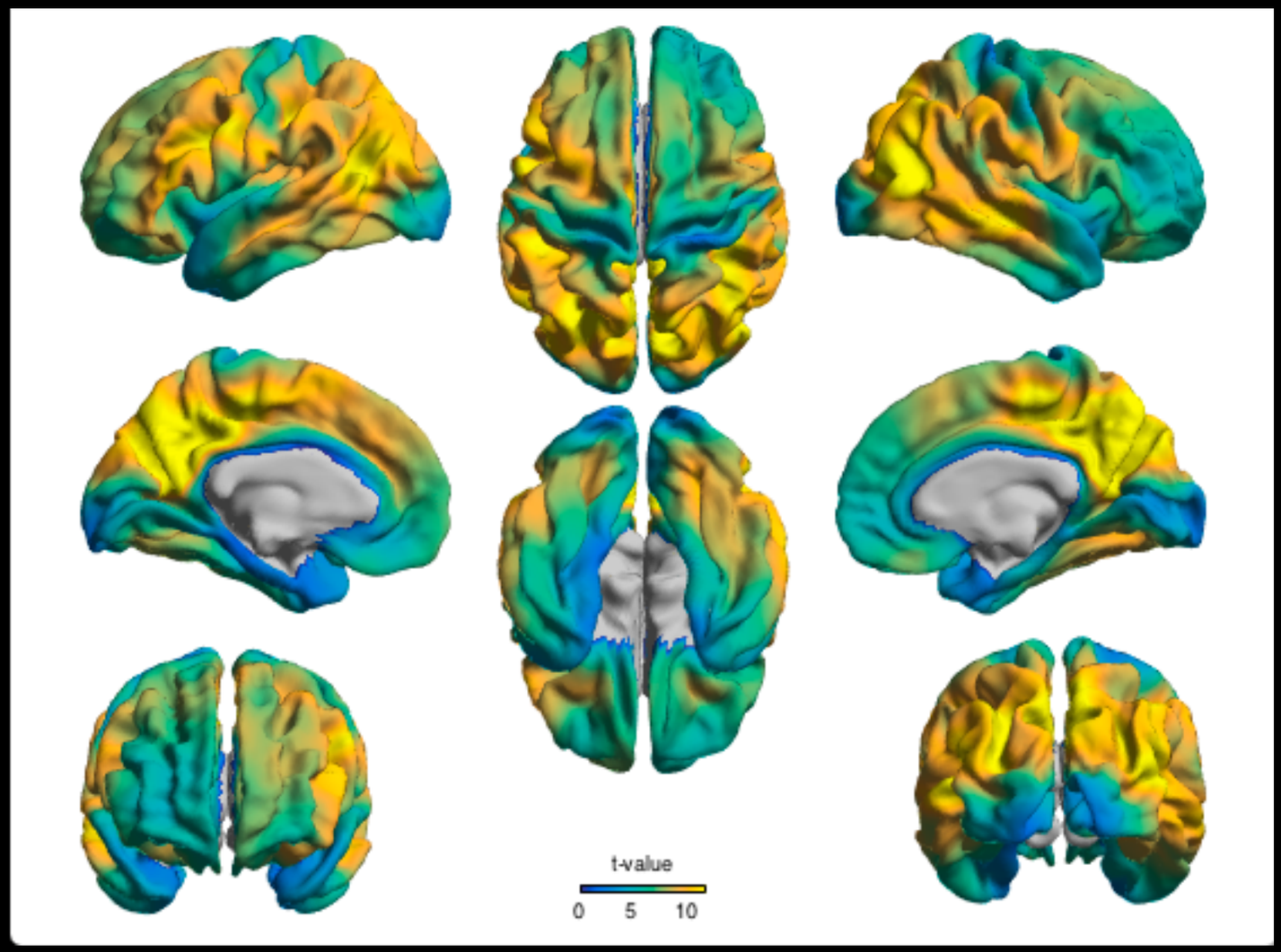
Alexander-Bloch et al. (2013) Nat Rev Neurosci

COVARIANCE MODELS

```
Seed = T(:,14446);

S = term(Seed);

M = 1 + S

 slm = SurfStatLinMod(T,M, S)

 slm = SurfStatT(slm, Seed )
```

is a model that assesses the correlation between a seed and cortical thickness at each surface point

Structural covariance analysis



COVARIANCE DIFFERENCES

```
Seed = T(:,14446);

 S = term(Seed); G = term(Group);

 Model = 1 + S + G + G*S

 slm = SurfStatLinMod(T,Model, S)

 slm = SurfStatT(slm,(G.Group1.*Seed)-(Group2.*Seed))
```

is a model that assesses the interaction between seed and group, assessing a stronger correlation with seed thickness in controls than patients

SUMMARY

SurfStat is a swiss army knife to flexibly analyze surface data

- reading and writing data
- perform surface-based statistical analysis
- correct for multiple comparison
- display results

OTHER COOL STUFF

Mixed effects models

```
M = 1 + A + S + random(SUBJID)
```

Non-surface based analysis in e.g. thickness in ROI

```
SurfStatLinMod(roi, Model)
```

Analysing volume data (e.g., VBM, DBM, rs-fMRI)

```
SurfStatReadVol1 ...
```

Smoothing on surfaces, mapping between volume and surface space

```
SurfStatSmooth ... SurfStatVol2Surf …
```

- visit: http://www.math.mcgill.ca/keith/surfstat/

SESSION OUTLINE

PART 2 (20 MINS)

HANDS-ON IN MATLAB

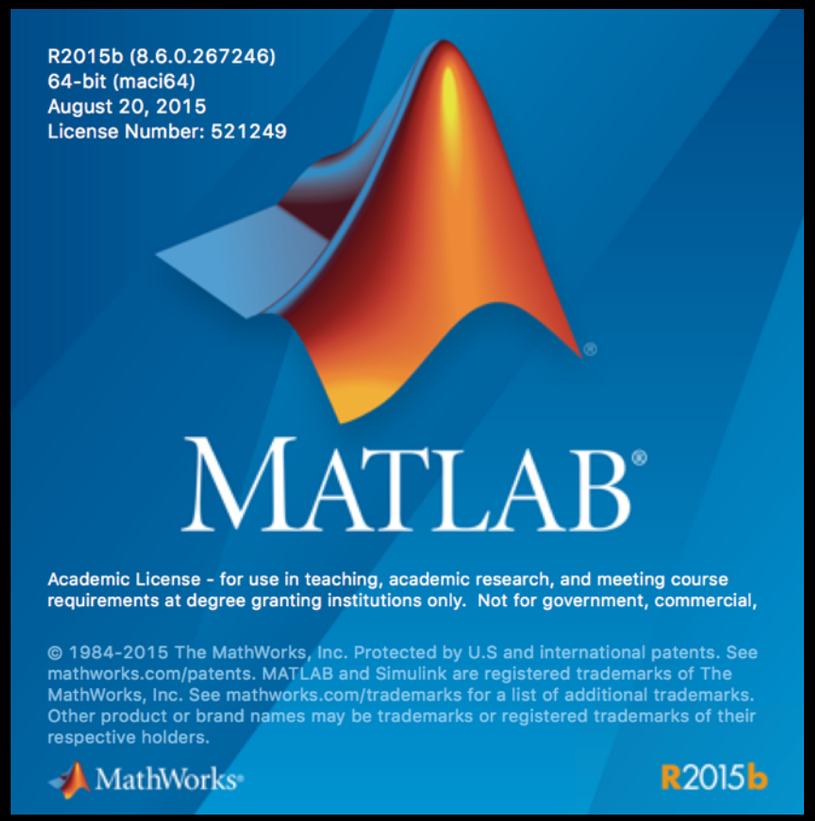
X2GO

on the x2go virtual machine

cd /data/noel/noel10/workshop/users/yourname/Day2_1400_Bernhardt_MRIStats/surfstat_tutorial

TO GET STARTED

LAUNCH MATLAB



TO GET STARTED