STATISTICAL ANALYSIS USING SURFSTAT

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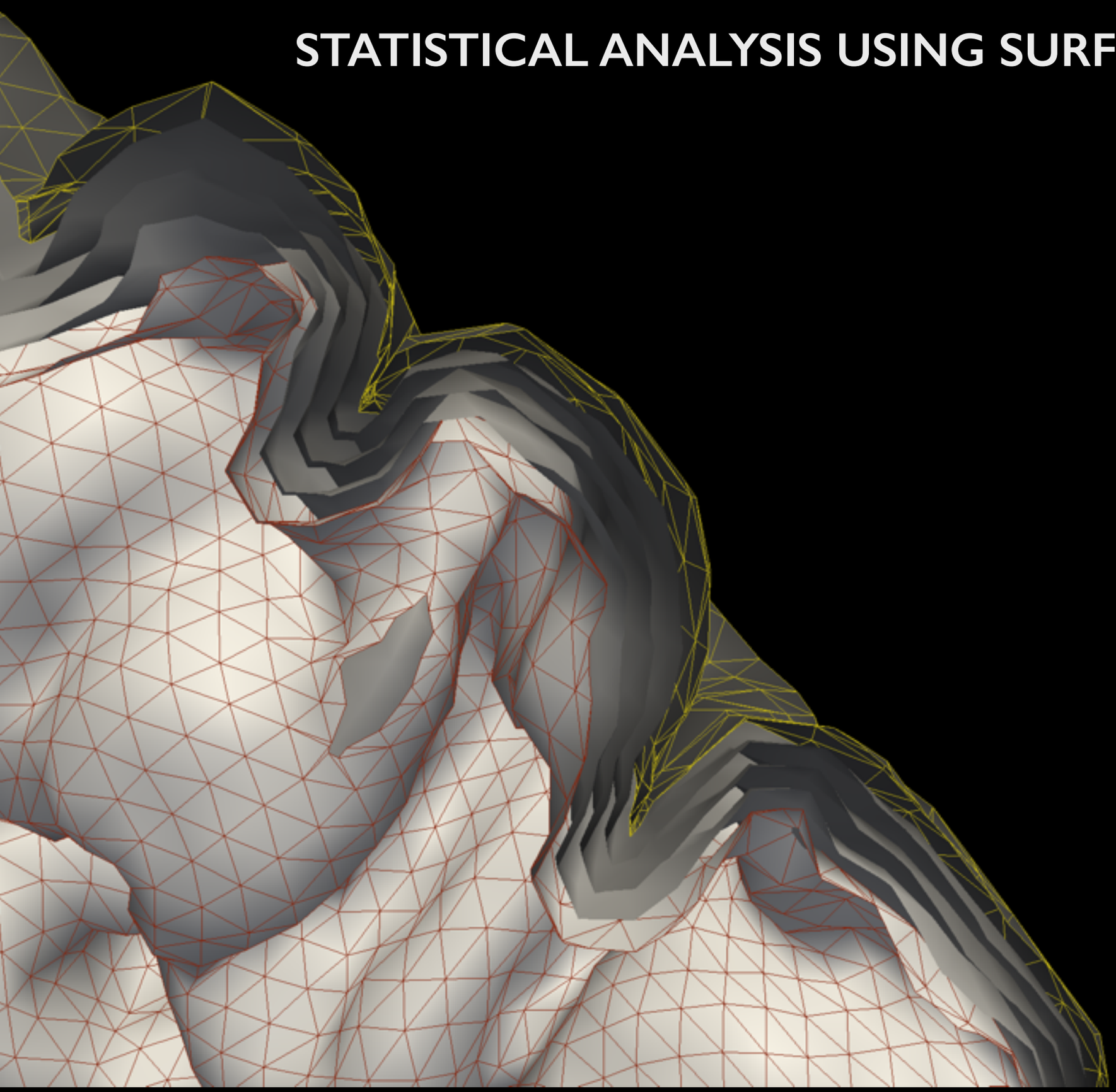
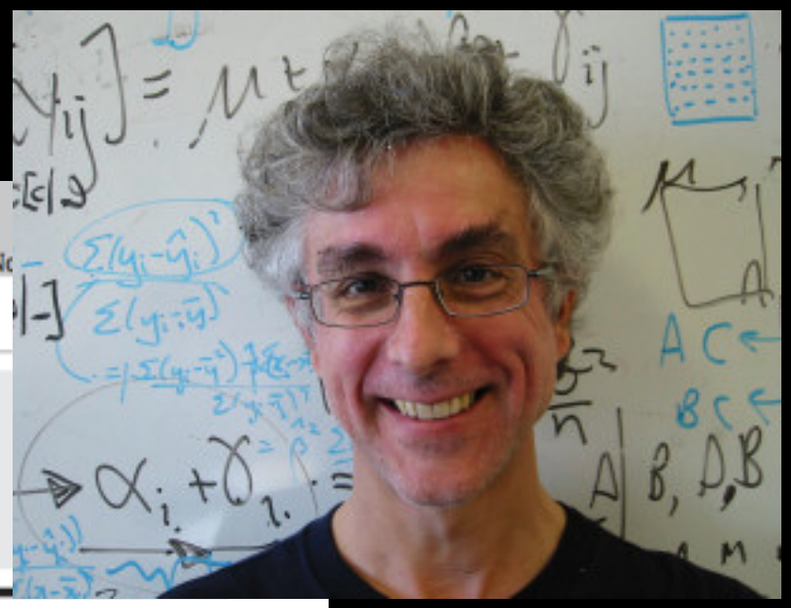


Keith Worsley (1951—2009)



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In Memoriam

A Tribute to: Keith Worsley — 1951–2009

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Legend has it that Keith's introduction to neuroimaging followed a chance encounter in a verdant corner of McGill University. One of us (Alan Evans) found Keith gathering maple leaves in the fond hope that variations in their shape would provide a useful source of data, against which to test his statistical ideas. This was in the late 80s when PET scanners had just started producing images of cerebral hemody-

psychophysical data (Worsley et al., 2007), through to the analysis of foot pressure images in the clinic (Pataky and Goulermas, 2008); from astrophysics though to meteorology (Worsley, 2002) In short, Keith was responsible for a paradigm shift that enabled statistical inference to move from scalar statistics to statistical fields or images.

These advances were particularly important for neuroimaging

What can SurfStat do with your surfaces?

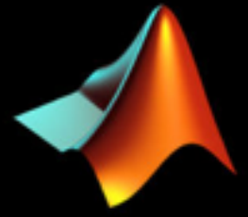
- read data
- perform surface-and volume-based statistical analysis
  - Model fitting
    - contrast estimation
    - multiple comparisons correction
- display results

- Fast and flexible Matlab coding, powerful visualizations
- http://www.math.mcgill.ca/keith/surfstat/

To get started

1. Download SurfStat from: http://www.math.mcgill.ca/keith/surfstat/

2. Launch Matlab (free from McGill IT)

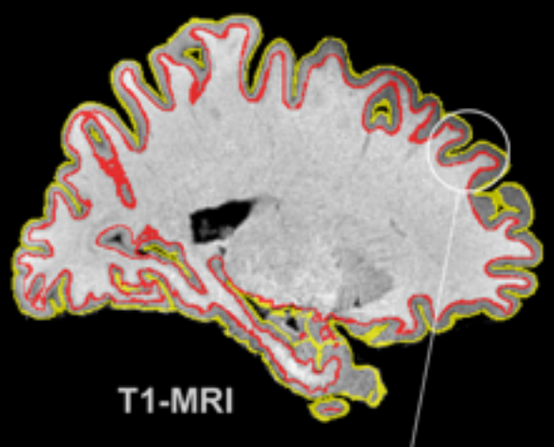


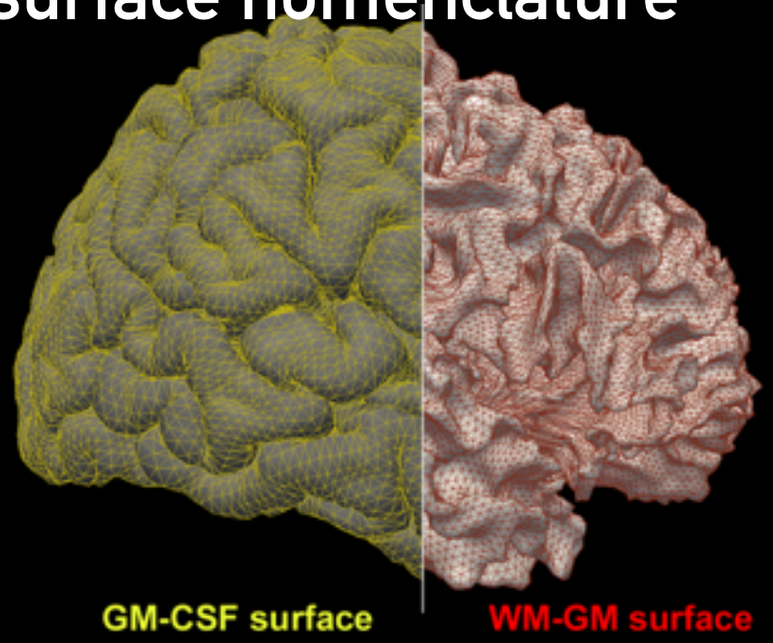
3. Add SurfStat to matlab path

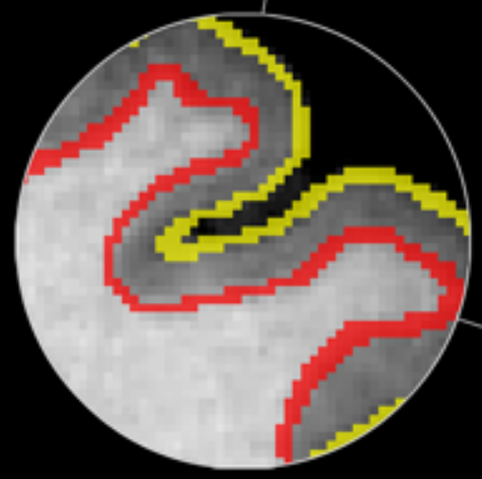
```
>> addpath( PathToSurfStat )

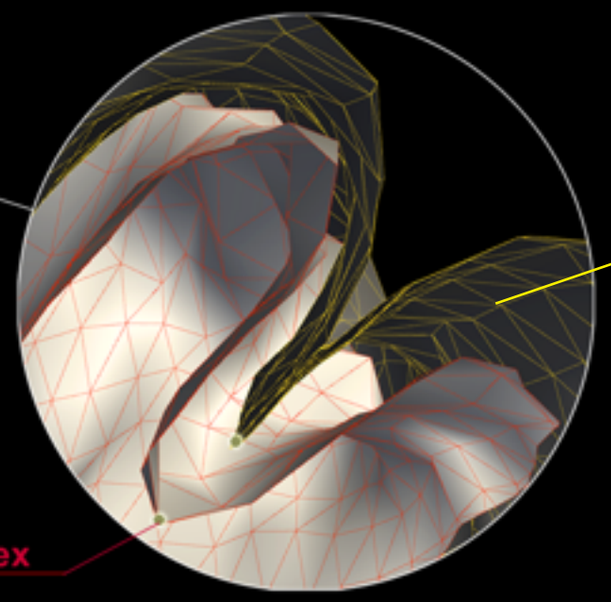
>> addpath ('/usr/local/matlab7a/toolbox/surfstat')
```

A little bit of surface nomenclature









cortical thickness measurement

Reading 1 surface

```
>> S = SurfStatReadSurf1( SurfaceFile )
```

`SurfaceFile` can be

surface files of individual cases (.obj for CIVET, e.g. lh.white for FS)

or template surfaces

```
surf_reg_model_left_81920.obj (CIVET)

lh.white, lh.pial…. of fsaverage (FreeSurfer)
```

`S.coord` = vertex coordinates on the mesh (e.g., 3x40962 in CIVET)

e.g., `-20,33,15` - x,y,z coordinates in MNI space

`S.tri`= triangles that make up the mesh (81920x3)

e.g. 2,5,700 - the vertex ids that make up a triangle

Reading 1 surface feature

```
>> T = SurfStatReadData1( ThicknessFile )
```

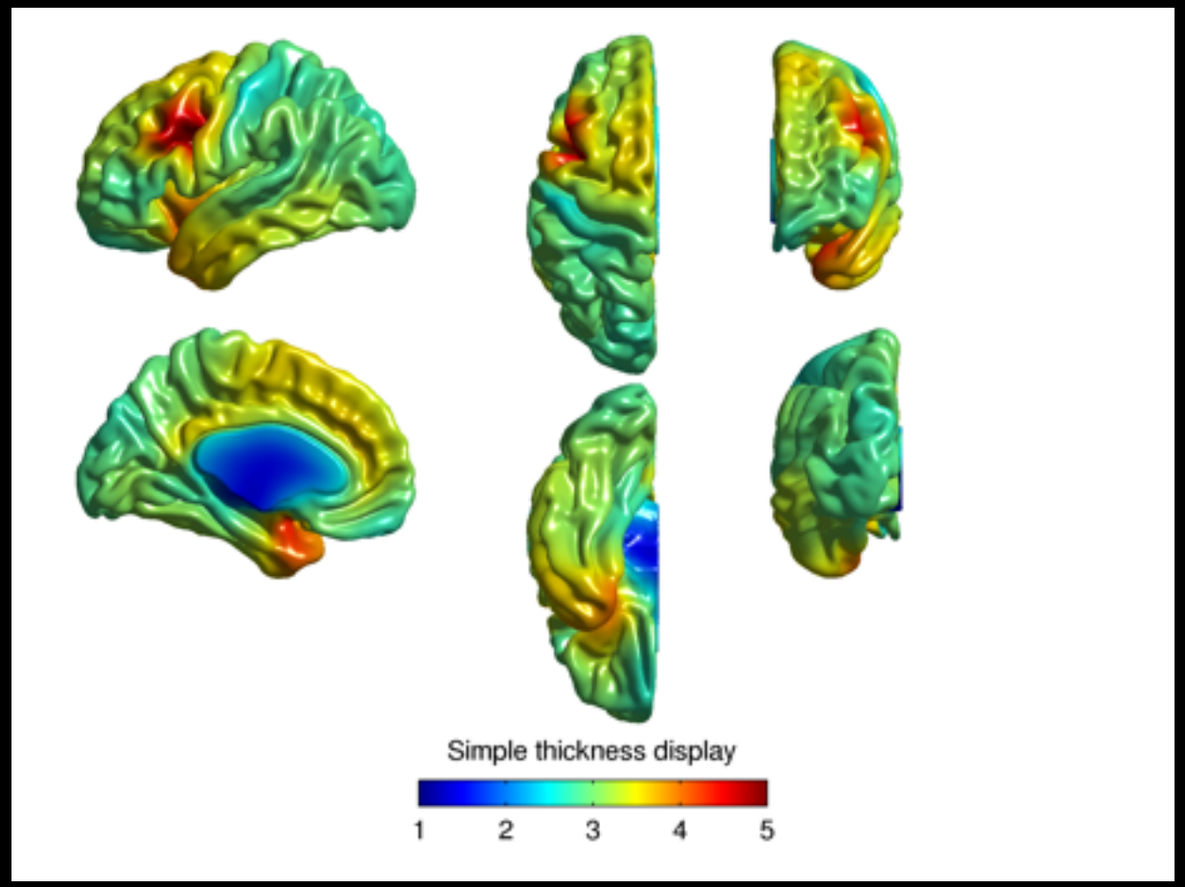
ThicknessFile can be .txt (CIVET) .mgh (FreeSurfer)

T is 1 x k vector

```
[2.13445 2.1234 2.45633 2.34566 …]
```

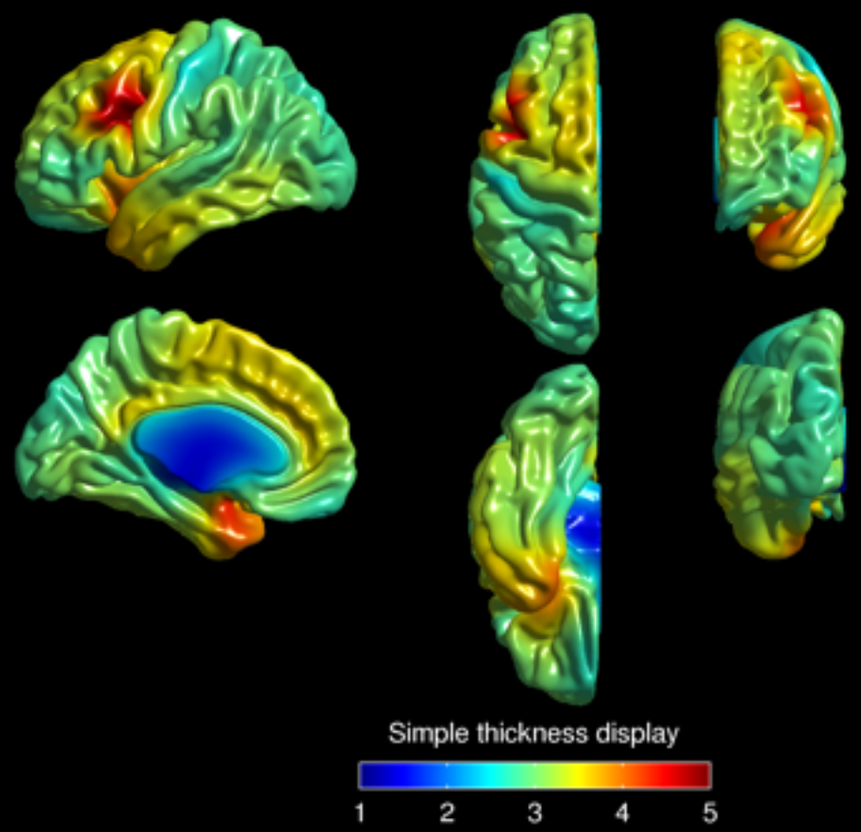
Displaying surface data

```
f=figure;
  SurfStatView(T, S, ‘Simple thickness display’)
  SurfStatColLim([1 5]), colormap( ‘jet’)
```



Displaying surface data

```
f=figure;
  SurfStatView(T, S, ‘Simple thickness display’,’black’)
  SurfStatColLim([1 5]), colormap( ‘jet’)
```



Reading many subjects

Thickness

```
T = SurfStatReadData( [namesleft, namesright] )
```

Surfaces

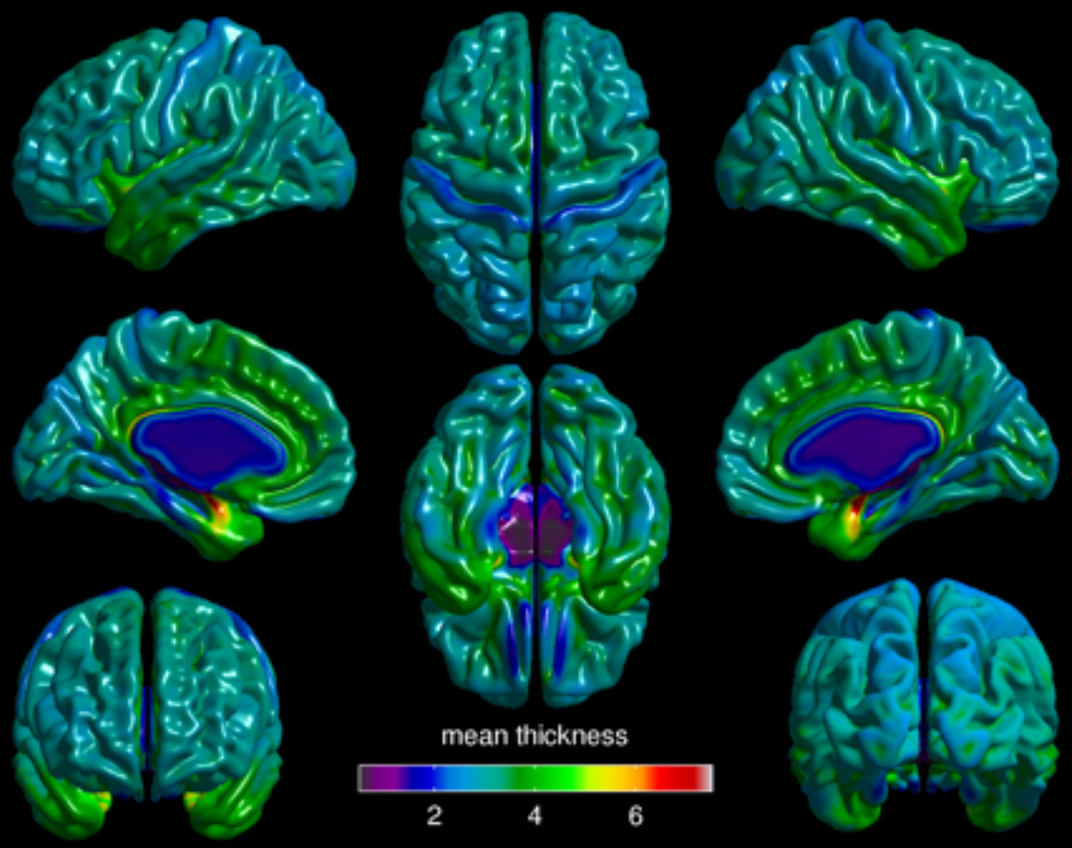
```
S = SurfStatReadSurf( [namesleft, namesright] )

S = SurfStatAvSurf( {'surf_reg_model_left.obj',…
                     'surf_reg_model_right.obj'}
```

Display some simple statistics

```
me = mean(T,1);

f=figure; SurfStatViewData(me, S, ‘mean thickness’,’black’)
```



Simple linear models

say you have a variable `group`

```
group = [ ‘Patient’, ...., ‘Control’, ... ] ;
```

of n x 1 length, then

```
G = term(group)
```

will convert the variable into a term

To specify a linear model, type

```
Model = 1 + G
```

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

Simple linear models

You can then use

```
slm = SurfStatLinMod(T,Model, S)
```

to estimate the parameters in the model

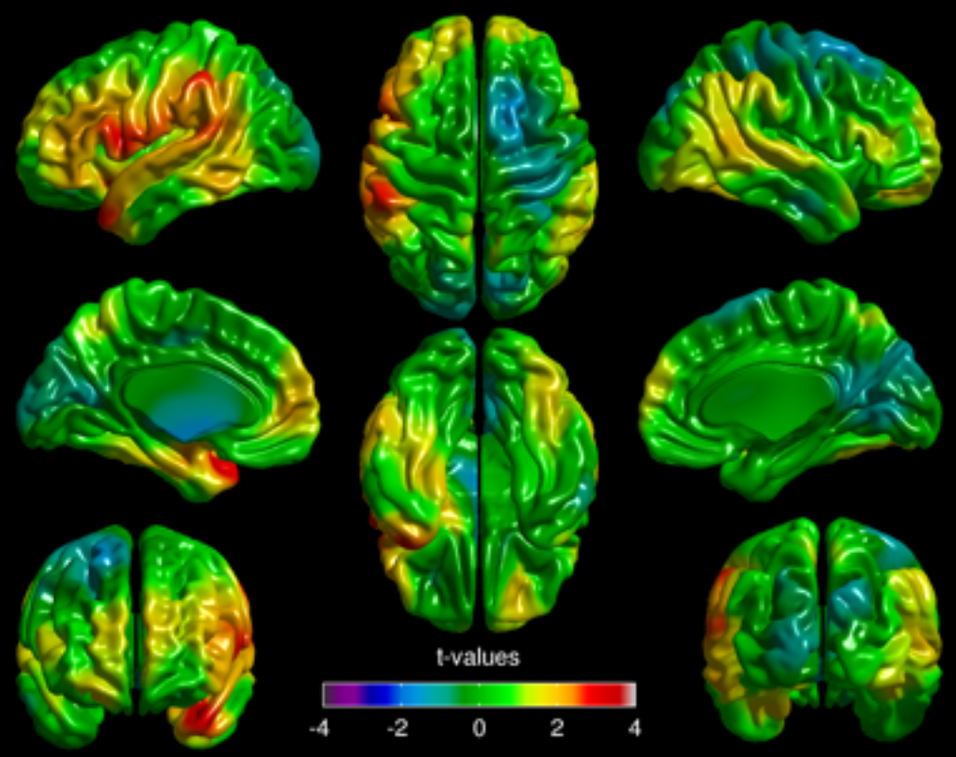
```
slm.X, slm.df, slm.coeff, slm.SSE, slm.tri, slm.resl
```

Simple linear models

and use SurfStatT to estimate the effect of a contrast

```
slm = SurfStatT(slm,G.Control-G.Patient)

f=figure; SurfStatViewData(slm.t, S, 't-val','black')
```



Simple linear models

Different models and contrasts are possible

```
A = term(Age); G = term(Group);

Model = 1 + A + G

slm = SurfStatLinMod(T,Model, S)

slm = SurfStatT(slm, G.Controls-G.Patients)
```

is a model that assesses group differences, controlling for age

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

Simple linear models

Different models and contrasts are possible

```
A = term(Age); G = term(Group);

Model = 1 + A + G

slm = SurfStatLinMod(T,Model, S)

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

is a model that assesses an effect of age across both groups

Simple linear models

Different models and contrasts are possible

```
A = term(Age); G = term(Group);

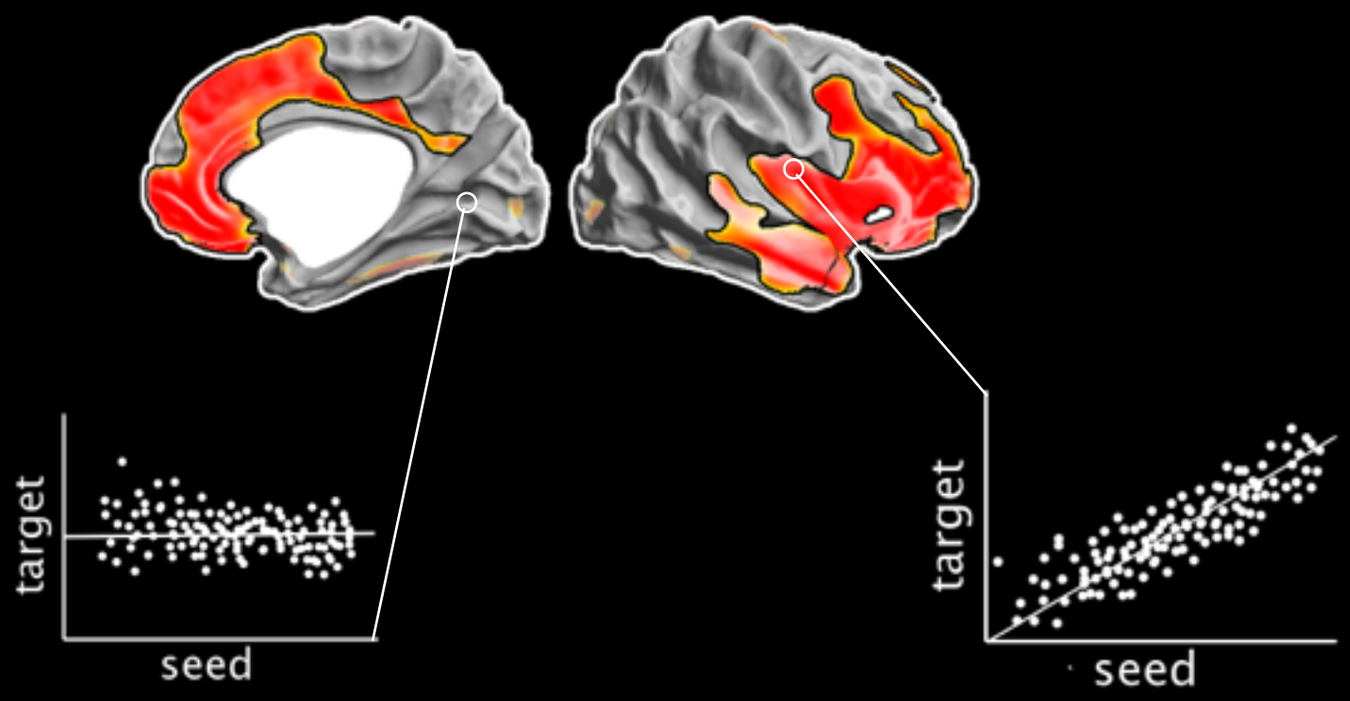
Model = 1 + A + G + A*G

slm = SurfStatLinMod(T,Model, S)

slm = SurfStatT(slm, (-Age.*G.Patients)-(-Age.*G.Controls))
```

is a model that assesses the interaction between age and group, assessing a faster age decline in thickness in patients than controls

Structural covariance analysis



Lerch et al. (2006) NeuroImage

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

Structural covariance analysis

Different models and contrasts are possible

```
Seed = T(:,674);

Se = term(Seed);

Model = 1 + Se

slm = SurfStatLinMod(T,Model, 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

Different models and contrasts are possible

```
Seed = T(:,674);

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

Model = 1 + Se + G + Se*G

slm = SurfStatLinMod(T,Model, S)

slm = SurfStatT(slm,(G.Controls.*Seed)-(G.Patients.*Seed))
```

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

Mixed effects models

One can also analyse mixed-effects models

```
Model = 1 + random(Subject) + A + I
```

to study clustered, hierarchical data

e.g., within-subject change (e.g. longitudinal change)

e.g., data of correlated observations, siblings, twins,…

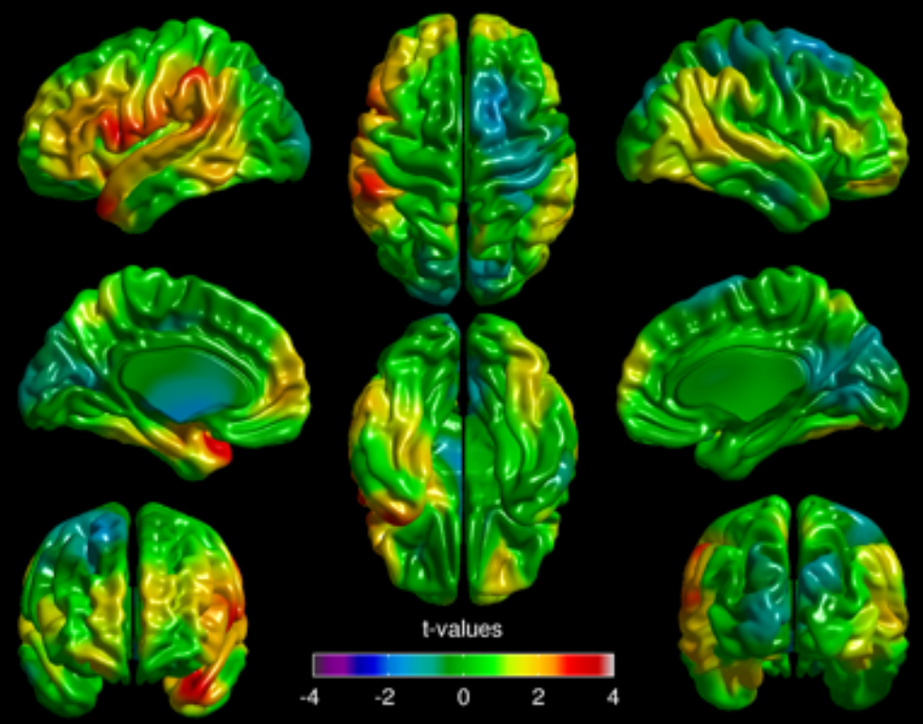
cf. http://cran.r-project.org/doc/contrib/Fox-Companion/appendix-mixed-models.pdf

Correction for multiple comparisons

1. no correction

```
p = 1 - tcdf(slm.t,slm.df)

f=figure; SurfStatViewData(p, S, 'p-value','black')
SurfStatColLim([0 0.05])
```



Correction for multiple comparisons

1. no correction

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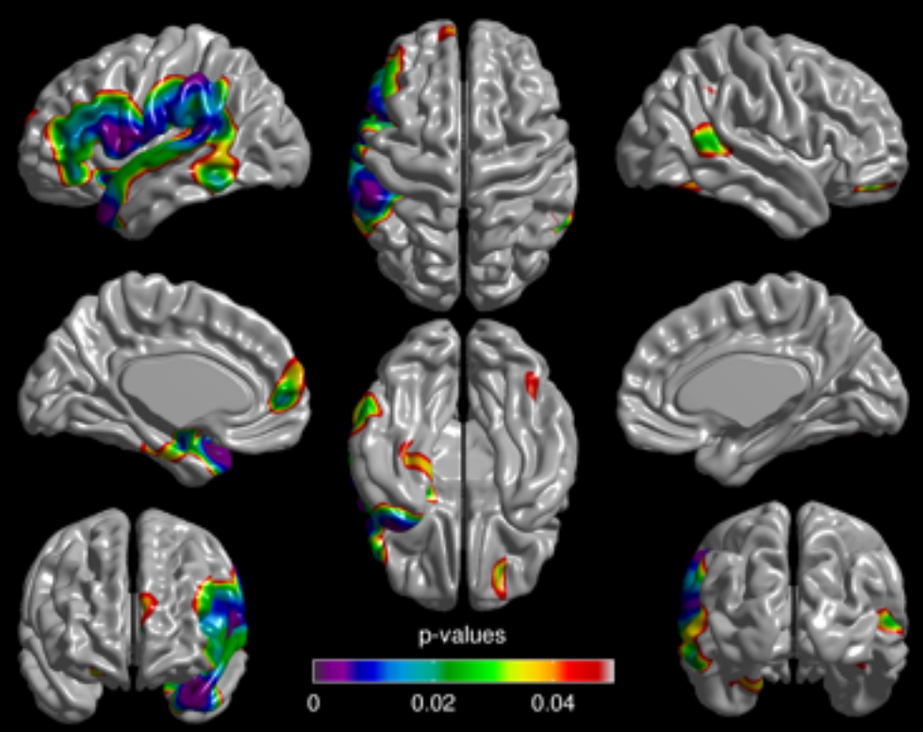
p = 1 - tcdf(slm.t,slm.df)

f=figure; SurfStatViewData(p, S, ‘p-value’,’black’)
SurfStatColLim([0 0.05])
```



Correction for multiple comparisons

2. Bonferroni

```
mask = SurfStatMaskCut(S)

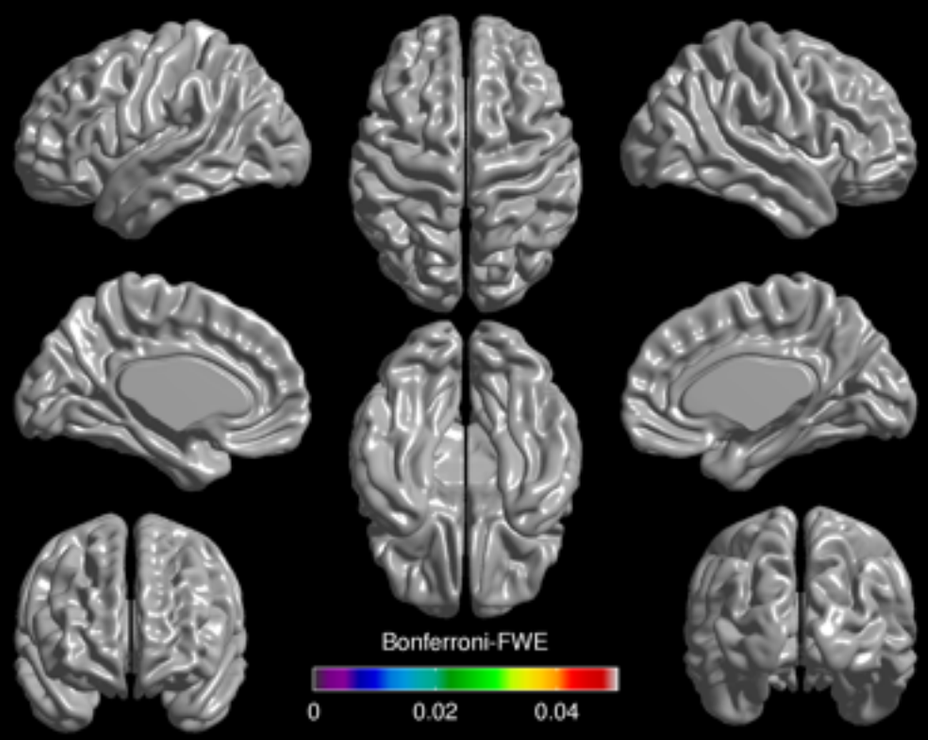
p = 1 - tcdf(slm.t,slm.df)

f=figure; SurfStatViewData(p*sum(mask), S, ‘Bonferroni-FWE’)

 SurfStatColLim([0 0.05])
```

Correction for multiple comparisons

2. Bonferroni

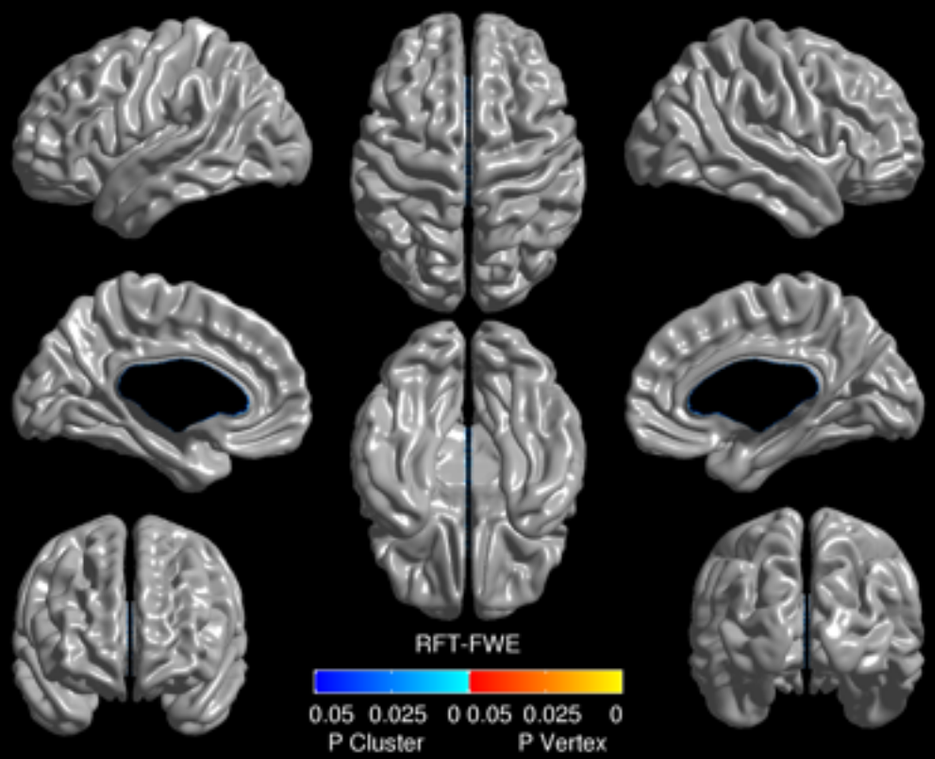


Correction for multiple comparisons

3. Random field theory-correction (Worsley et al. 1999)

```
[pval,peak,clus,clusid] = SurfStatP(slm,mask)

f=figure; SurfStatView(pval, S, 'RFT-FWE', 'black')
```

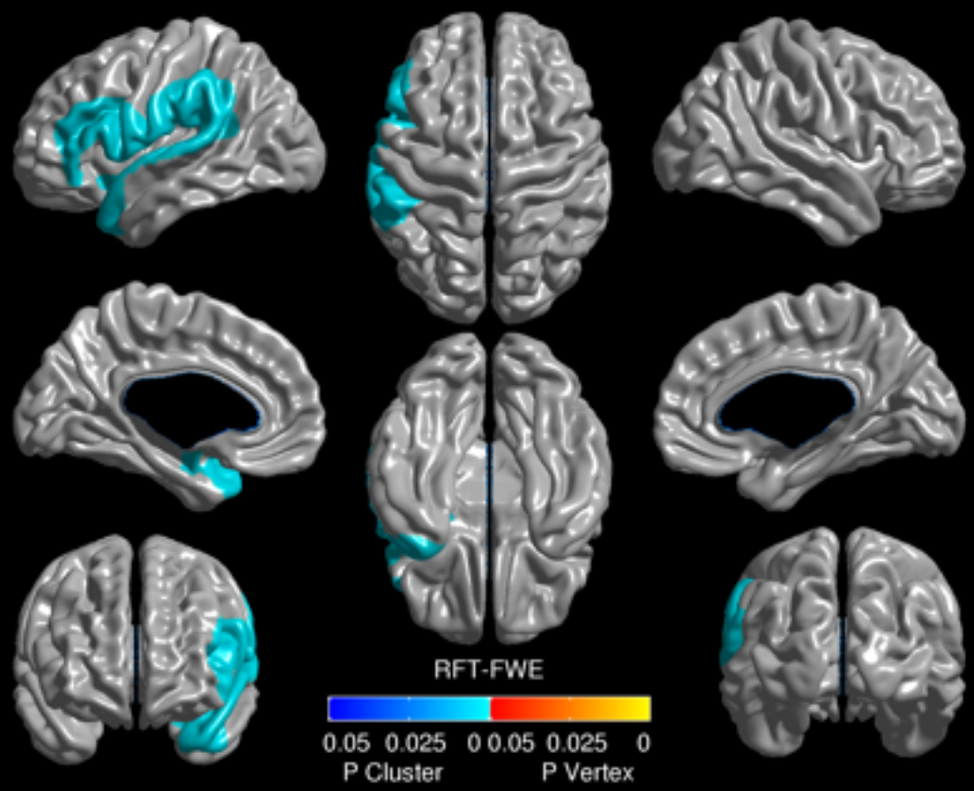


Correction for multiple comparisons

3b. Random field theory-correction (Worsley et al. 1999)

```
[pval,peak,clus,clusid] = SurfStatP(slm,mask,0.01)

f=figure; SurfStatView(pval, S, 'RFT-FWE')
```



Correction for multiple comparisons

```
>> term(clus)

clusid nverts resels   P

1      689     3.82   0.0012

2      829     0.56   0.2123

…
```

Correction for multiple comparisons

4. FDR-correction (Benjamini and Hochberg 1995)

```
qval = SurfStatQ(slm,mask)

f=figure;
 SurfStatViewData(qval.Q, S, ‘FDR’)
 SurfStatColLim([0 0.05])
```

or

```
  SurfStatView(qval,S,’FDR')
```

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 you can do

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

```
SurfStatSmooth ...
```

Mapping between volume and surface space

```
SurfStatVol2Surf …
```

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