Bayesian Inference
(BayInf)

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BayInf is a graphical user interface (GUI) for Bayesian inference, built in the Matlab computing environment and based on Statistical Parametric Mapping (SPM12, v6906). This GUI is comprised of these three segments:

- **Bayesian Parameter Inference** (BPI) (bayinf_bpi.m), a function for calculating *Posterior Probability Maps* (PPMs) of finding the effect within or outside the Region Of Practical Equivalence (ROPE), as well as *Log Posterior Odds maps* (LPOs) based on PPMs.
- **ROPE maps** (bayinf_rope_maps.m), a function for calculating the ROPE maps based on the 'ROPE-only' or 'HDI+ROPE' decision rule.
- **Visualisation:** a GUI for visualising structural MRI images & overlaying statistical maps over them, as well as producing slices of these MRI images.

1. Before use

BayInf is a toolbox based on the SPM package. Before running these scripts, use SPM12 (v6906) to:

1. Create GLM for a one-sample or two-sample test.
2. Estimate model using the *Classical* method.
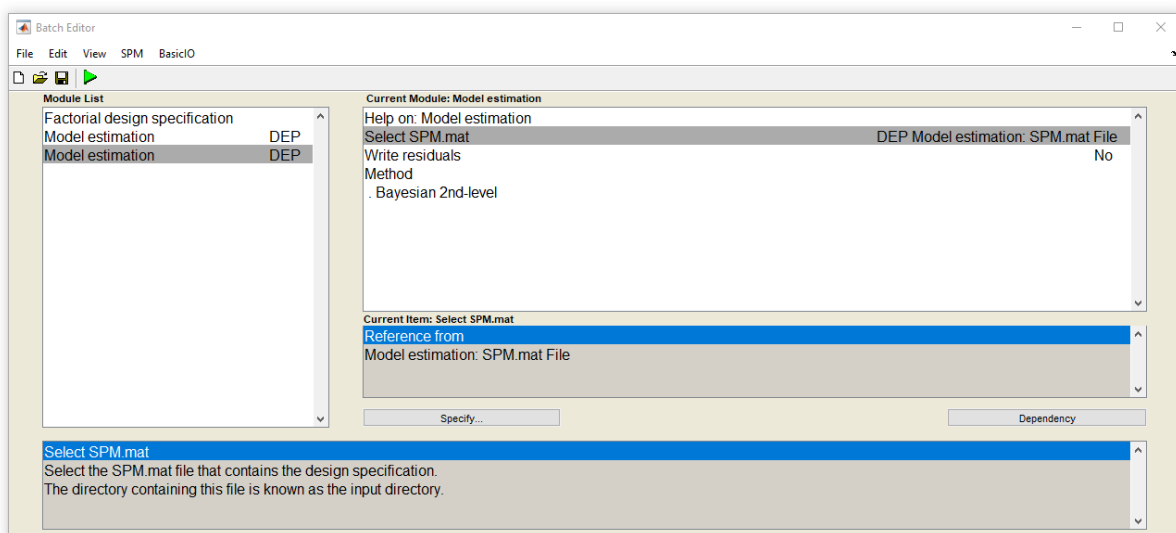3. Estimate model using the *Bayesian 2nd-level* method (see Fig.1).

Figure 1. SPM12 batch editor. Model estimation: Bayesian 2nd-level.

It is recommended to scale linear contrasts of beta-values ($\theta = cB$) to percent signal change (PSC) before model estimation (for example, see the 'scale_raw_betas_to_PSC.m' script).
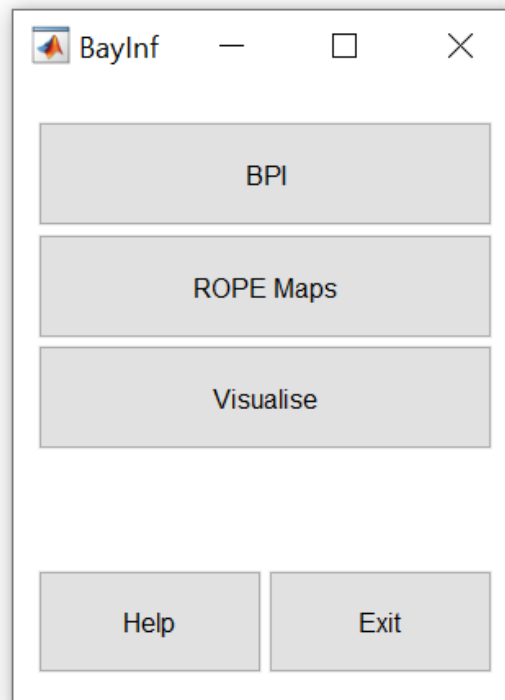
2. How to Use

Figure 2. The starting BayInf GUI window.

1. Download the *BayInf_GUI* folder and add it to the MATLAB path.
2. Run the *bayinf.m* script for the GUI to appear (see Fig.2).
3. Click *BPI* to run the Bayesian Parameter Inference function (alternatively, run the *bayinf_bpi.m* script directly from the command window).
4. Click *ROPE Maps* to calculate ROPE maps (alternatively, run the *bayinf_rope_maps.m* script directly from the command window).
5. Click *Visualisation* to open the GUI for visualising the structural image and its overlays (alternatively, run the *bayinf_vis.m* script directly from the command window). The same GUI will also appear after either *BPI* or *ROPE Maps* function is completed; in that case, the windows will open with overlays already added to the image, produced by these functions.
6. Click *Help* to open the manual (manual.pdf).
7. Click *Exit* to close the GUI.

3. GUI Functions

3.1. Bayesian Parameter Inference (*bayinf_bpi.m*)

1. Select *SPM.mat* file for one-sample or two-sample model.
2. Select contrast.
3. Choose decision rule: 'ROPE-only' or 'HDI+ROPE'.
4. Choose effect size (ES) threshold γ, which defines the region of practical equivalence (ROPE) .

   4.1. The $\gamma(Dice_{max})$ threshold can be used when there are significant voxels revealed by classical NHST with FWE-correction of p<0.05 (*optionally*). $\gamma(Dice_{max})$ threshold ensures maximum similarity of the activation patterns revealed by classical NHST (pFWE<0.05) and BPI.

   4.2. The user can choose any ES threshold in PSC values (PSC corresponding to one prior SD of the contrast is offered by default) (*recommended*).
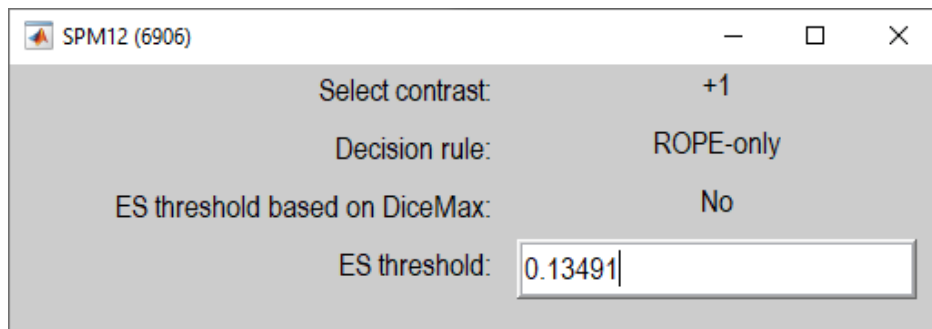

Figure 3. Bayesian parameter inference GUI window.

The output files will be created in the same folder where the SPM.mat file is stored. The output files will be stored in 'ROPE-only' or 'HDI-ROPE' folder. The (*bayinf_bpi.m*) script creates raw Posterior Probability Maps (PPMs) and PPMs scaled to Log Posterior Odds (LPOs).

$$LPO = \ln\left(\frac{PP}{1 - PP}\right)$$

LPO > 3 corresponds to PP > 95%.

LPOs and PPMs are created for:

1. Positive effects: $P_{act} = P(\theta > \gamma | D)$
2. Null effects: $P_{null} = P(-\gamma \leq \theta \leq \gamma | D)$
3. Negative effects: $P_{deact} = P(\theta < -\gamma | D)$

3.2. ROPE maps (*bayinf_rope_maps.m*)

1. Select *SPM.mat* file for one-sample or two-sample model.
2. Select contrast.
3. Choose decision rule: 'ROPE-only' or 'HDI+ROPE'.

The output files will be created in the same folder where the SPM.mat file is stored. The output files will be stored in 'ROPE_maps' folder.

For positive/negative or "(de)activated" voxels, the ROPE map contains maximum ES thresholds allowing to classify voxels as "(de)activated" based on the "ROPE-only" or "HDI+ROPE" decision rules. For null or "not activated" voxels, it contains minimum effect size thresholds allowing to classify voxels as "not activated."

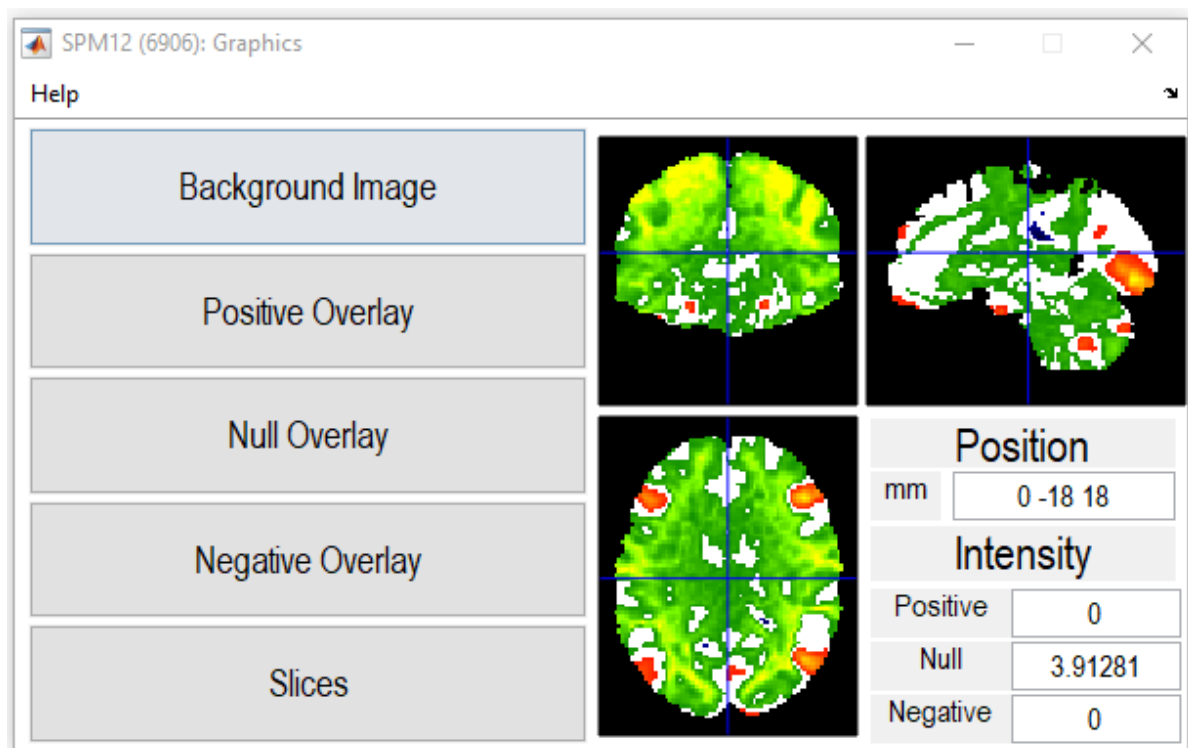## 3.3. Visualisation (*bayinf_vis.m*)

Figure 4. Visualisation GUI window.

Visualisation produces a window containing three orthogonal brain images, as well as various buttons for interacting with these images:

1. *Position* is a field containing the current cross-hairs coordinates of the image's slices, in millimeters. If the user inputs their own coordinates in the field, the location of the crosshair will change accordingly. All coordinates used in the GUI correspond to the standard MNI coordinate space.
2. *Intensity* (*Positive*, *Null* and *Negative*) signifies the intensity of the overlay at the crosshair's position (positive, null and negative respectively).

3. *Background Image* opens a file dialog allowing the user to select a structural image or binary mask (e.g. *mask.nii*). By default, the *mni152_2009_256.nii* structural image is selected. However, if the visualisation window is opened after producing overlays with the *BPI* or *ROPE Maps* functions, the *mask.nii* binary mask will be used instead (stored in the same folder as SPM.mat).

4. *Positive Overlay, Null Overlay* and *Negative Overlay* allow the user to select overlays (red-, green- and blue-coloured, respectively). The buttons open a new window for customising the appearance of the overlays, which consists of these elements:

● *Path* (button): selects the path to the NIFTI file containing the overlay. If the visualisation window was opened after the completion of either the BPI or ROPE Maps function, then the paths to the overlays created by these functions will be selected automatically.
● *Minimum* and *Maximum* (fields): defines the lowest and highest levels of intensity displayed in the GUI. Any parts of the overlay whose intensity is lower than the minimum threshold are removed from the overlay entirely, while any intensity higher than the maximum will be shown by the brightest colour possible, without any differentiation between them. The default thresholds are 3 and 27, unless called from the ROPE Maps function, in which case the minimum is 0 and the maximum is the highest intensity in the overlay.
● *Reset* (button): removes the overlay and sets the minimum and maximum thresholds to the default levels.
● *Save* (button): saves the overlay, containing only the values above the minimum threshold, as a separate file.
● *Done* (button): confirms the changes and closes the window.
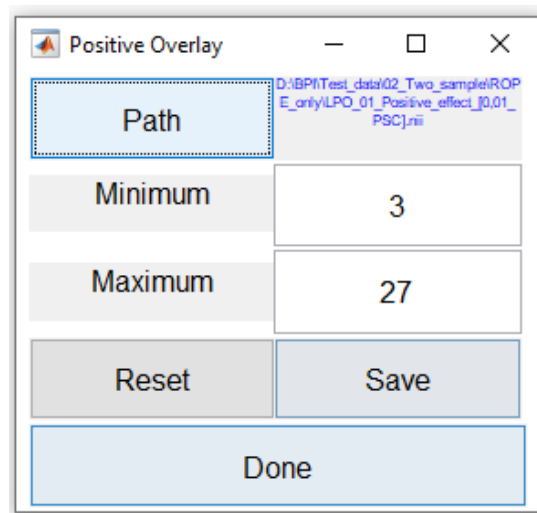

Figure 5. Overlay GUI window.

5. *Slices* allows the user to view the slices of the background image with the overlays, and save them as a separate image. It also opens a separate window with these elements:

- *Positions* (field): defines the positions (in millimeters) at which slices will be made.
- *Direction* (box): defines the direction at which the three-dimensional image will be cut (Sagittal, Coronal or Axial).
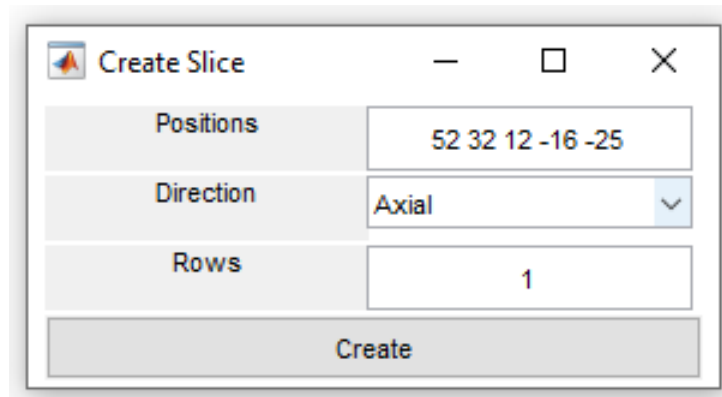- *Rows* (field): defines the amount of rows in the final image.

Figure 6. Create slice GUI window.

- *Create* (buttons): confirms the settings and creates the image. That image can then be saved by right-clicking it and pressing the *Save* button.
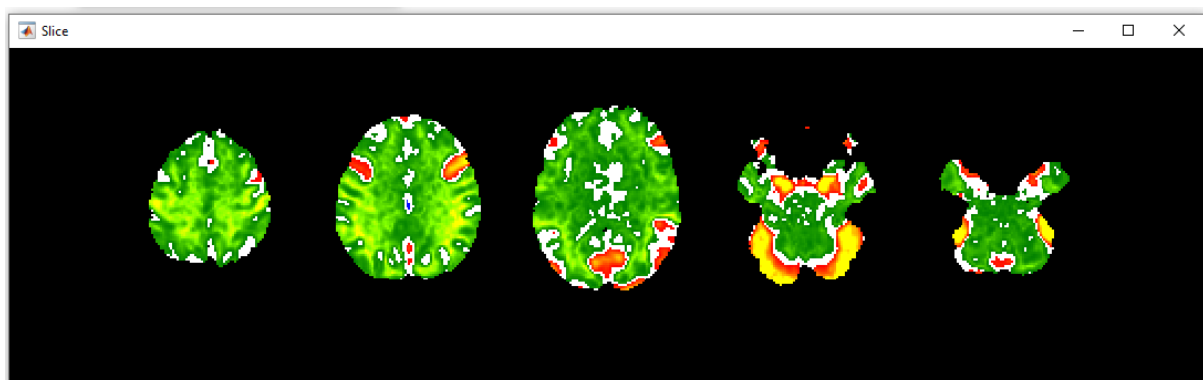

Figure 7. Created slices. The image can then be saved by right-clicking it and pressing the *Save* button.

References

Friston, K., Penny, W., Phillips, C., Kiebel, S., Hinton, G., & Ashburner, J. (2002a). Classical and Bayesian Inference in Neuroimaging: Theory. NeuroImage, 16(2), 465–483. https://doi.org/10.1006/nimg.2002.1090

Friston, K., Glaser, D., Henson, R., Kiebel, S., Phillips, C., & Ashburner, J. (2002b). Classical and Bayesian Inference in Neuroimaging: Applications. NeuroImage, 16(2), 484–512. https://doi.org/10.1006/nimg.2002.1091

Friston, K., & Penny, W. (2003). Posterior probability maps and SPMs. NeuroImage, 19(3), 1240–1249. https://doi.org/10.1016/s1053-8119(03)00144-7

Kruschke, J. K., & Liddell, T. M. (2017). The Bayesian New Statistics: Hypothesis testing, estimation, meta-analysis, and power analysis from a Bayesian perspective. Psychonomic Bulletin & Review, 25(1), 178–206. https://doi.org/10.3758/s13423-016-1221-4

Penny, W. D., & Ridgway, G. R. (2013). Efficient Posterior Probability Mapping Using Savage-Dickey Ratios. PLoS ONE, 8(3), e59655. https://doi.org/10.1371/journal.pone.0059655