Test of Goodness for Population Receptive Field Estimates

simulation study

A. Ashrafnejad[1] H. Mehrzadfar[2] H. Boyaci[2 3]

[1]Department of Electrical and Electronics Engineering

[2]Neuroscience Graduate Program

[3]Department of Psychology
Bilkent University

November 5, 2018

Stimulation

- drifting bar stimululation in Dumoulin and Wandell, 2008:

fMRI Signal Modelling

BOLD response model

$$B(t) = \mathcal{H}(\quad r(t, \Theta = \theta)) + e(t)$$

fMRI Signal Modelling

BOLD response model

$$B(t) = \mathcal{H}(\quad r(t, \Theta = \theta)) + e(t)$$

Linear or Non-linear HRF function

fMRI Signal Modelling

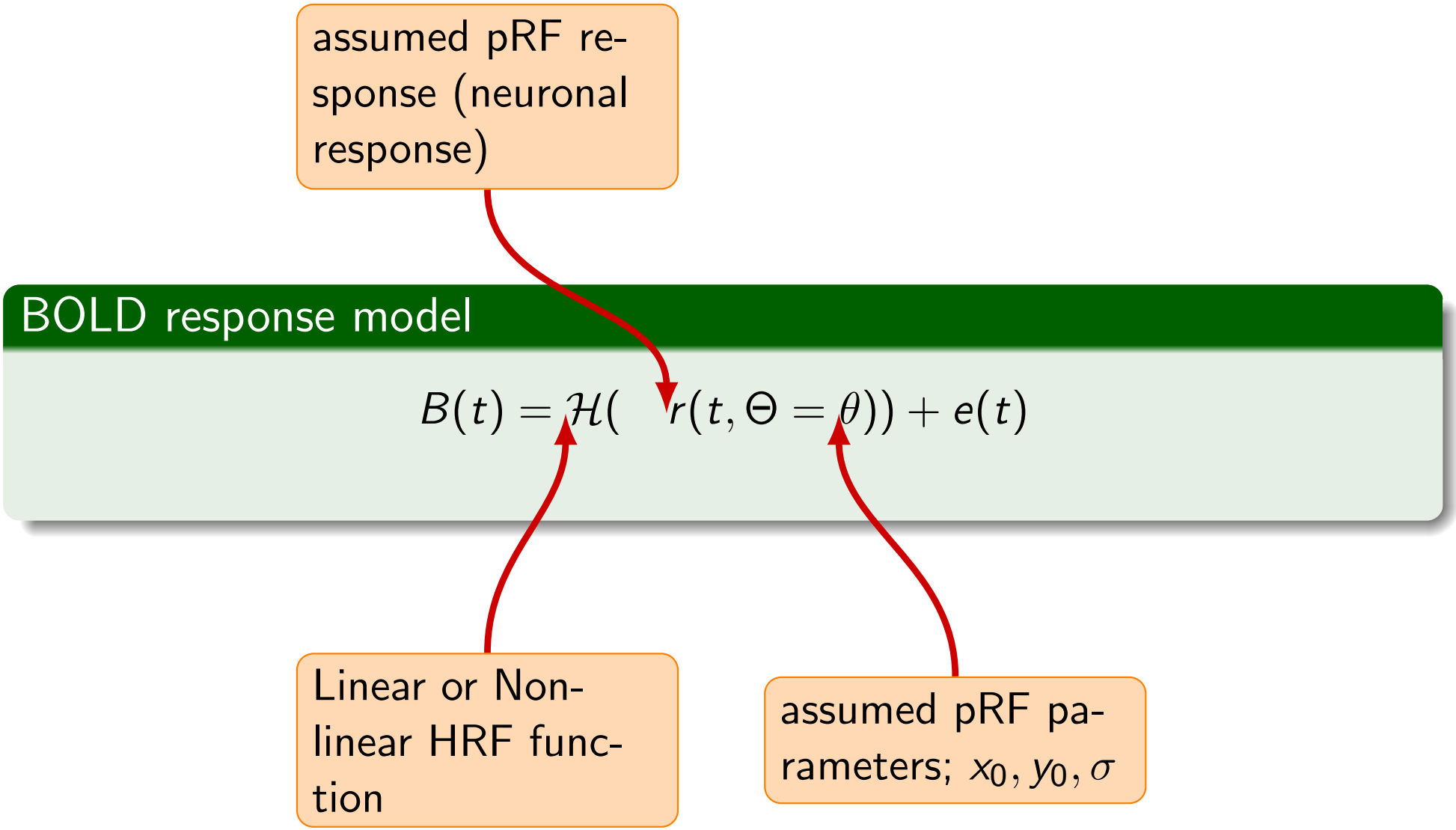
assumed pRF response (neuronal response)

BOLD response model

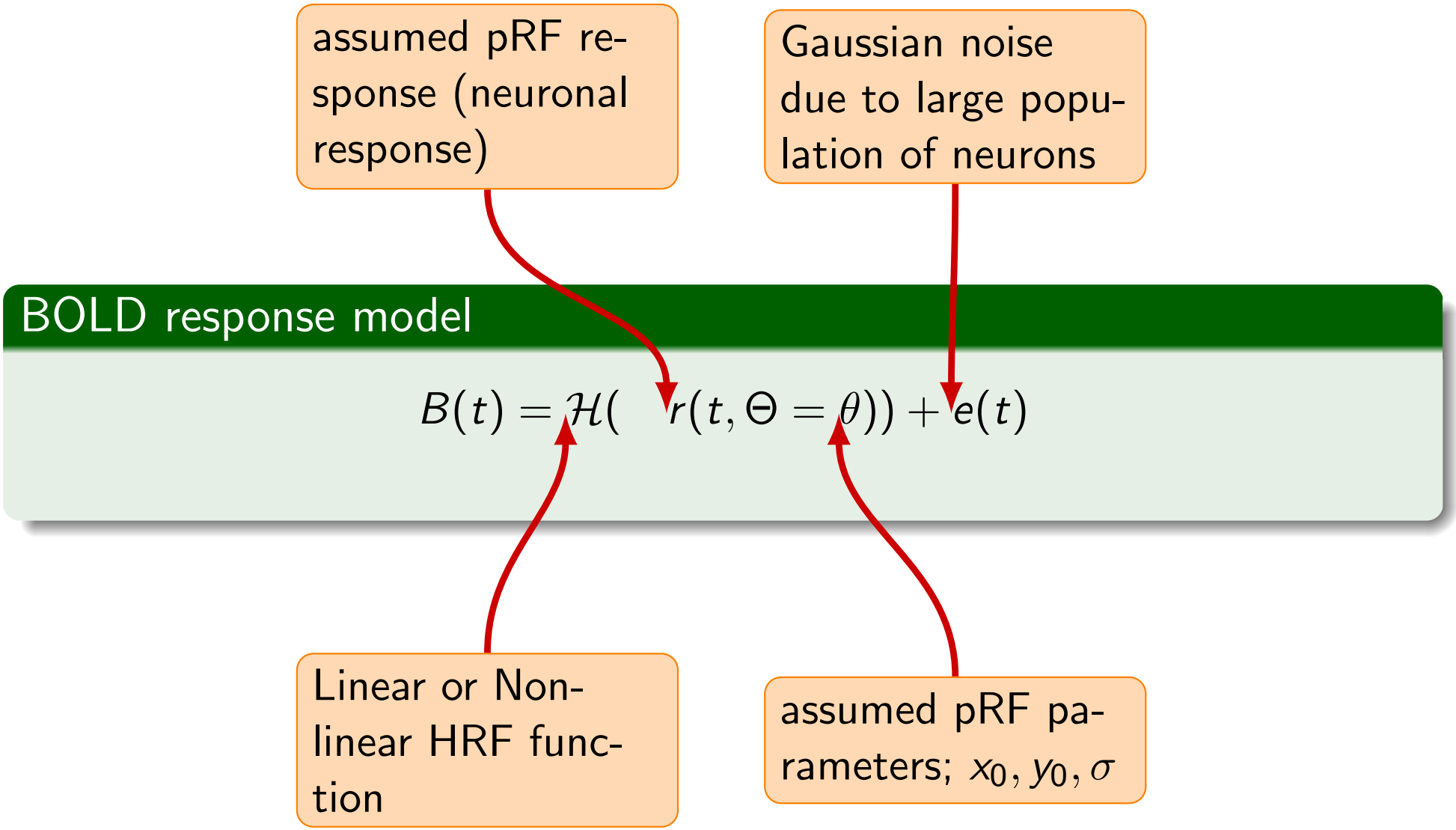
$$B(t) = \mathcal{H}(\quad r(t, \Theta = \theta)) + e(t)$$

Linear or Non-linear HRF function

fMRI Signal Modelling



fMRI Signal Modelling



Neuronal Response Modelling

- Neurons within a small region of visual cortex respond to stimuli within a restricted region of the visual field.
- The population response of such neurons can ***not*** be modeled using a model that sums contrast linearly across the visual field. hence, Compressive spatial summation (CSS) model is used Kay et al., 2013,

pRF response model

$$r(t, \Theta = \theta) = (\sum_{x,y} s(x, y, t) g(x, y, \theta))^n$$

Neuronal Response Modelling

- Neurons within a small region of visual cortex respond to stimuli within a restricted region of the visual field.
- The population response of such neurons can ***not*** be modeled using a model that sums contrast linearly across the visual field. hence, Compressive spatial summation (CSS) model is used Kay et al., 2013,

pRF response model

$$r(t, \Theta = \theta) = (\sum_{x,y} s(x, y, t) g(x, y, \theta))^n$$

stimulus function to be presented

Neuronal Response Modelling

- Neurons within a small region of visual cortex respond to stimuli within a restricted region of the visual field.
- The population response of such neurons can ***not*** be modeled using a model that sums contrast linearly across the visual field. hence, Compressive spatial summation (CSS) model is used Kay et al., 2013,

pRF response model

$$r(t, \Theta = \theta) = (\sum_{x,y} s(x, y, t) g(x, y, \theta))^n$$

stimulus function to be presented

assumed pRF model

Neuronal Response Modelling

- Neurons within a small region of visual cortex respond to stimuli within a restricted region of the visual field.
- The population response of such neurons can ***not*** be modeled using a model that sums contrast linearly across the visual field. hence, Compressive spatial summation (CSS) model is used Kay et al., 2013,

pRF response model

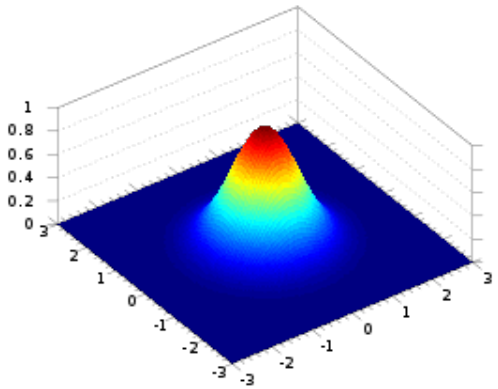
$$r(t, \Theta = \theta) = (\sum_{x,y} s(x, y, t) g(x, y, \theta))^n$$

stimulus function to be presented

assumed pRF model

spatial linearity factor from 0 to 1

pRF Modelling

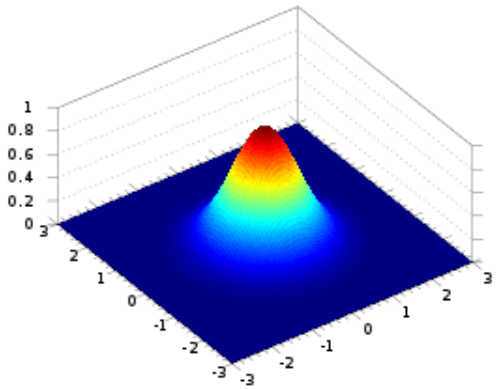


$$\sigma = \frac{1}{2}\ln(e + \sqrt{x_0^2 + 2y_0^2})$$

pRF response model

$$g(x, y, \Theta = \theta) = e^{-\frac{(x-x_0)^2+(y-y_0)^2}{2\sigma^2}}$$

pRF Modelling



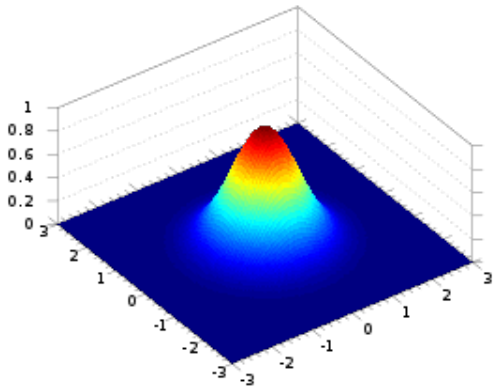
$$\sigma = \frac{1}{2}\ln(e + \sqrt{x_0^2 + 2y_0^2})$$

pRF response model

$$g(x, y, \Theta = \theta) = e^{-\frac{(x-x_0)^2+(y-y_0)^2}{2\sigma^2}}$$

assumed pRF center for the voxel

pRF Modelling



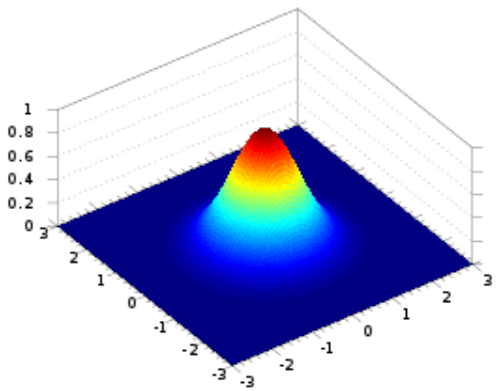
$$\sigma = \frac{1}{2}\ln(e + \sqrt{x_0^2 + 2y_0^2})$$

pRF response model

$$g(x, y, \Theta = \theta) = e^{-\frac{(x-x_0)^2+(y-y_0)^2}{2\sigma^2}}$$

assumed pRF center for the voxel

pRF Modelling



$$\sigma = \frac{1}{2}\ln(e + \sqrt{x_0^2 + 2y_0^2})$$

pRF size assumed to be a log-polar function of pRF center Harvey and Dumoulin, 2011

pRF response model

$$g(x, y, \Theta = \theta) = e^{-\frac{(x-x_0)^2+(y-y_0)^2}{2\sigma^2}}$$

assumed pRF center for the voxel

Haemodynamic Response Function Modelling

Canonical Linear HRF model

$$\mathcal{H}(r(t)) = r(t) * h(t)$$

$$h(t) = \frac{1}{C}\frac{\lambda_1^{n_1}(t-t_1)^{n_1-1}e^{-\lambda_1(t-t_1)}}{(n_1-1)!} - a\frac{\lambda_2^{n_2}(t-t_2)^{n_2-1}e^{-\lambda_2(t-t_2)}}{(n_2-1)!}$$

Friston Non-Linear HRF

$$\mathcal{H}(r(t)) = \sum_{i=1}^{3}\beta_i x_i(t) + \sum_{i=1}^{3}\sum_{j=1}^{3}\beta_{ij}x_i(t)x_j(t)$$

$$x_i(t) = (r * b_i)(t), \quad b_i(t) = \frac{1}{k!}t^k e^{-t} \quad k = 5, 7, 15$$

pRF Estimation

MSE model

$$r(t,\Theta) = (\sum_{x,y} s(x,y,t)g(x,y,\Theta))^n$$

$$p(t,\Theta) = \mathcal{H}(r(t,\Theta))$$

$$\hat{\Theta} = \arg\min \sum_{t} (B(t) - p(t,\Theta))^2$$

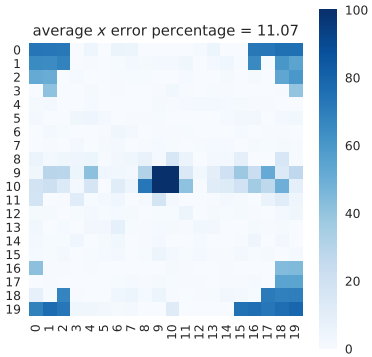
pRF Evaluation

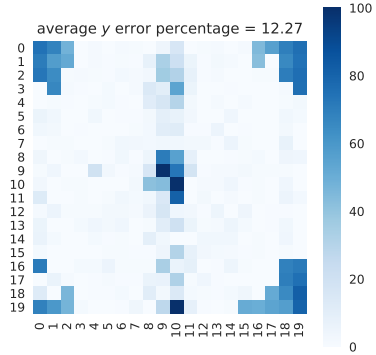
Accuracy Map Evaluation

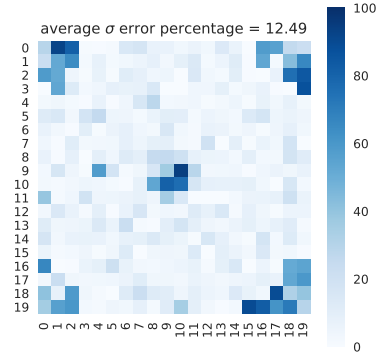
$$\tilde{x} = \frac{|\hat{x_0} - x_0|}{x_0}, \ \tilde{y} = \frac{|\hat{y_0} - y_0|}{y_0}, \ \tilde{\sigma} = \frac{|\hat{\sigma} - \sigma|}{\sigma}$$

Preliminary Results

- Estimating with non-linear HRF.

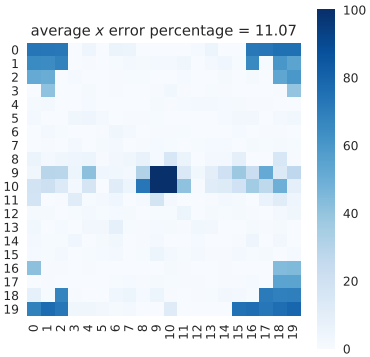


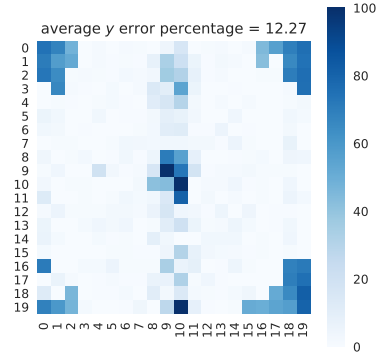


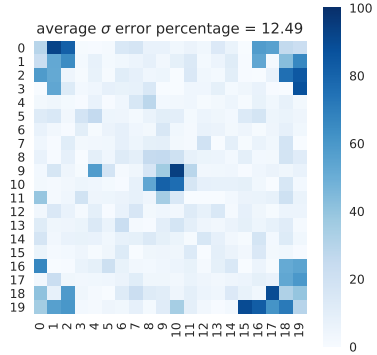


Preliminary Results

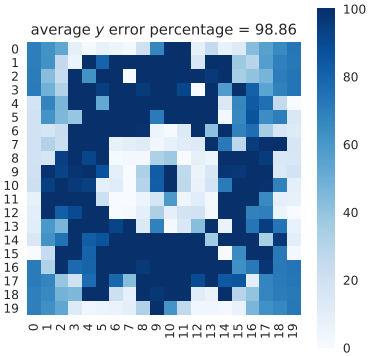
- Estimating with non-linear HRF.

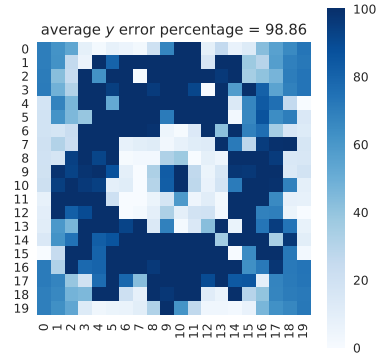


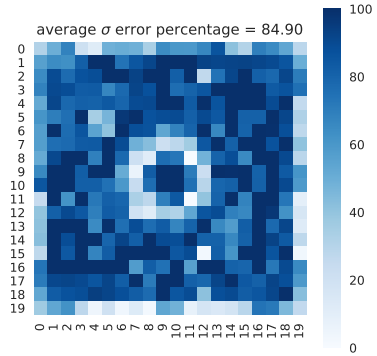




- Estimating with linear HRF.

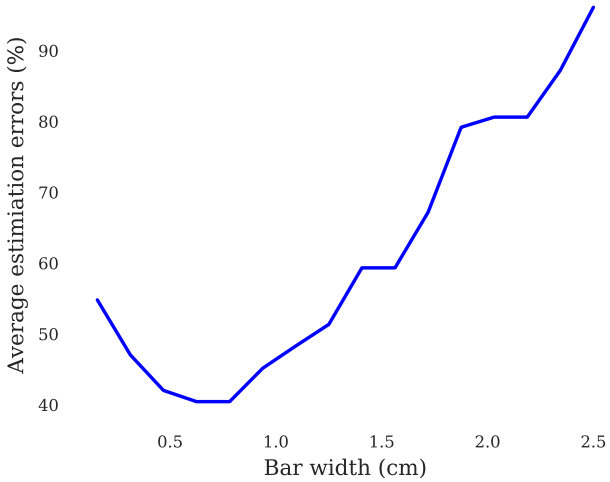


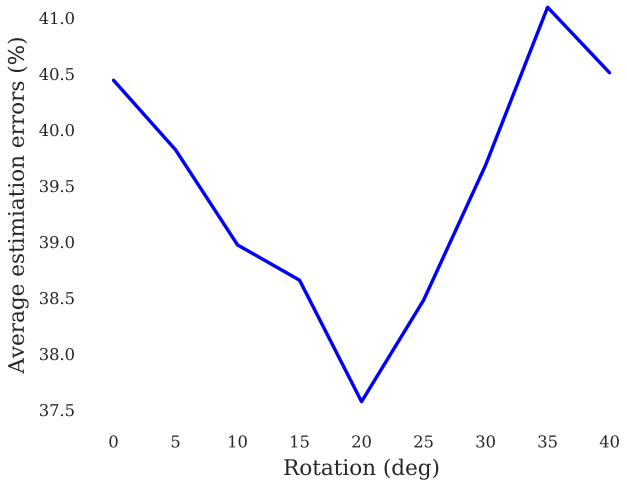




Optimization

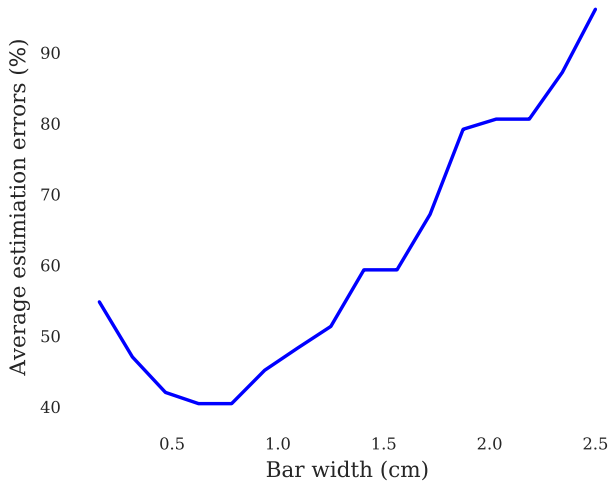
- Optimization of parameters.

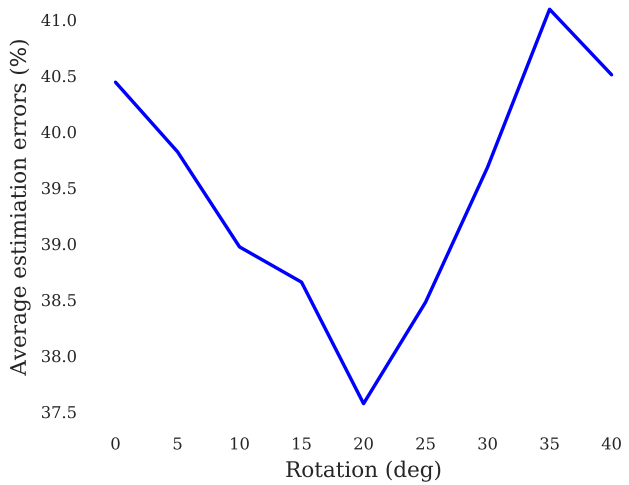




Optimization

- Optimization of parameters.

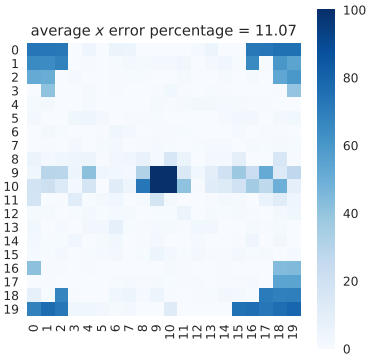


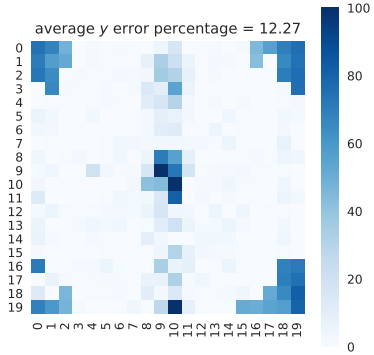


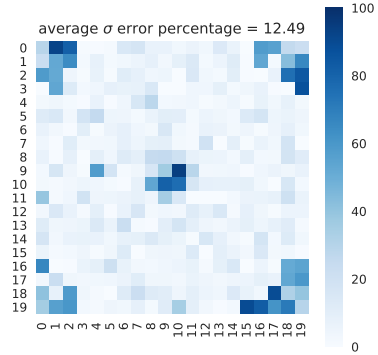
- Optimized Stimulus.

Optimized Results

- Estimating with linear HRF via Non-optimized stimulus

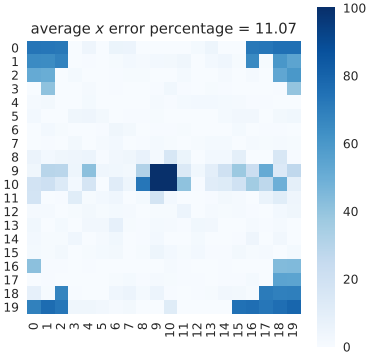


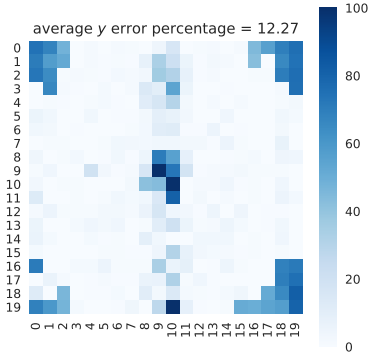


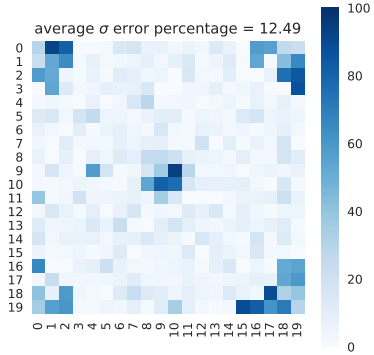


Optimized Results

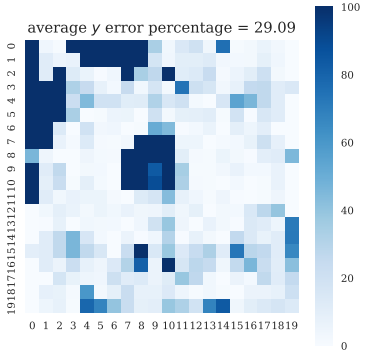
- Estimating with linear HRF via Non-optimized stimulus

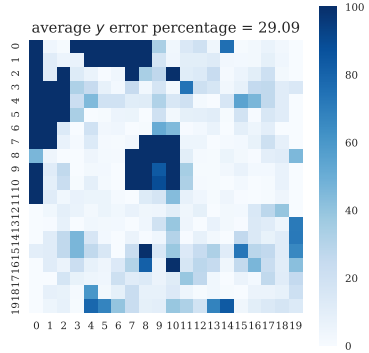


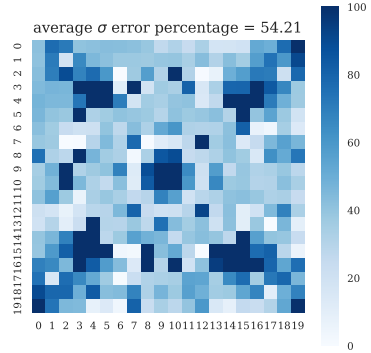




- Estimating with linear HRF via Optimized stimulus







Discussion and Future work

Discussion

- We found that non-linearity in simulation HRFs may lead to erroneous pRF estimations. However, we showed that it is possible to optimize the stimulution parameters to ameliorate the effect this non-linearity.
- Therefore, we highly recommend that the stimulation protocol (i.e., stimulation and experiment parameters) should be fine-tuned using computer simulations before an actual fMRI experiment is conducted.

Future work

- Optimization of more parameters using different stimulus.
- fMRI experiments to validate the improvement of pRF estimates.

References I

Dumoulin, Serge O. and Brian A. Wandell (2008). "Population receptive field estimates in human visual cortex". In: *NeuroImage* 39.2, pp. 647–660. ISSN: 10538119. DOI: 10.1016/j.neuroimage.2007.09.034.

Harvey, B. M. and S. O. Dumoulin (2011). "The Relationship between Cortical Magnification Factor and Population Receptive Field Size in Human Visual Cortex: Constancies in Cortical Architecture". In: *Journal of Neuroscience* 31.38, pp. 13604–13612. ISSN: 0270-6474. DOI: 10.1523/JNEUROSCI.2572-11.2011. URL: http://www.jneurosci.org/cgi/doi/10.1523/JNEUROSCI.2572-11.2011.

Kay, Kendrick N. et al. (2013). "Compressive spatial summation in human visual cortex.". In: *Journal of neurophysiology*. ISSN: 1522-1598. DOI: 10.1152/jn.00105.2013.