

# TEST OF GOODNESS OF POPULATION RECEPTIVE FIELD ESTIMATES

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#### INTRODUCTION

We present a method based on computer simulations to test the goodness of population receptive field (pRF) estimates. In particular, we have examined the effect of having non-linearity in the hemodynamic response function (HRF) by,

- 1. Simulating fMRI responses with nonlinear "simulation HRFs"
- 2. Estimating pRFs with a "similar" linear "estimation HRF"

This is an important scenario to test since many estimation methods assume linear HRF models but actual HRF response is nonlinear. Hence we present a pipeline to test robustness of stimulation protocols against non-linearities in the BOLD response.

#### METHOD

We have developed a test based on models in [1][2] with following steps:

1. Parameter Initialization

Define pRF vector  $\Theta = (x_0, y_0, \sigma)$ . Initialize  $\Theta = \theta$  such that  $x_0, y_0$  are receptive field locations in the visual field corresponding to a voxel measurement and the pRF size is modeled accordingly to account for cortical mapping,

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

2. Data Generation

$$g(x, y, \Theta = \theta) = e^{-\frac{(x - x_0)^2 + (y - y_0)^2}{2\sigma^2}}$$
$$r(t, \Theta = \theta) = (\sum_{x,y} s(x, y, t)g(x, y, \theta))^n$$
$$B(t) = h(r(t, \Theta = \theta)) + e(t)$$

3. Parameter Estimation

$$r(t,\Theta) = (\sum_{x,y} s(x,y,t)g(x,y,\Theta))^n$$
 
$$p(t,\Theta) = h(r(t,\Theta))$$
 
$$\hat{\Theta} = \arg\min \sum_{t} (B(t) - p(t,\Theta))^2$$

4. Accuracy Map Evaluation

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

with following variable descriptions:

x, y =point in visual space

n =spatial linearity factor

 $g(x, y, \Theta) = pRF \text{ model}$ 

s(x, y, t) = stimulation function

 $r(t, \Theta) = pRF$  response

e(t) = Gaussian noise

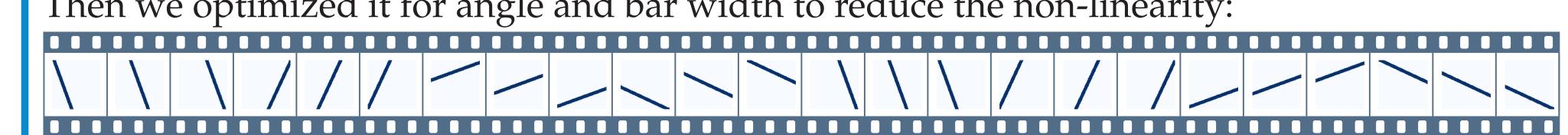
B(t) = BOLD response

h(.) = HRF function

#### STIMULATION

We first used the exact drifting bar stimululation in [1]:

Then we optimized it for angle and bar width to reduce the non-linearity:



#### EXPERIMENT

We use following HRFs:

• Double-Gamma Linear HRF

$$p(t) = r(t) * h(t)$$

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

$$- a \frac{\lambda_2^{n_2} (t - t_2)^{n_2 - 1} e^{-\lambda_2 (t - t_2)}}{(n_2 - 1)!}$$

where C is the normalizing constant.

• Friston Non-Linear HRF

$$p(t) = \sum_{i=1}^{3} \beta_{i} x_{i}(t)$$

$$+ \sum_{i=1}^{3} \sum_{j=1}^{3} \beta_{ij} x_{i}(t) x_{j}(t)$$

$$x_{i}(t) = (r * b_{i})(t)$$

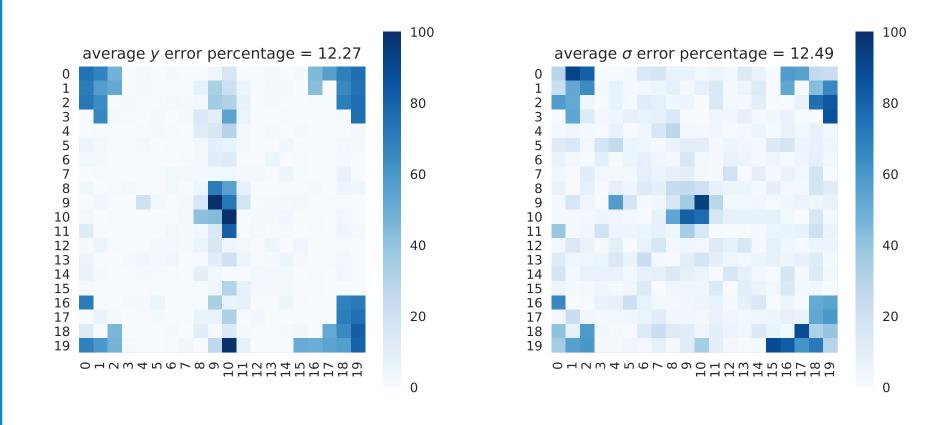
$$b_{i}(t) = \frac{1}{k!} t^{k} e^{-t} \quad k = 5, 7, 15$$

HRF non-linearity experiment steps:

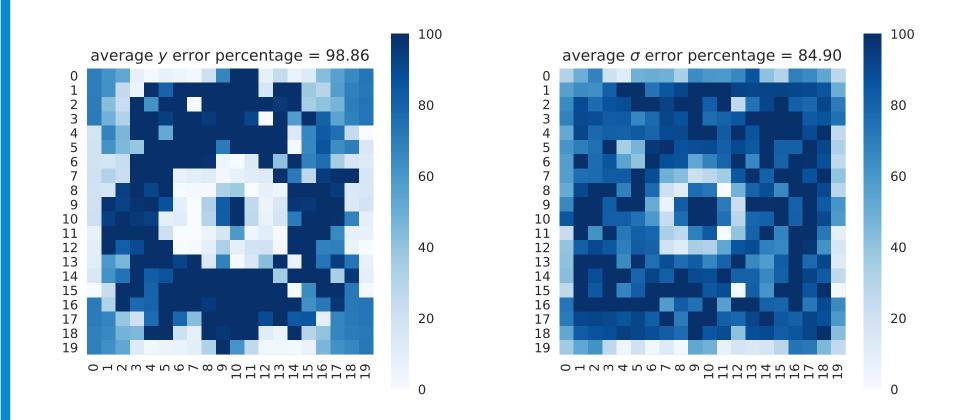
- 1. Initialize parameters
  - (a) number of voxels to simulate
  - (b) spatial linearity factor
  - (c) double-Gamma HRF
- 2. Estimate from linear BOLD response
- 3. Find parameter of non-Linear HRF
- 4. Estimate from non-Linear response
- 5. Repeat 4 to optimize the bar width size
- 6. Repeat 4 with optimized bar width to optimize the rotation angle

#### RESULTS

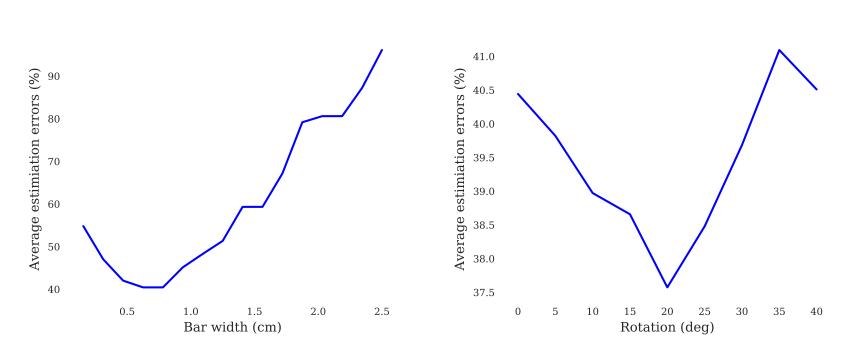
Accuracy maps when simulating with linear HRF and estimating with linear HRF.



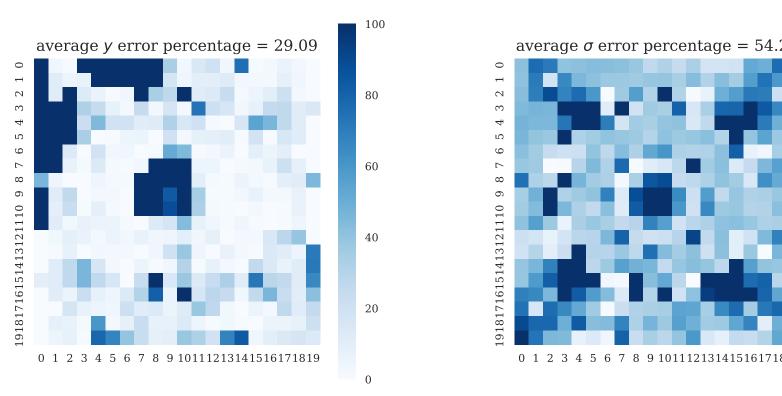
Accuracy maps when simulating with nonlinear HRF and estimating with linear HRF:



Optimization of parameters with average of estimation errors over all pRF parameters:



maps of same experiment with optimized parameters for size and rotation:



### 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 finetuned using computer simulations before an actual fMRI experiment is conducted.

## REFERENCES

- [1] S. Dumoulin, B. Wandell. Population Receptive Field Estimates in Human Visual Cortex. In NeuroImage '08
- [2] K. Kay and J. Winawer et all. Compressive Spatial Summation in Human Visual Cortex. In Journal of Neurophysiology '13

## SOURCE CODE

The Python prfsim package can directly be installed from PyPI: 'pip install prfsim' The source code is available at,

github.com/arash-ash/pRFsim

