BOLD Parameter Estimation using Sequential Monte Carlo Methods

Micah Chambers

Bradley Department of Electrical and Computer Engineering
Virginia Tech University

February 23, 2010

Outline

The BOLD Response

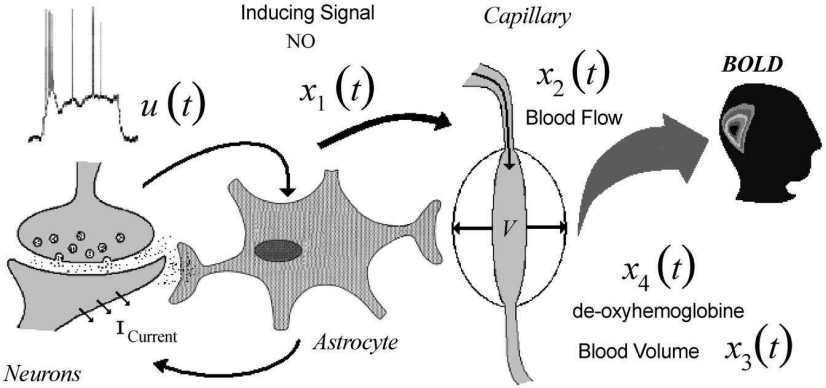


Figure: [Riera et al.(2004)Riera, Watanabe, Kazuki, Naoki, Aubert, Ozaki, and Kawashima]

Purpose/Usefullness

- blah

BOLD Signal Properties

- ...
  - Exact variables and parameters are unknown and are difficult to calculate.
  - Significant Amount of Lag between activation and a measurable output - can be as much as 8 seconds.
- Slow Temporal Resolution
- Noise characterized by brownian motion
- fft of mri signal, with and without DC

Preprocessing

- High Pass Filter and Low Pass Filter
- Wavelet Detrending
- ...
- Spline

Method

Results

- ...

Limitations

- ...

Equations

- Normalized Cerebral Blood Flow:

$$\ddot{f}(t) = \epsilon u(t) - \dot{f}(t)/\tau_s - (f(t)/\tau_f - 1)$$

- Normalized Cerebral Blood Volume:

$$\dot{v}(t) = (1/\tau_0)(f(t) - v(t)^{1/\alpha})$$

- Normalized Deoxyhaemoglobin Content:

$$\dot{q}(t) = \frac{1}{\tau_0}\left(\frac{f(t)(1-(1-E_0)^{1/f(t)})}{E_0} - \frac{q(t)}{v(t)^{1-1/\alpha}}\right)$$

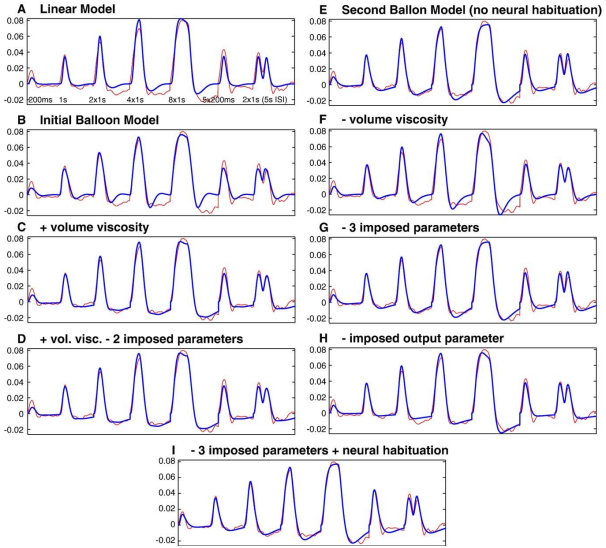
- Hemodynamic Response - BOLD Signal

$$y(t) = V_0(a_1(1-Q(t)) - a_2(1-V(t)))$$

Alternative Equations

- The Balloon Model proposed by [**?**] is the basic model.
- There are more complicated versions of the BOLD model:
  - [Deneux and Faugeras(2006)] Reviews several existing models
  - [Buxton et al.(2004)Buxton, Uludag, Dubowitz, and Liu] Pioneered the Balloon model which was shown in the beginning.
  - [Zheng et al.(2005)Zheng, Johnston, Berwick, Chen, Billings, and Mayhew] Adds interesting neural activation and a habituation model
  - Some models loosen the link between CMRO2 (oxygen metabolism) and Cerebral Blood Flow - likely due to several papers that report such a decoupling.

Model Comparisons



Particle Filters

- Why Particle Filters
- Goal: ϵ
- Entire brain

Single Timeseries Results

Simulation

Simulation Results

R. B. Buxton, K. Uludag, D. J. Dubowitz, and T. T. Liu. Modeling the hemodynamic response to brain activation. *NeuroImage*, 23(Supplement 1):S220 – S233, 2004. ISSN 1053-8119. doi: DOI:10.1016/j.neuroimage.2004.07.013. URL http://www.sciencedirect.com/science/article/B6WNP-4D98255-3/2/1bd7e28b57ff7243e1c32b07b94fc911. Mathematics in Brain Imaging.

J. J. Chen and G. B. Pike.
Origins of the BOLD post-stimulus undershoot.
NEUROIMAGE, 46(3):559–568, JUL 1 2009.
ISSN 1053-8119.
doi: {10.1016/j.neuroimage.2009.03.015}.

T. Deneux and O. Faugeras.
Using nonlinear models in fMRI data analysis: Model selection and activation detection.
NEUROIMAGE, 32(4):1669–1689, OCT 1 2006.
ISSN 1053-8119.
doi: {10.1016/j.neuroimage.2006.03.006}.

J. Riera, J. Watanabe, T. Kazuki, M. Naoki, E. Aubert, T. Ozaki, and R. Kawashima.
A state-space model of the hemodynamic approach: nonlinear filtering of BOLD signals.
NEUROIMAGE, 21(2):547–567, FEB 2004.
ISSN 1053-8119.
doi: {10.1016/j.neuroimaging.2003.09.052}.

A. Smith, B. Lewis, U. Ruttimann, F. Ye, T. Sinnwell, Y. Yang, J. Duyn, and J. Frank.
Investigation of low frequency drift in fMRI signal.
NEUROIMAGE, 9(5):526–533, MAY 1999.
ISSN 1053-8119.

A. T. Smith, K. D. Singh, and J. H. Balsters.
A comment on the severity of the effects of non-white noise in fMRI time-series.
NEUROIMAGE, 36(2):282–288, JUN 2007.
ISSN 1053-8119.
doi: {10.1016/j.neuroimage.2006.09.044}.

Y. Zheng, D. Johnston, J. Berwick, D. Chen, S. Billings, and J. Mayhew.
A three-compartment model of the hemodynamic response and oxygen delivery to brain.
NEUROIMAGE, 28(4):925–939, DEC 2005.
ISSN 1053-8119.
doi: {10.1016/j.neuroimage.2005.06.042}.