An Adaptive Computational Modeling Framework with an application to real-time fMRI study

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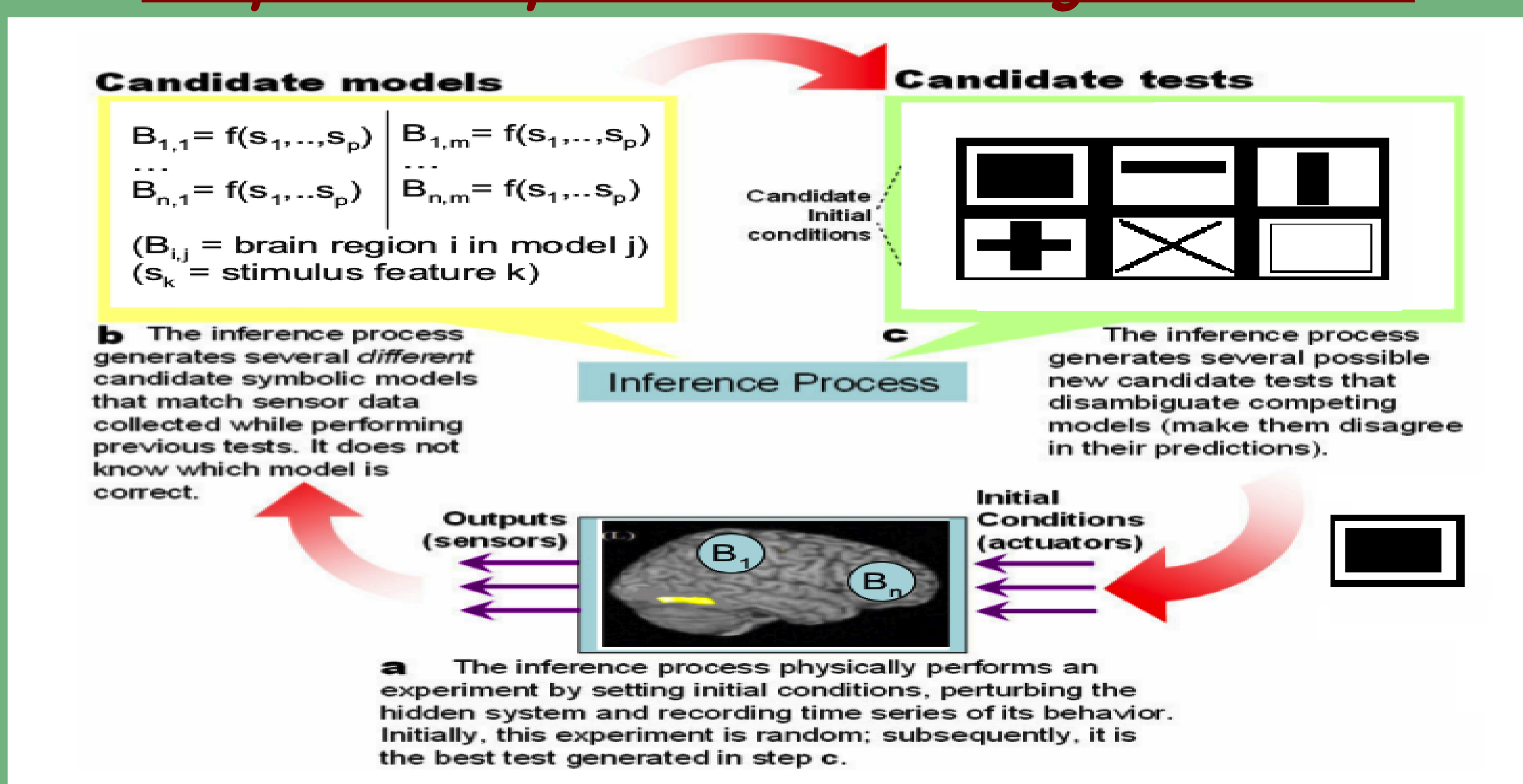
Introduction

Neuroimaging technologies such as the functional magnetic resonance imaging (fMRI) are widely used to collect large amounts of brain activity data in response to stimuli. The common practice in a task-based fMRI study is to design stimuli sequence before conducting the study on human subjects. Then, a mathematical model relating the brain activity to stimuli can be built *off-line*. Stimuli design and experimentation stages can be repeated multiple times to revise the model.

In contrast to the common approach, we automate the fMRI study by integrating the stimulus generation, data collection and modeling stages in alternating cycles *in real-time.* This process, which is based on machine learning, is similar to playing the 20 questions game. By intelligently selecting the next question based on the responses, it is possible to decrease the number of questions one needs to ask to get the correct answer.

Adaptive Computational Modeling Framework



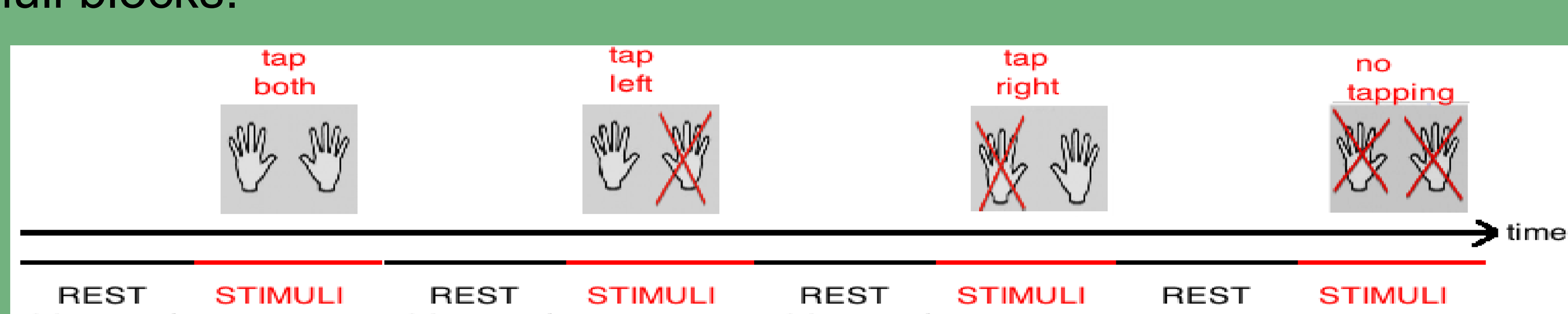
The adaptive computational modeling framework automates the test sequence creation process by intelligently selecting the next test based on the previous outcomes of the experiment and builds the accurate model in much fewer steps in comparison to random selection of tests [1].

Case study: Real-time fMRI on finger-tapping task

Real-time fMRI (rtfMRI) is generally used in neurofeedback applications where participants in the MRI scanner can observe and monitor their brain activity in real-time [2]. Here, we utilize rtfMRI to run a task-based study in real-time. Our framework builds computational models of brain activity by selecting the next stimuli to be presented while the participant is in the scanner.

Task: The participant was a young (20s), right-handed male who was asked to perform finger-tapping in a steady pace (twice a second) according to the visual commands: tap left hand, tap right hand, tap both hands, none.

Scanning sessions: Each scanning session lasted approximately 90 minutes with 4 ~12 minute experiments + pre-processing. Each experiment consisted of 12 rest + stimuli blocks.



References

[1] Bongard, J and Lipson, H (2007). *Automated reverse engineering of nonlinear dynamical systems*. Proceedings of the National Academy of Sciences, 104(24): 9943-9948
[2] deCharms RC (2008). *Applications of real-time fMRI*,Nat Rev Neurosci. 2008 Sep;9(9):720-9.

Acknowledgements

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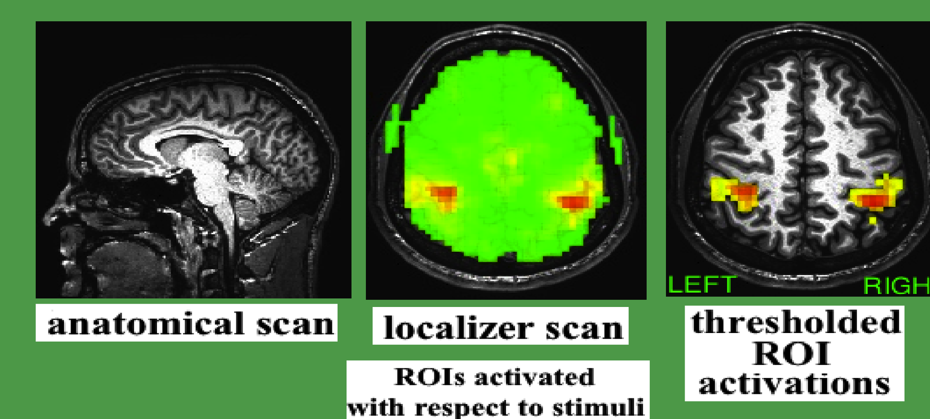
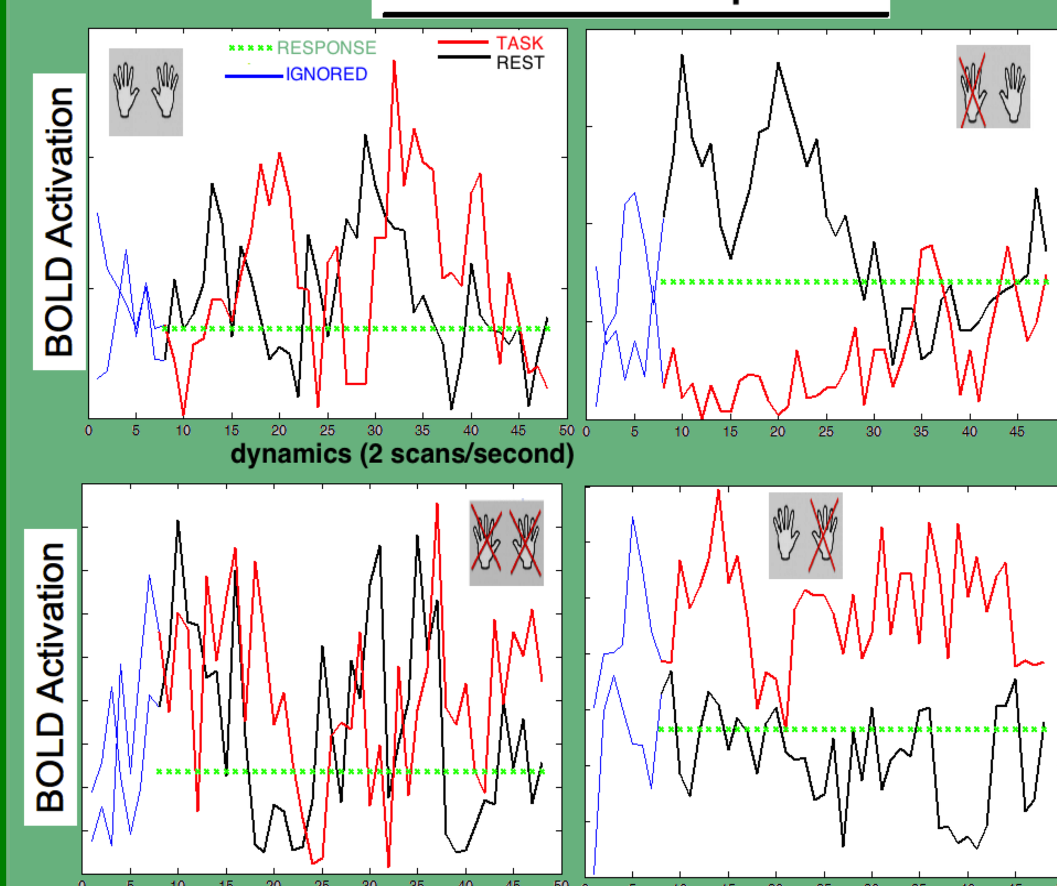
Methods

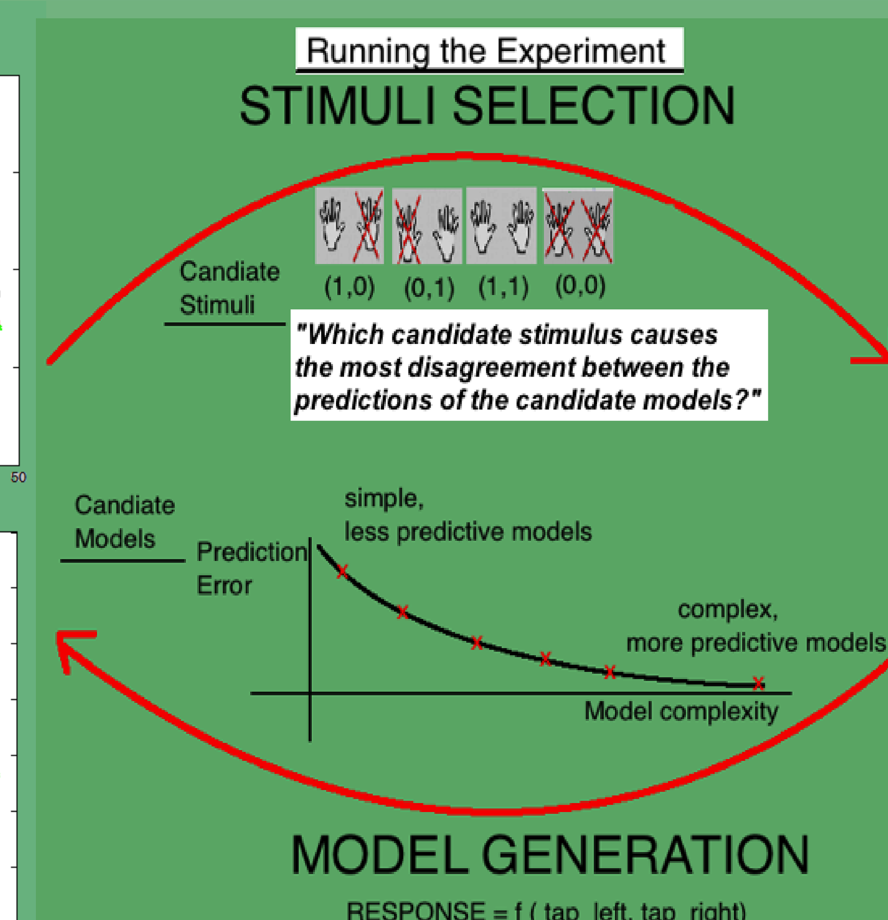
Pre-Processing

1. Image Acquisition (Anatomical and whole-brain functional 'localizer' scans)
2. Identify participant specific ROIs and thresholds
3. Generate masks from which to extract the signal
4. For subsequent acquisition sessions, reorient those masks into the native space of the participant



Real-time Data Acquisition





Results

Variables

controlled (independent variables) -> tap_left (1/0), tap_right(1/0)

observed (dependent variable) - > response

Collected Data

response = | LEFT_ROI_BOLD - RIGHT_ROI_BOLD |

response is high for one handed tapping and low for no tapping/tapping both hands

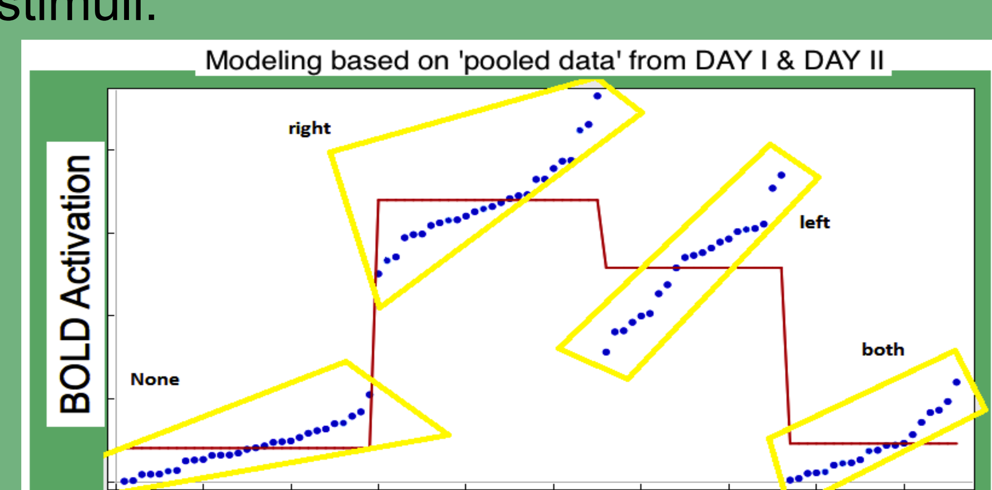
Modeling

tap left	tap right	response
YES (1)	YES (1)	Low (0)
YES (1)	NO (0)	High (1)
NO (0)	YES (1)	High (1)
NO (0)	NO (0)	Low (0)

Exclusive-OR (XOR) function

*response = tap_left + tap_right - 2 * tap_left * tap_right*

We model the absolute difference between the Blood-oxygen-level dependent (BOLD) activations of left and right motor strips in response to the features of the presented stimuli.



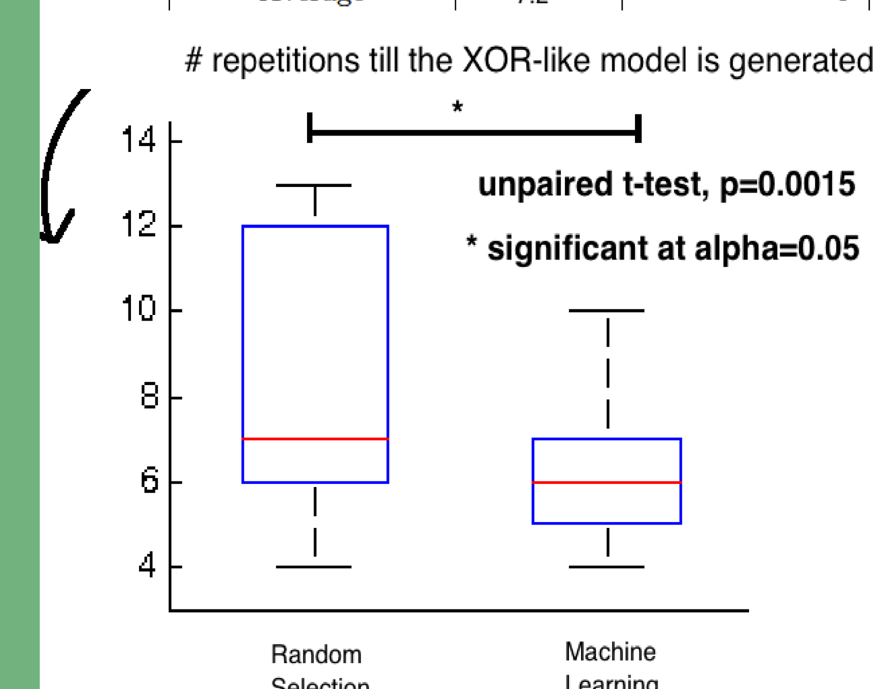
response = 0.00149*tap_right + 0.00109*tap_left - 0.00255*tap_left*tap_right 2.03e-5

Total of 12 rtfMRI finger-tapping experiments completed in three scanning sessions. Half of the experiments utilized the machine learning based method while the rest selected stimuli at random (with replacement).

12 rest-task blocks per experiment

6 experiment sessions per algorithm using rtFMRI

Experiment Day	Random Selection	Machine Learning
DAY I	6	7
DAY I	5	10
DAY II	9	5
DAY II	6	4
DAY III	13 (**)	6
DAY III	4	4
Average	7.2	6



30 'simulated runs' per algorithm based on the response model built from the rtFMRI sessions

Conclusions

The computational modeling framework sketched here has been successfully used in modeling various nonlinear dynamical systems [1] and it is a promising tool for developing more efficient studies automatically, especially when the space of possible inputs (stimuli) is large. Such a tool can be useful in various neuroscience research settings including those utilizing the fMRI.

Presented here is a proof-of-concept implementation of our framework applied to task-based fMRI experiments to study stimulus-response relationships in human brain in a real-time setting.