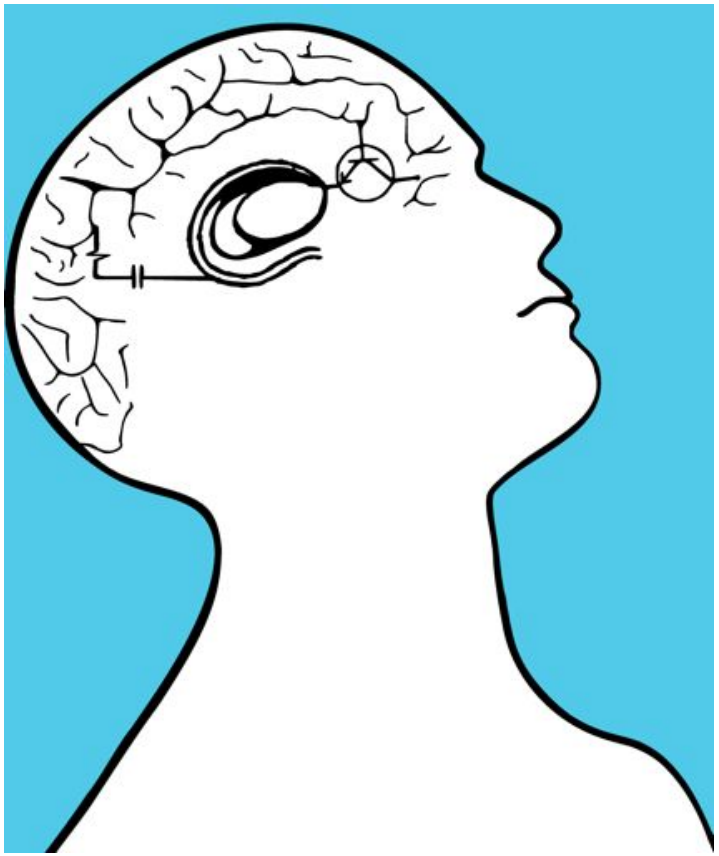
The drift diffusion model as a tool for computational psychiatry and neurology



Michael J. Frank
Laboratory for Neural Computation and Cognition
Brown University

Deep Brain Stimulation of the Subthalamic Nucleus (STN) for treatment of Parkinson's disease

Video #1: http://ski.clps.brown.edu/dbs2.mp4

Video #2: http://ski.clps.brown.edu/dbs.mp4

But not all is grand in the world of DBS...

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STN-DBS dramatically improves PD motor symptoms, but can induce impulsivity

(Saint-Cyr et al 06, Frank et al, 07; Wylie et al 10; Hälbig et al 09; Green et al 13)

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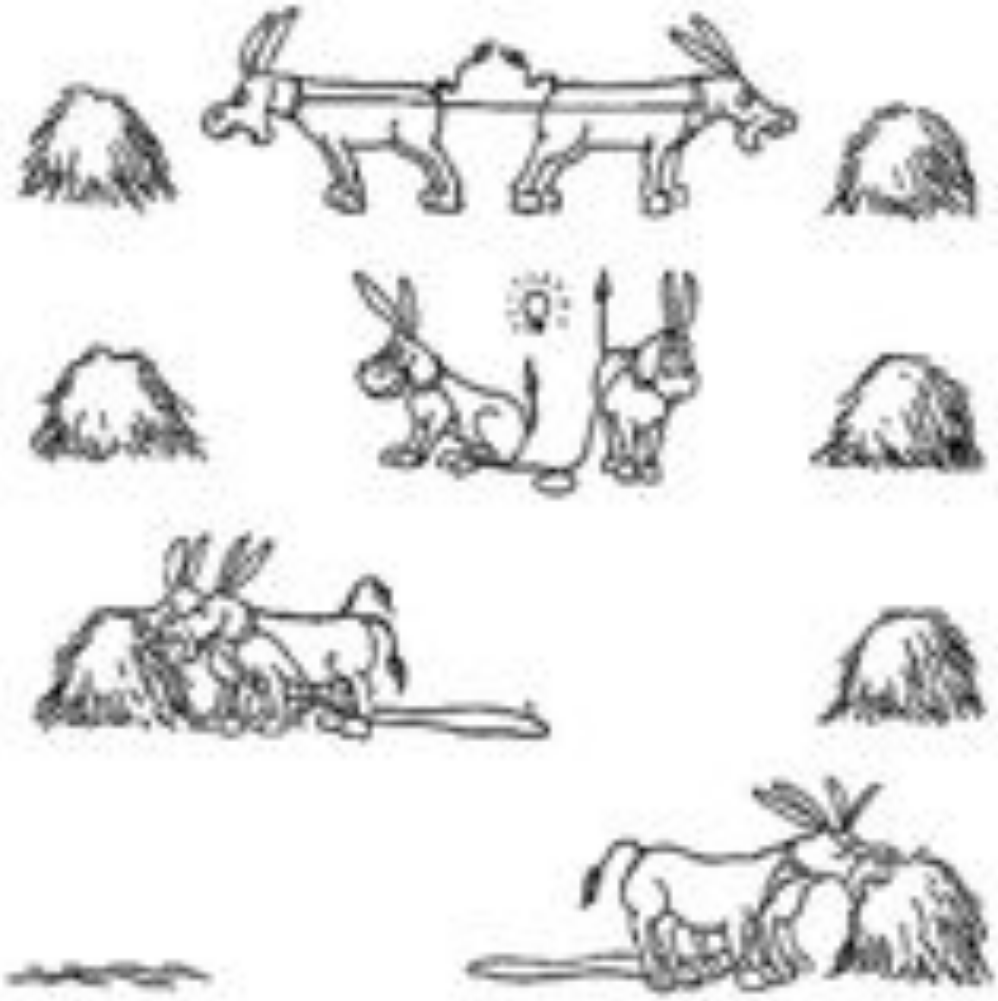
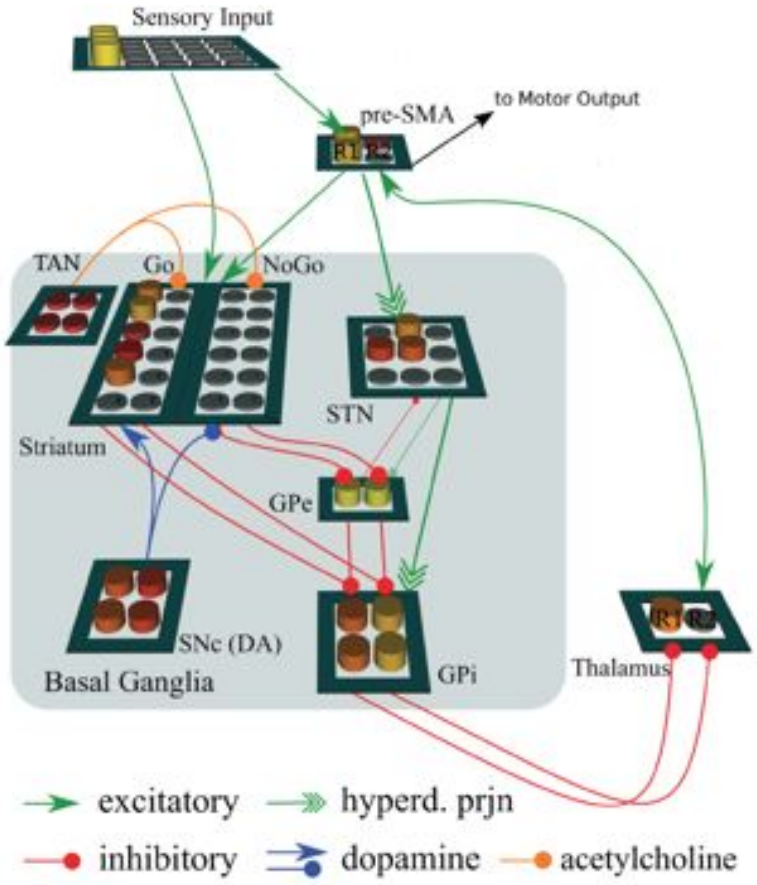
Mechanism? What sort of models can be useful?

From reinforcement learning...

...to reinforcement conflict-based decision making



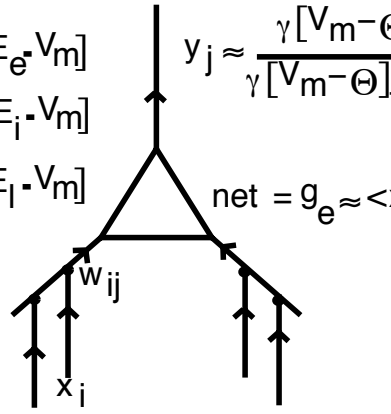
Neural model of basal ganglia (BG) in learning / decision making



$$c\dot{V}_m = g_e \bar{g}_e [E_e - V_m] + g_i \bar{g}_i [E_i - V_m] + g_l \bar{g}_l [E_l - V_m] + \ldots$$

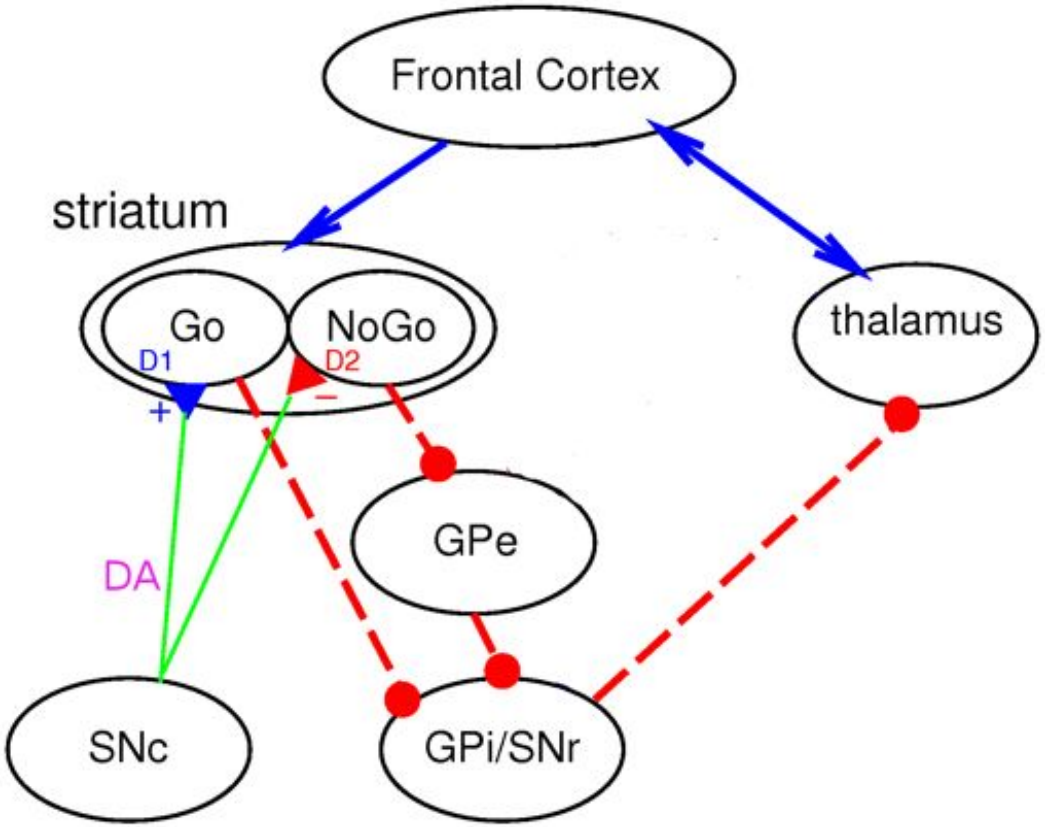
$$y_j \approx \frac{\gamma [V_m - \Theta]_+}{\gamma [V_m - \Theta]_+ + 1}$$

$$net = g_e \approx \langle x_i w_{ij} \rangle + \frac{\beta}{N}$$



Frank, 2005, 2006; Wiecki & Frank 2013, etc

Anatomy of action selection: without STN



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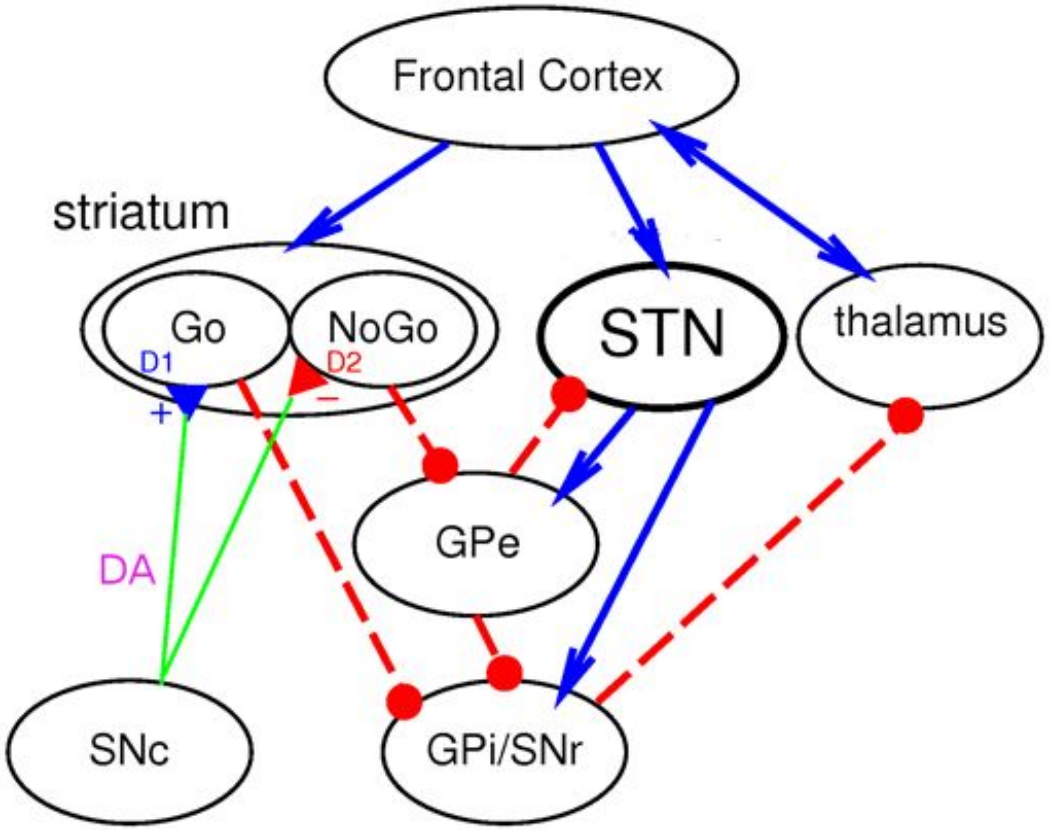
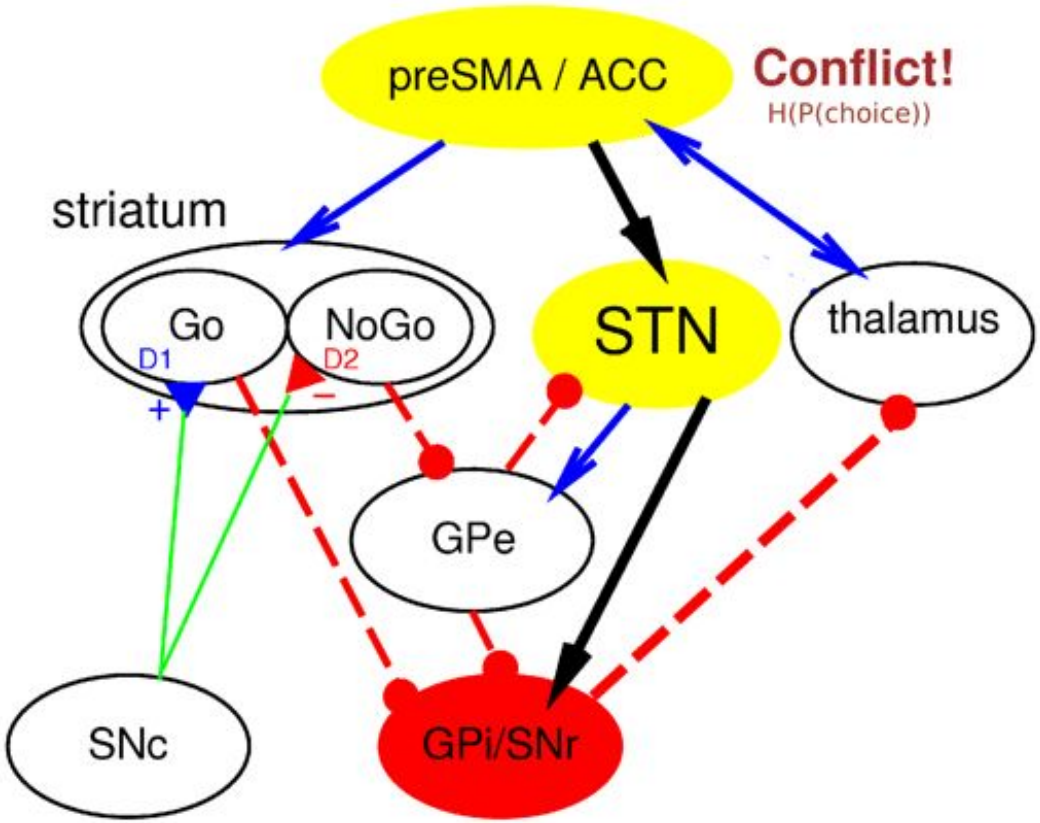
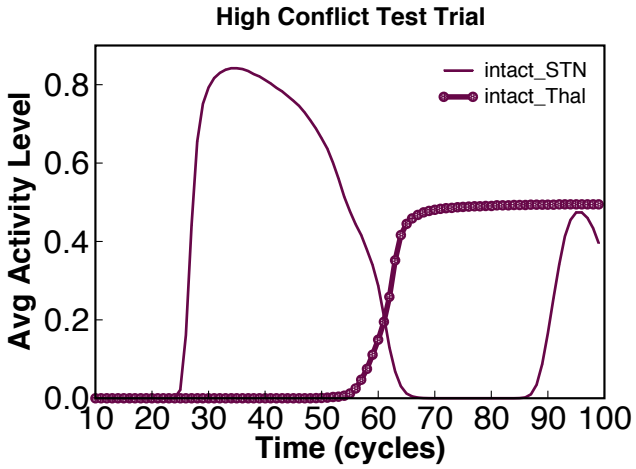


- Role of STN?

Subthalamic Nucleus: Dynamic modulation of decision threshold

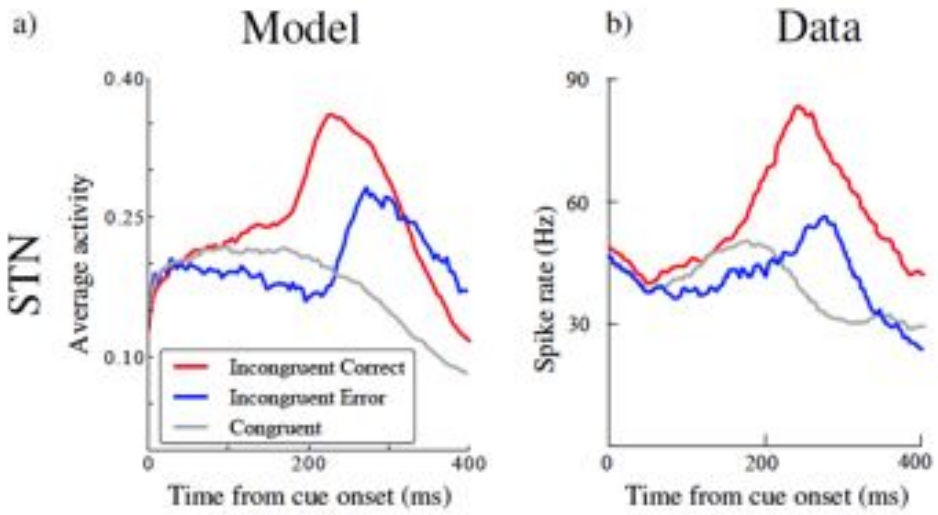




- Conflict (entropy) in choice prob: $\Rightarrow$ *Hold Your Horses!*

Neural model and STN ephys: decision conflict

spike rate:



data from Isoda & Hikosaka 2008

Wiecki & Frank, 2013 *Psych Review*

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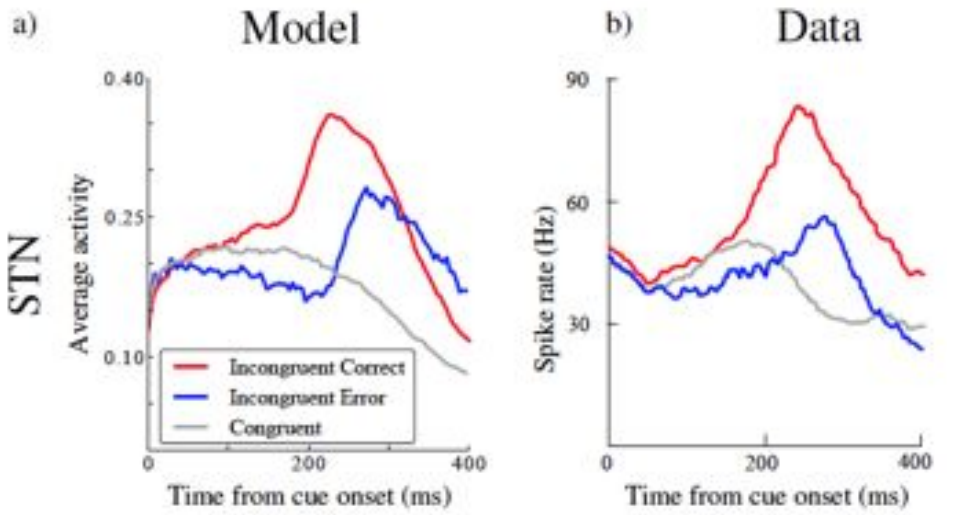
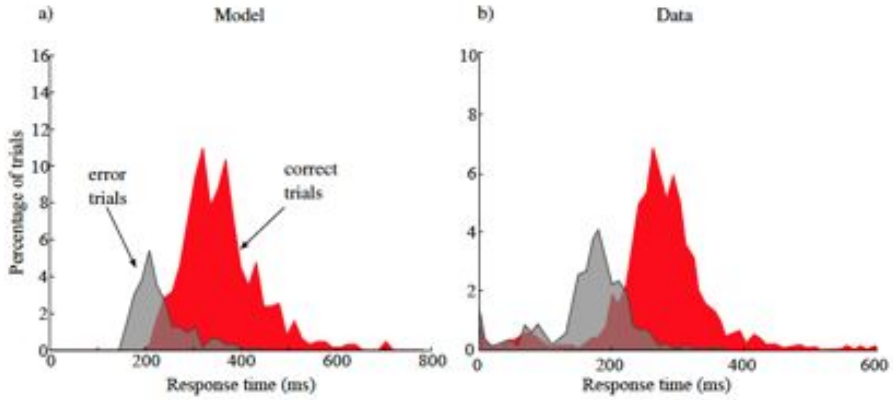


behavior:



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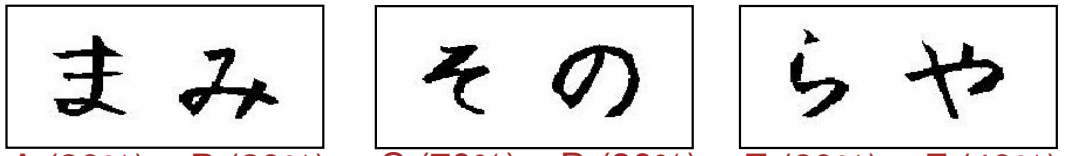
Human probabilistic reward/choice conflict



Low Conflict: e.g., 80 vs 30% $H(P_{softmax}) = .06$

High Conflict: e.g., 80 vs 70% $H(P_{softmax}) = .84$

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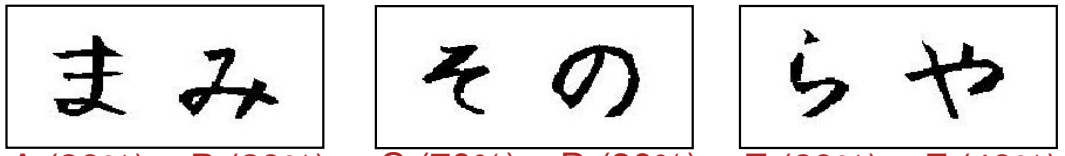

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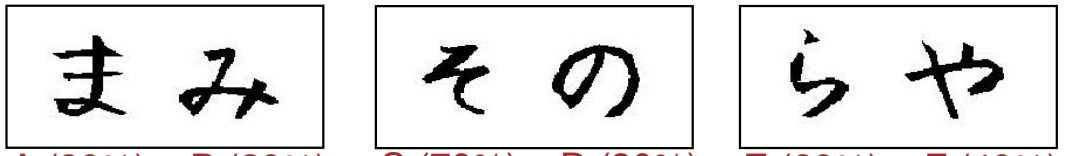

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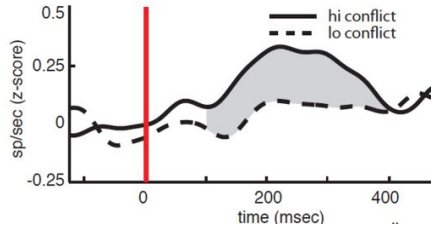
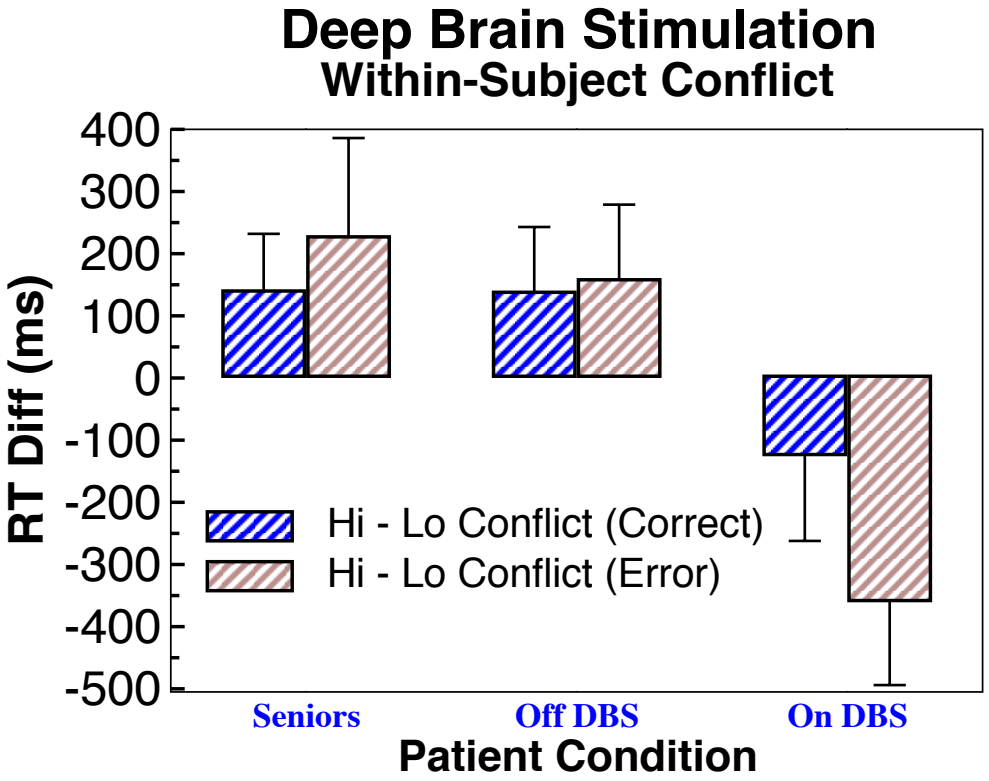


human STN spiking, Zaghloul et al., 2012

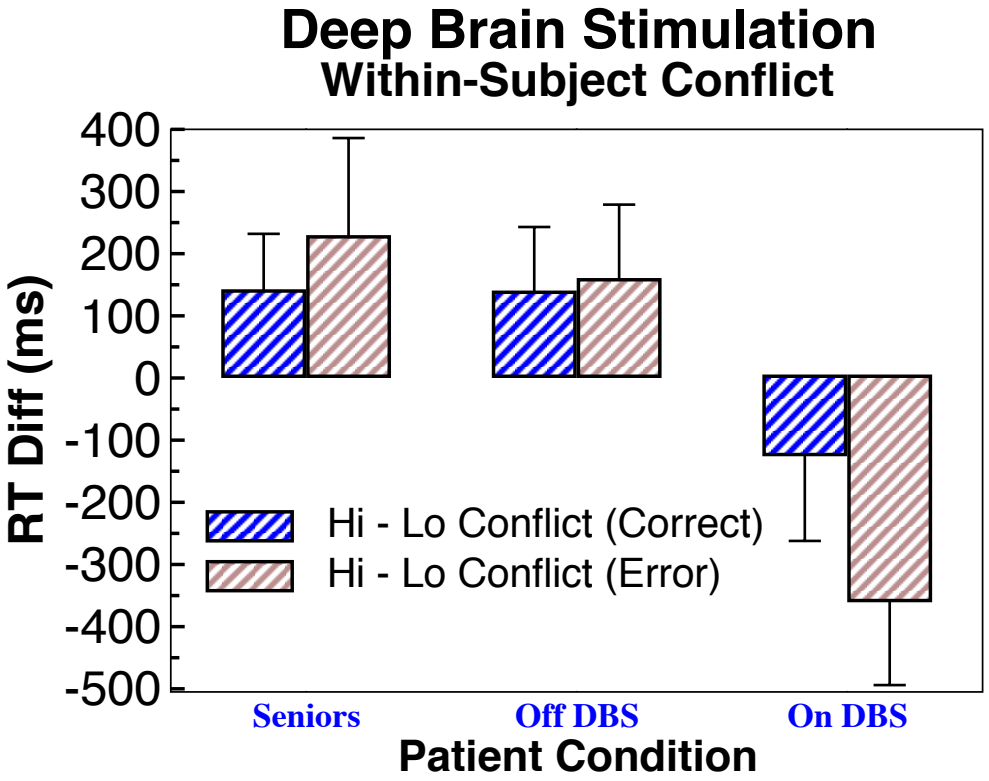
STN-DBS reverses conflict RT adjustments



Frank, Samanta, Moustafa & Sherman (2007)

see also Wylie et al 10; Hälbig et al 09; Cavanagh et al 11; Coulthard et al 12; Green et al 13

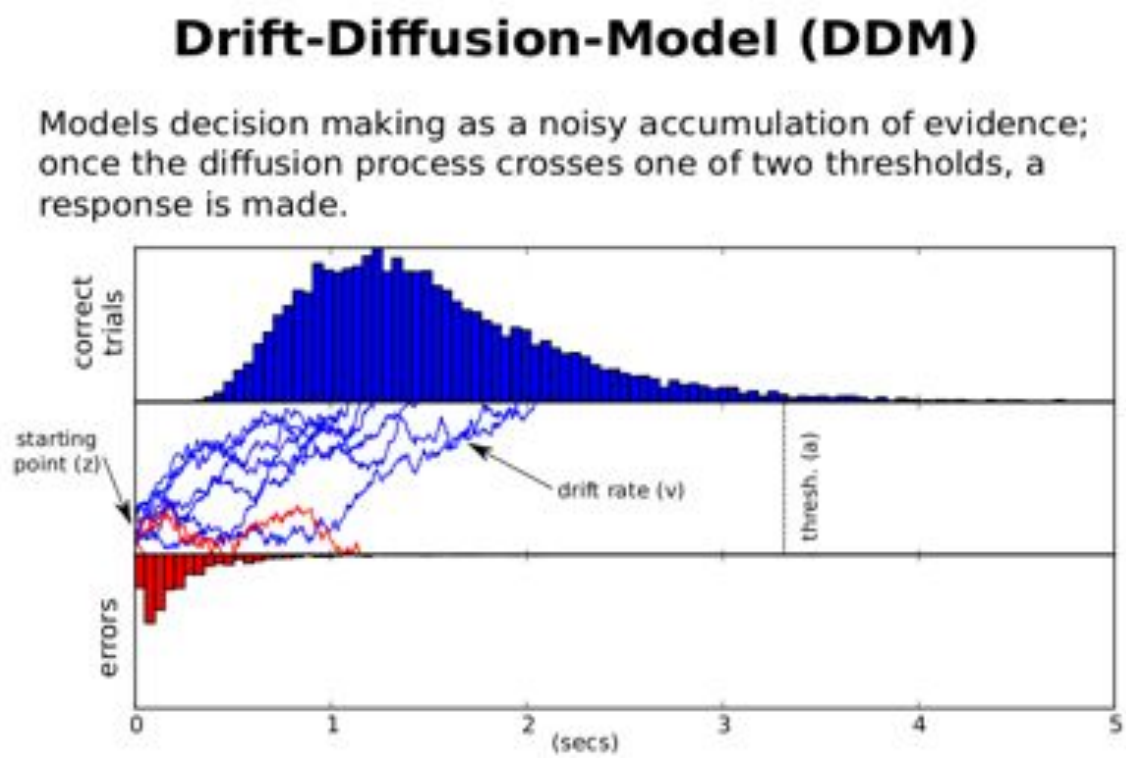
STN-DBS reverses conflict RT adjustments



... But RT is poor measure of generative process!

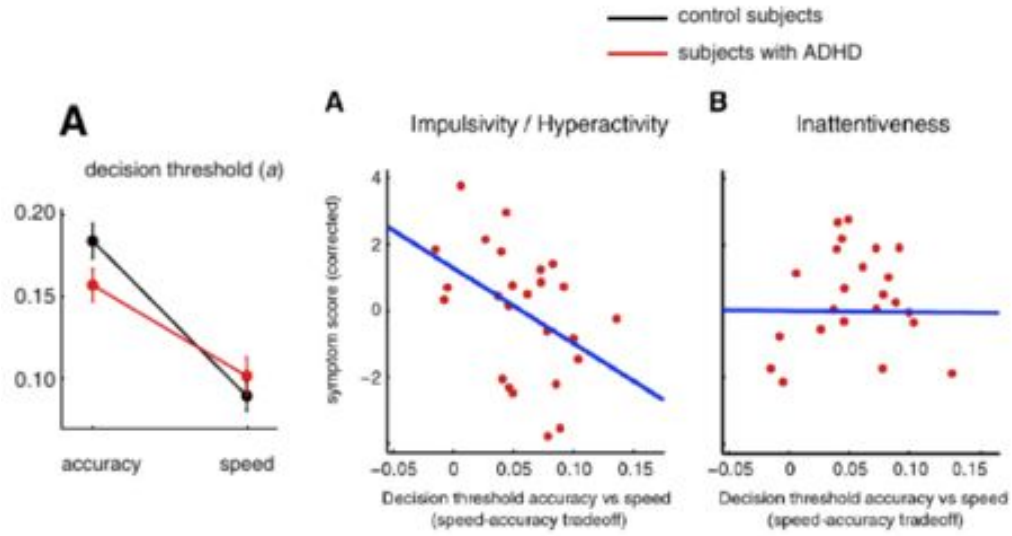
Frank, Samanta, Moustafa & Sherman (2007)

Abstraction: the drift diffusion model



- Provides quantitative fits to error rates and RT distributions in many tasks
- Allows estimation of decision threshold (a), separately from other factors (v, z, Ter)

Application to Computational Psychiatry



Mulder et al 2010

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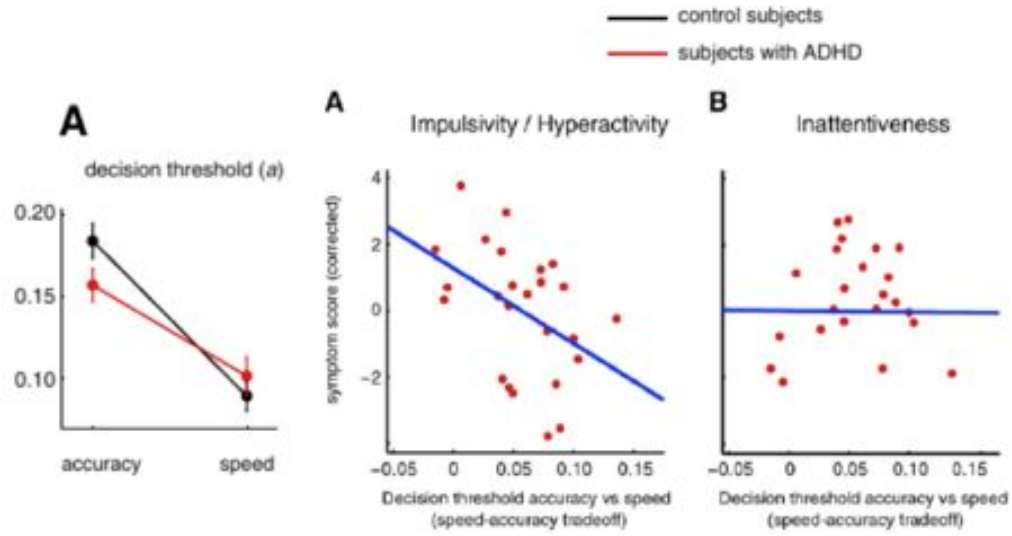

Mulder et al 2010

Which mechanism? Which treatment?

Linking levels

Linking Across Levels of Computation in Model-Based Cognitive Neuroscience

Michael J. Frank

Reinforcement-Based Decision Making in Corticostriatal Circuits: Mutual Constraints by Neurocomputational and Diffusion Models

- Strategy to interpret and link across levels of description
- Mutually informative: algorithm informs biological interpretation ; biophysics informs abstraction

Frank, 2015; Collins & Frank, 2013; Ratcliff & Frank, 2012; Franklin & Frank, submitted)

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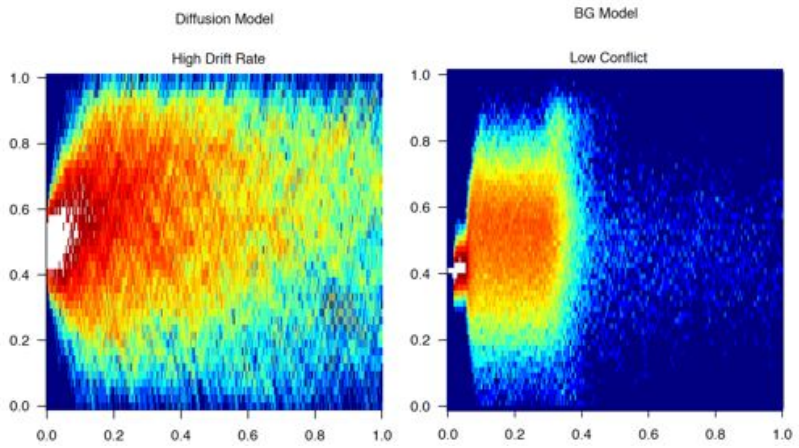
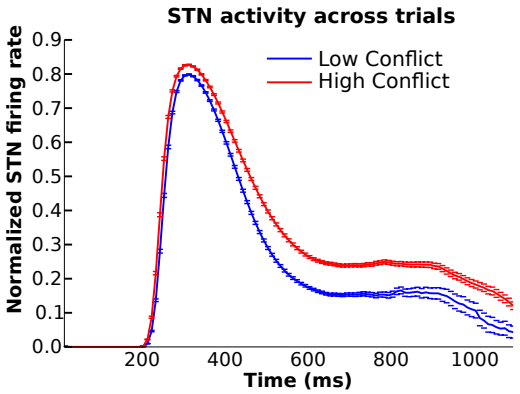


Frank, 2015; Collins & Frank, 2013; Ratcliff & Frank, 2012; Franklin & Frank, submitted)

Does STN affects network's decision threshold?
Collapsing bounds



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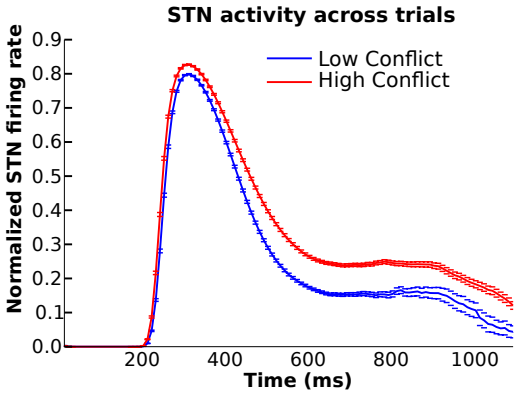
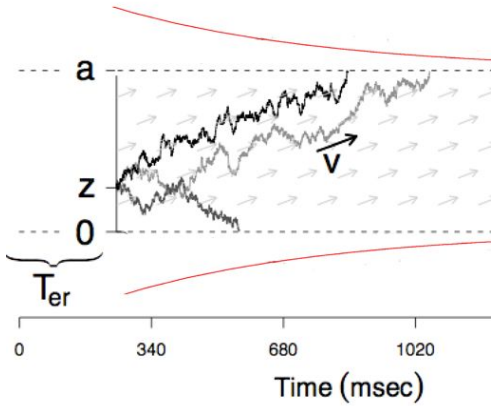
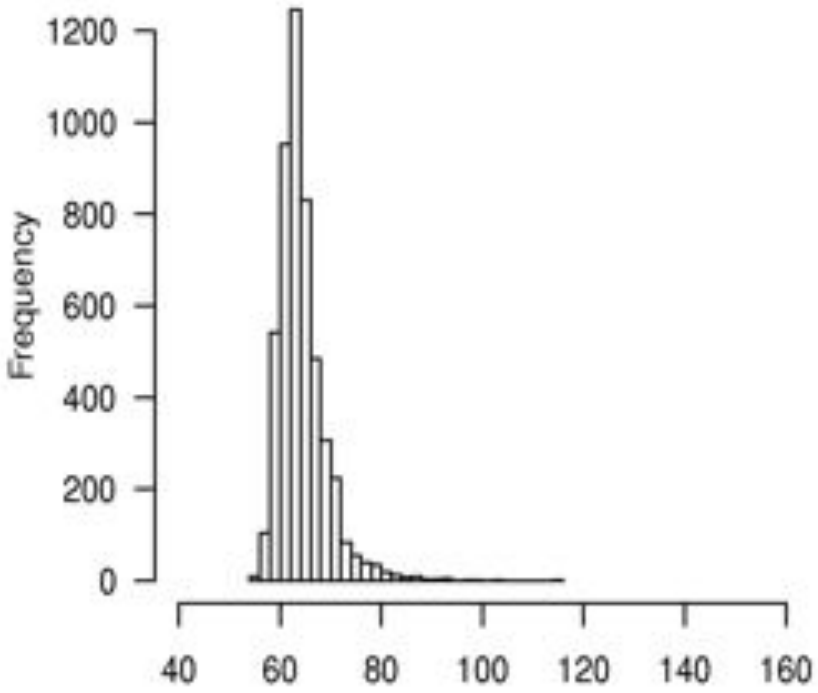


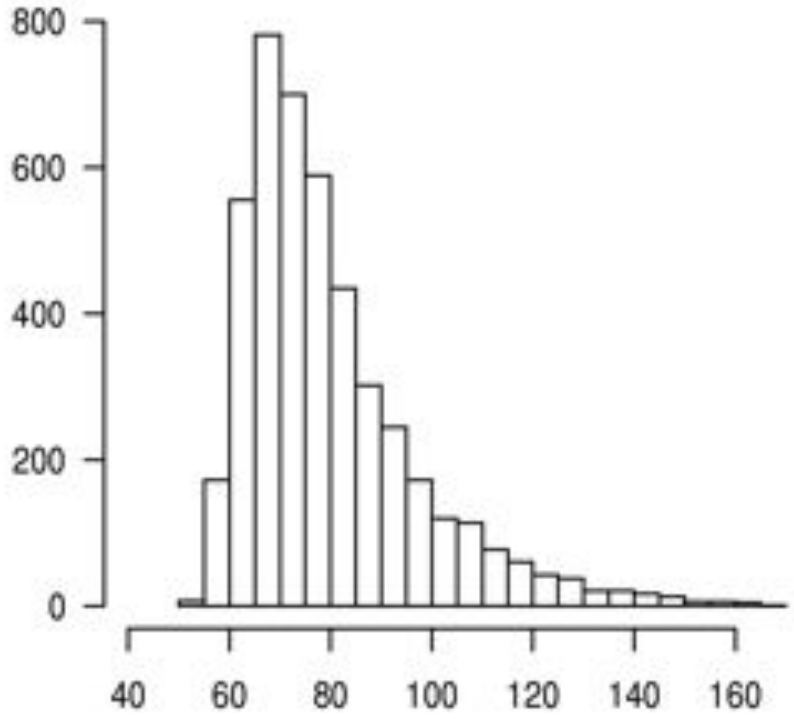


- Collapsing decision threshold in DDM (see also Frazier & Yu, 2008; Ditterich, 2006, Shadlen...)

Simulated RT distributions from BG model: Conflict effects



low conflict RT



high conflict RT

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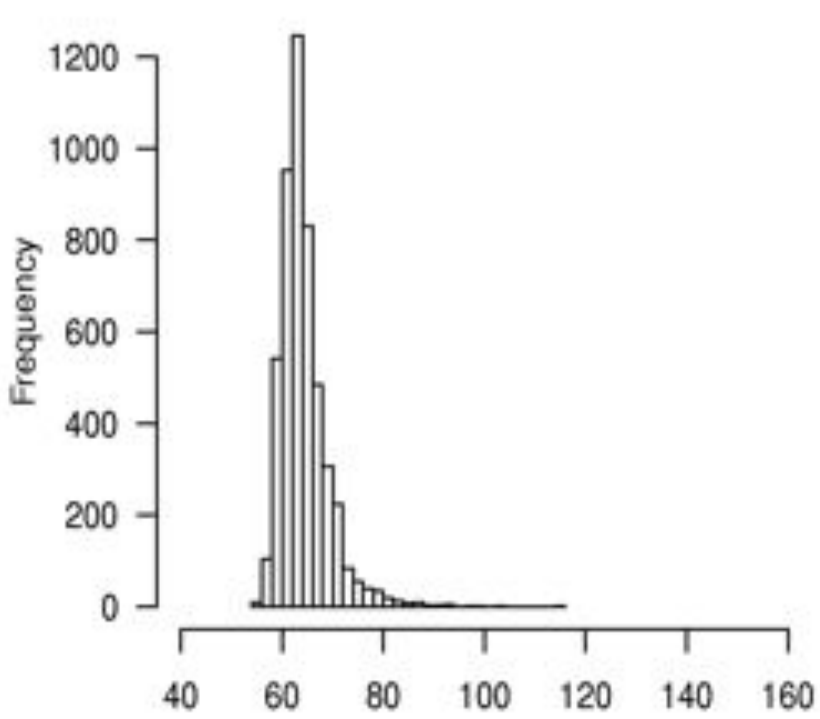
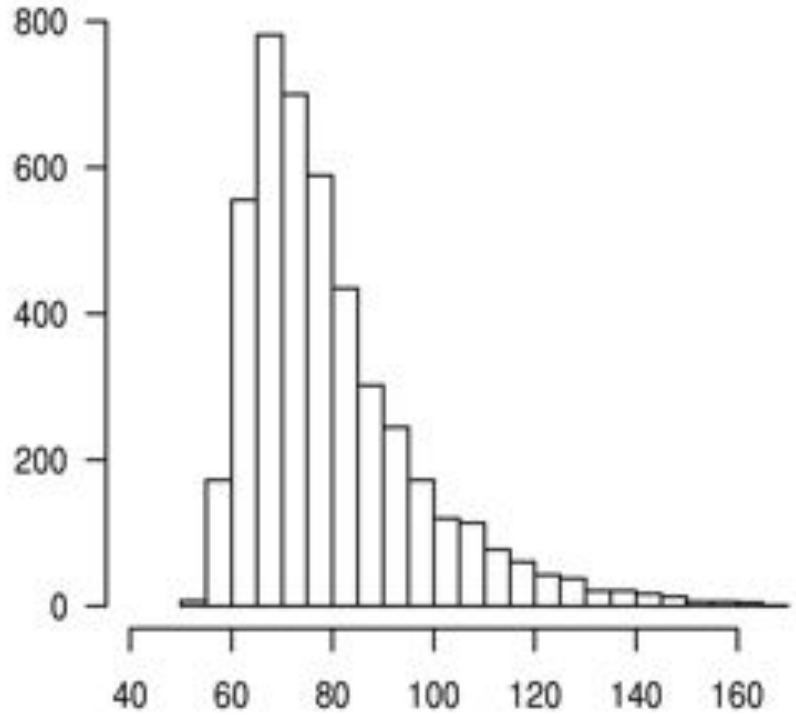


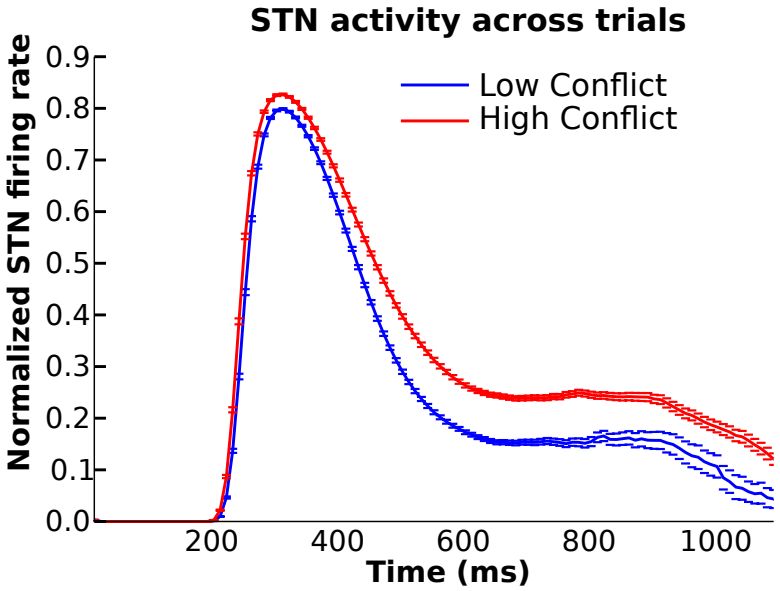
low conflict RT



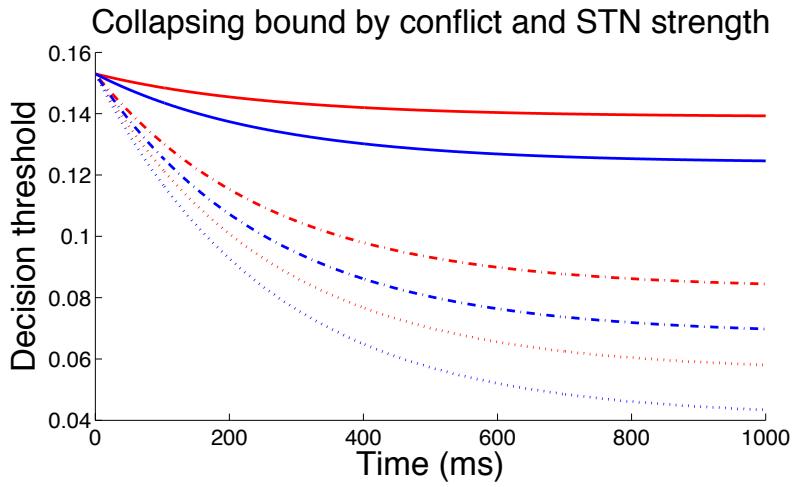
high conflict RT

Does conflict increase the decision threshold? Is this STN-dependent?

Diffusion model fits to BG neural model



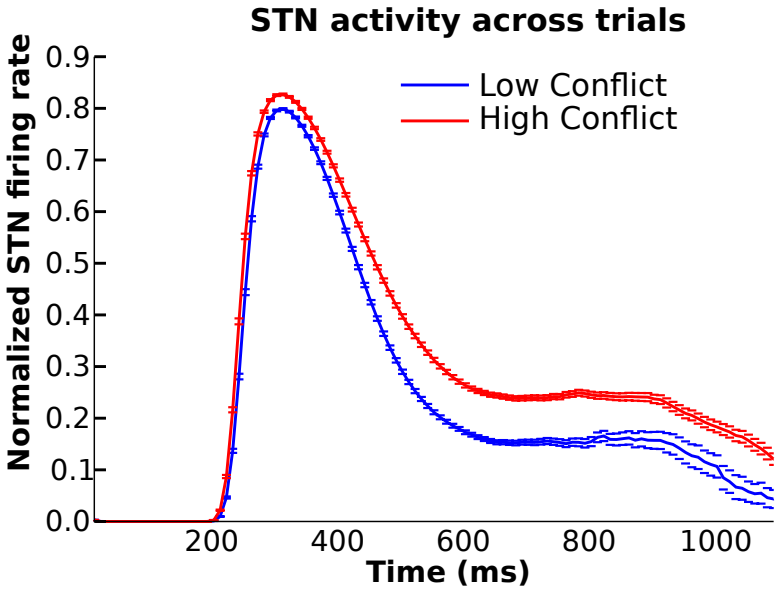
Simulated STN activity

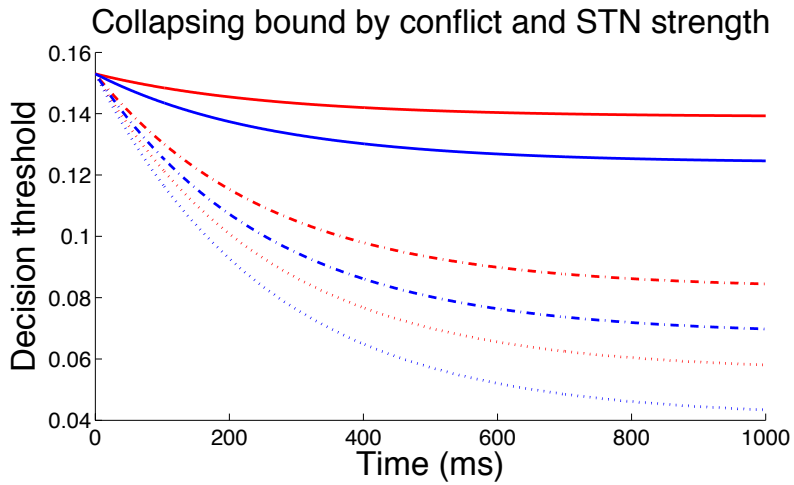


Best fit threshold trajectories

Ratcliff & Frank, 2012; Wiecki & Frank 2013

Diffusion model fits to BG neural model





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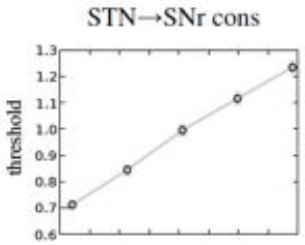
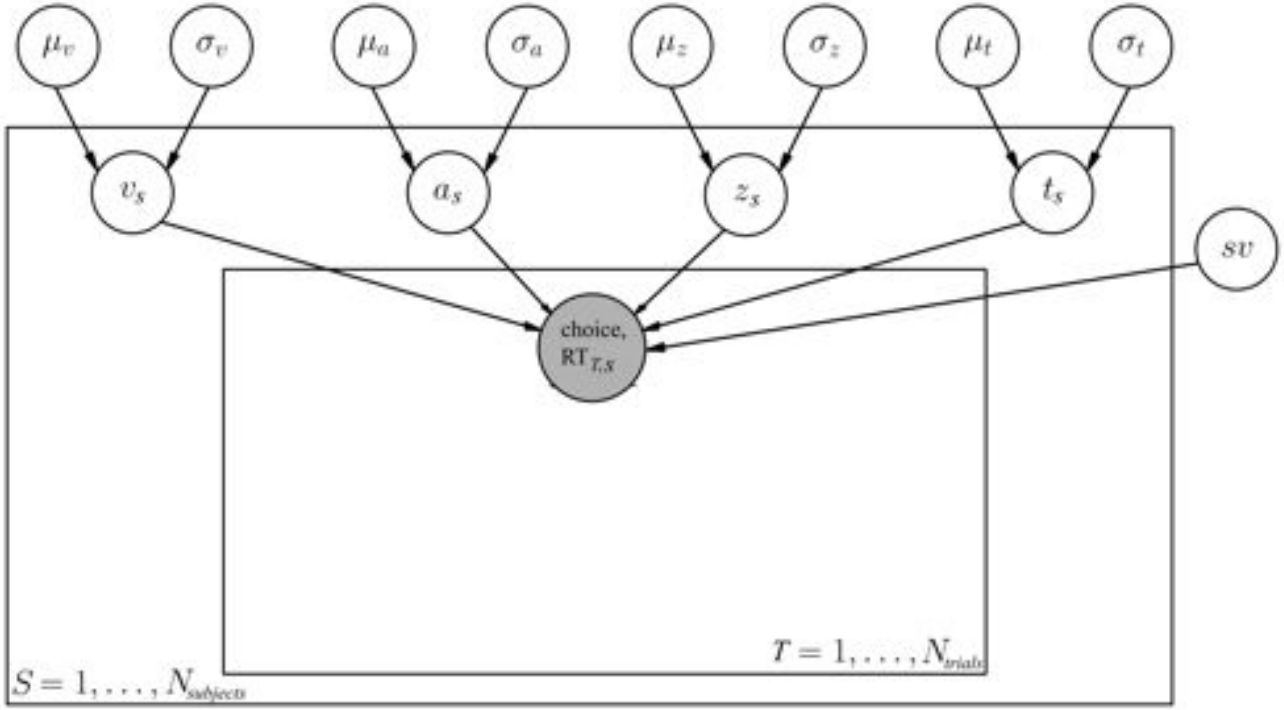


Ratcliff & Frank, 2012; Wiecki & Frank 2013

How to best fit DDM to real data?

Hierarchical bayesian parameter estimation of the DDM (*HDDM*)



Wiecki, Sofer & Frank 2013

free software: `http://ski.clps.brown.edu/hddm_docs`

Leveraging model synergy to test theory

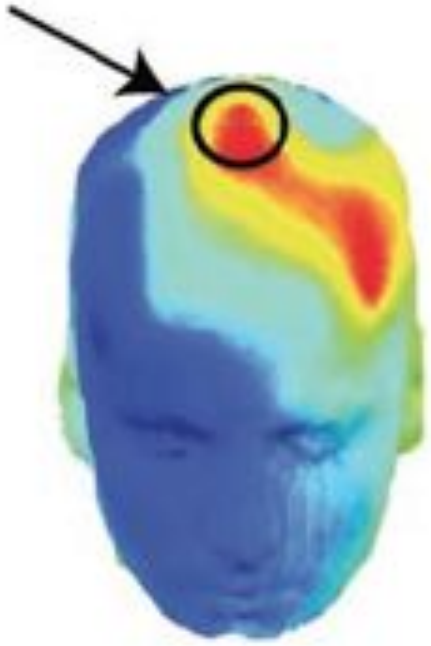
Example of how:

- bio informs abstraction (threshold change with conflict)
- abstraction yields tool to quantify latent threshold parameter from behavior

Question: Does decision threshold vary $\propto$ cortical-STN conflict?

- Test patients on and off STN-DBS while recording EEG
- Estimate decision threshold from behavior (RT distributions, error rates) and EEG

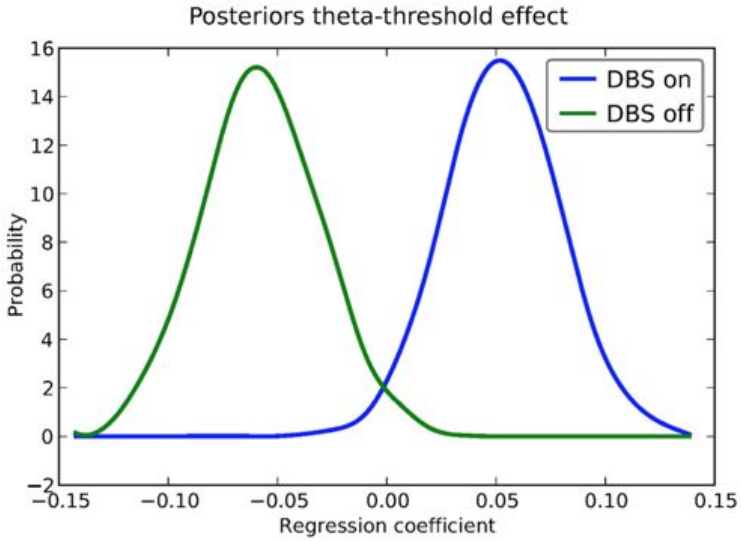
Conflict-related activity in mPFC theta



High - Low conflict effects on theta power

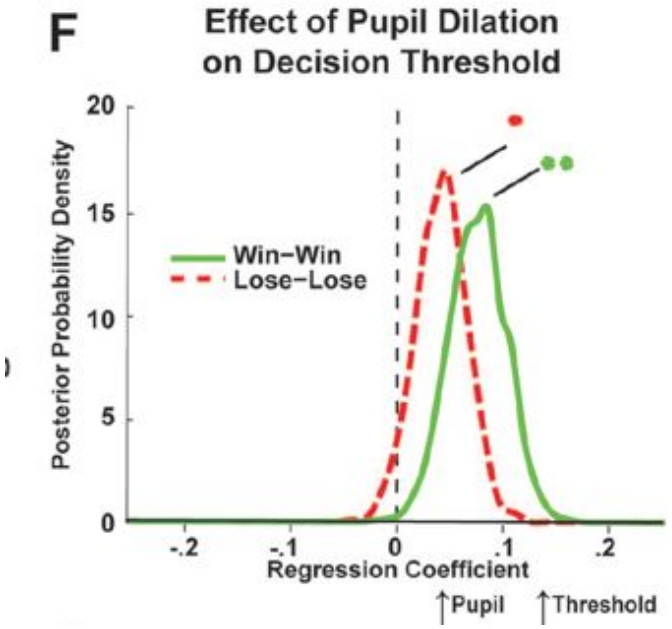
Cavanagh et al *2011, Nat Neurosci*

STN-DBS reverses mPFC influence over decision threshold



hierarchical-Bayes param estimation tool for DDM: `http://ski.clps.brown.edu/hddm_docs`

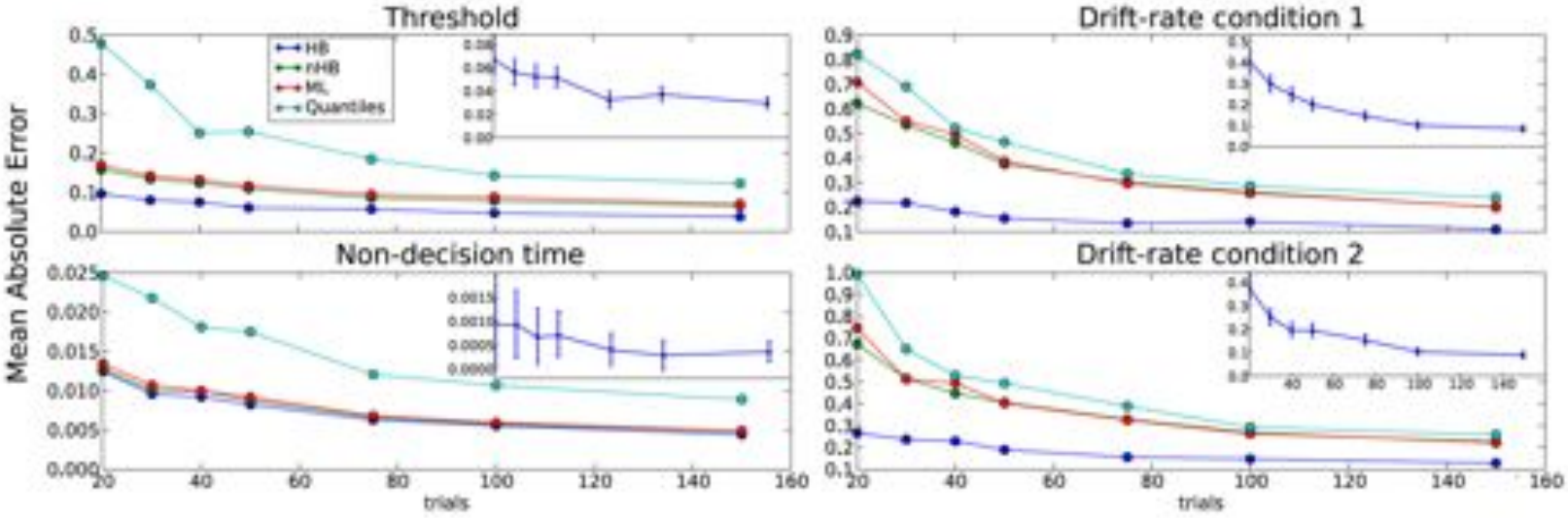
High conflict decision thresholds also correlate with trial to trial variation in pupil dilation



(whereas drift rate correlates with eye gaze)

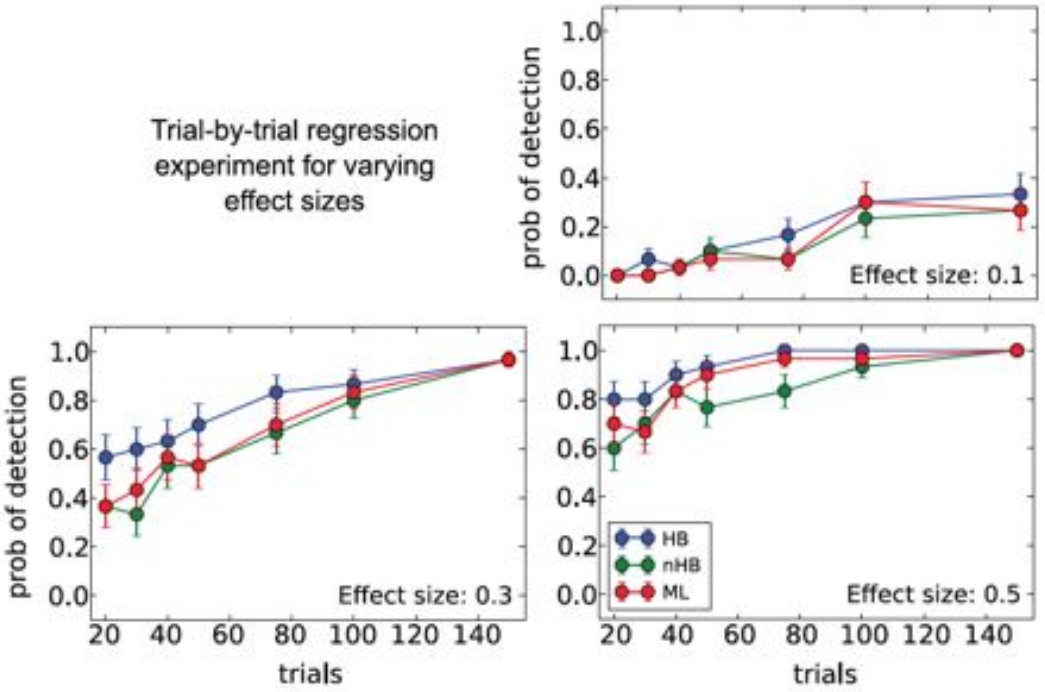
Cavanagh et al, 2014 JEPG

Why use HDDM:
Parameter Recovery as a Function of # Trials



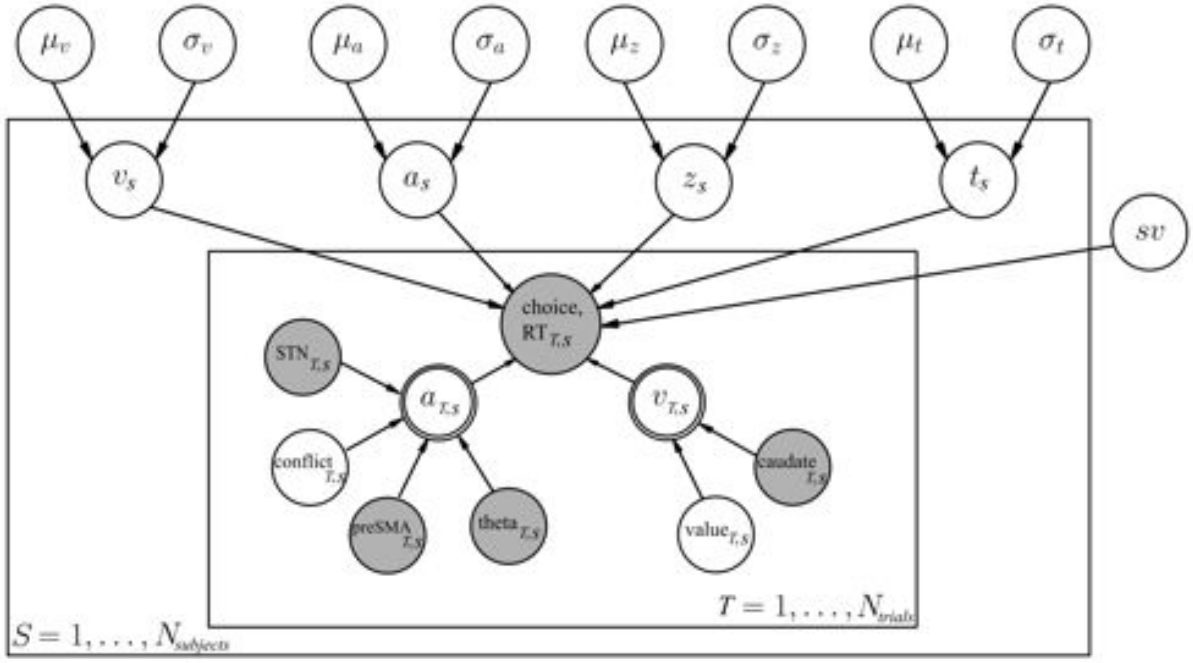
Wiecki et al 2013

Regression of physio variable onto DDM param: Probability of detecting an effect



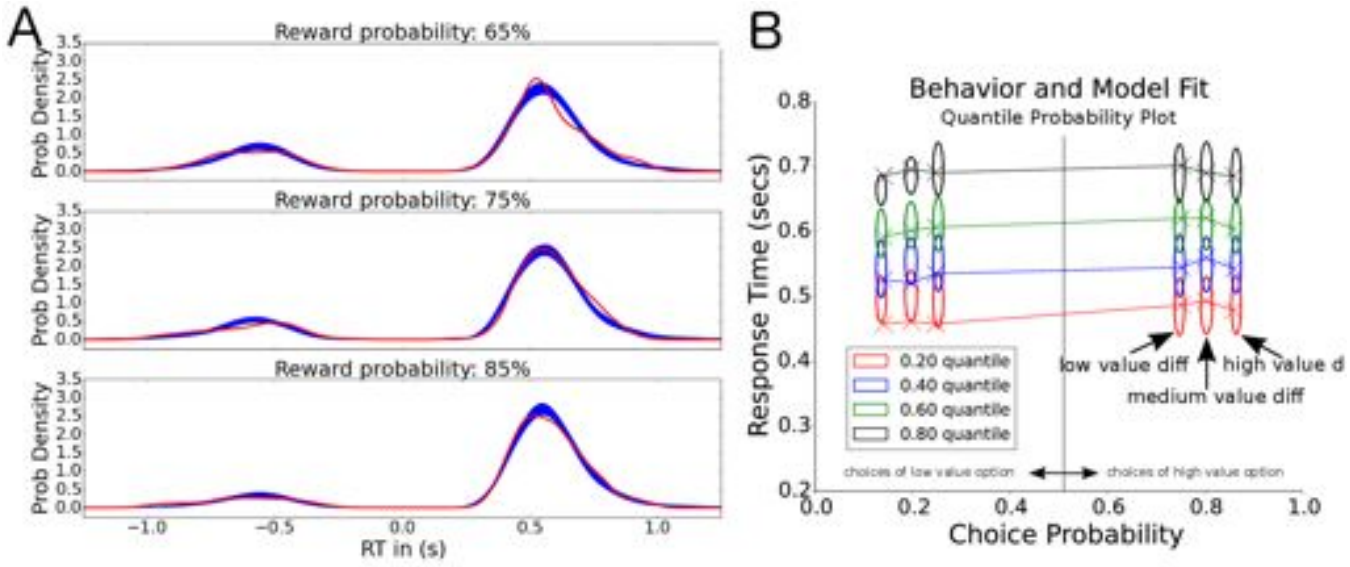
Wiecki et al 2013

fMRI and EEG experiment



Frank et al 2015

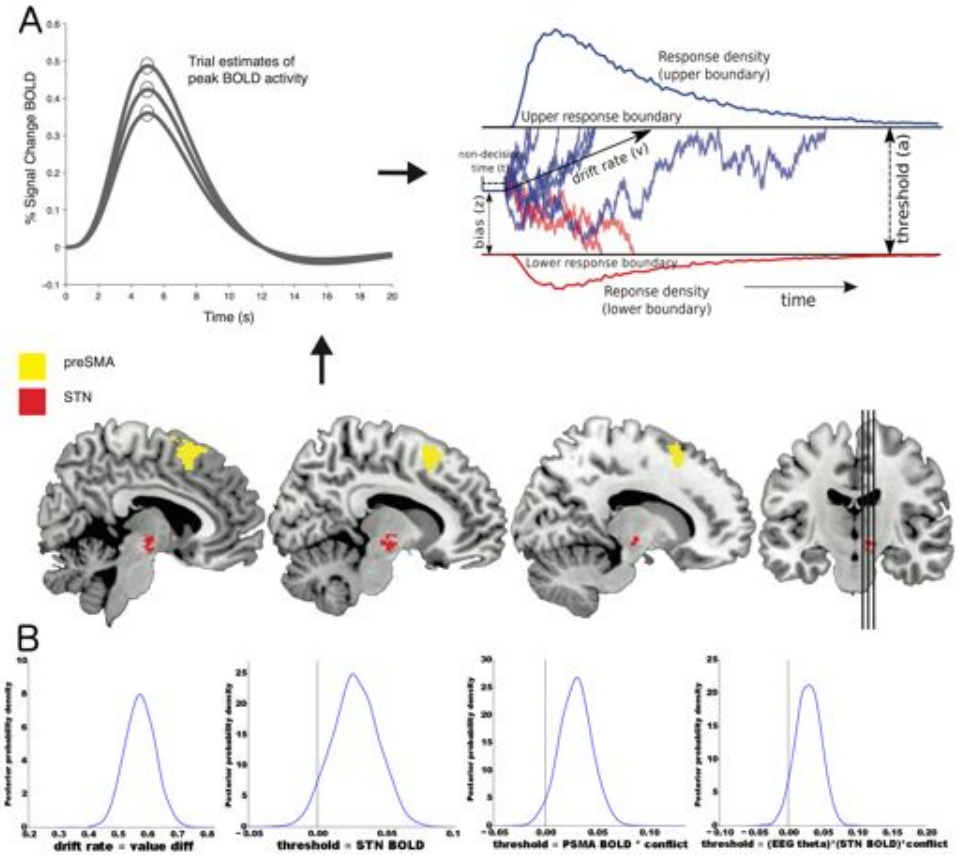
fMRI and EEG experiment: check if model fits behavior



posterior predictive checks are important!

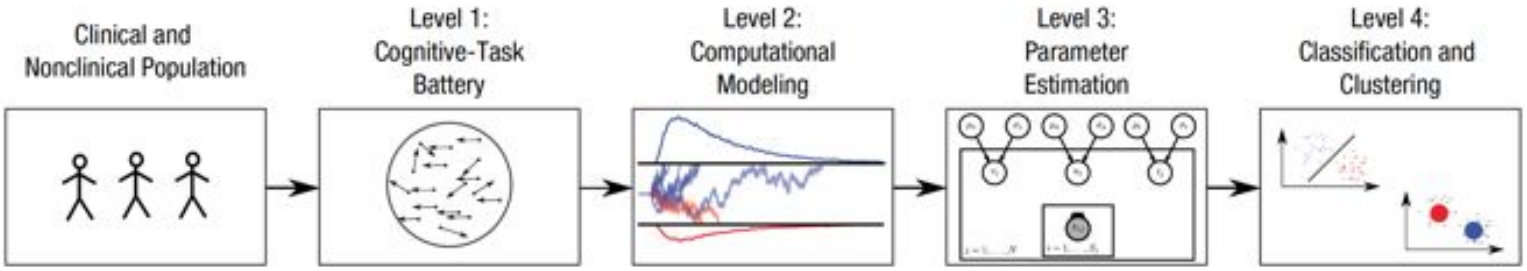
Frank et al 2015

fMRI and EEG experiment



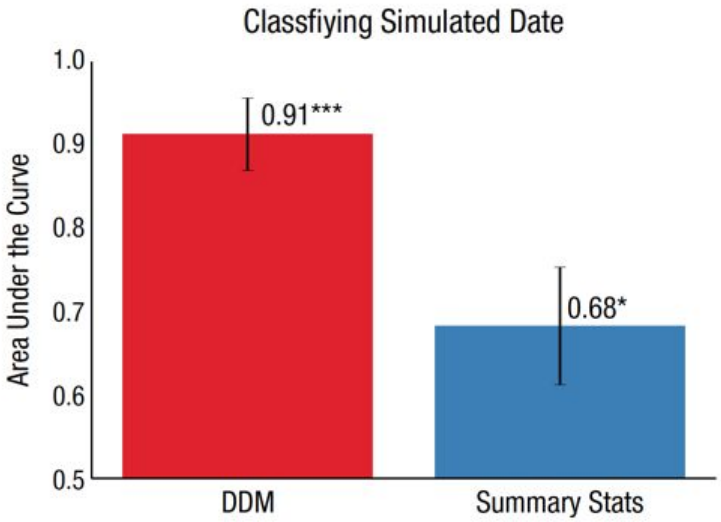
Frank et al 2015

Application to Computational Psychiatry and Neurology



Wiecki, Poland & Frank 2013

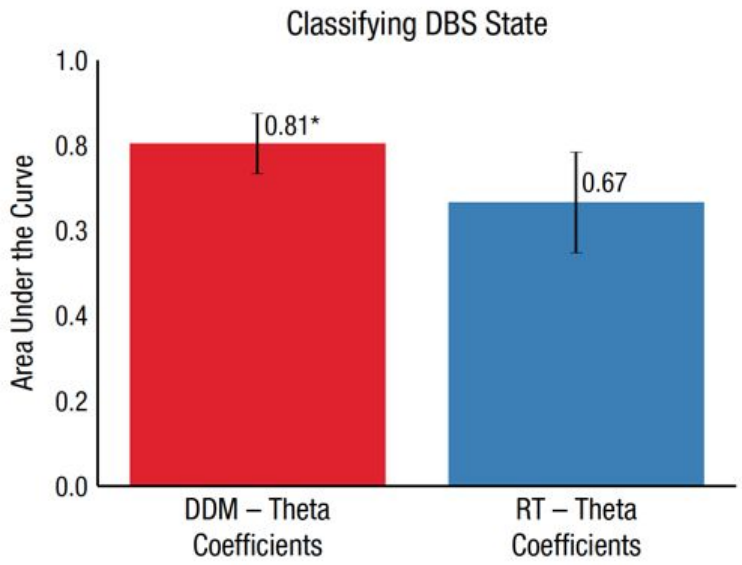
Why use DDM: Simulation experiment and classification of groups



- generated data from DDM with two groups with different parameters
- classification of observed data based on fitted model params or raw behavioral summary statistics

Wiecki, Poland & Frank 2013

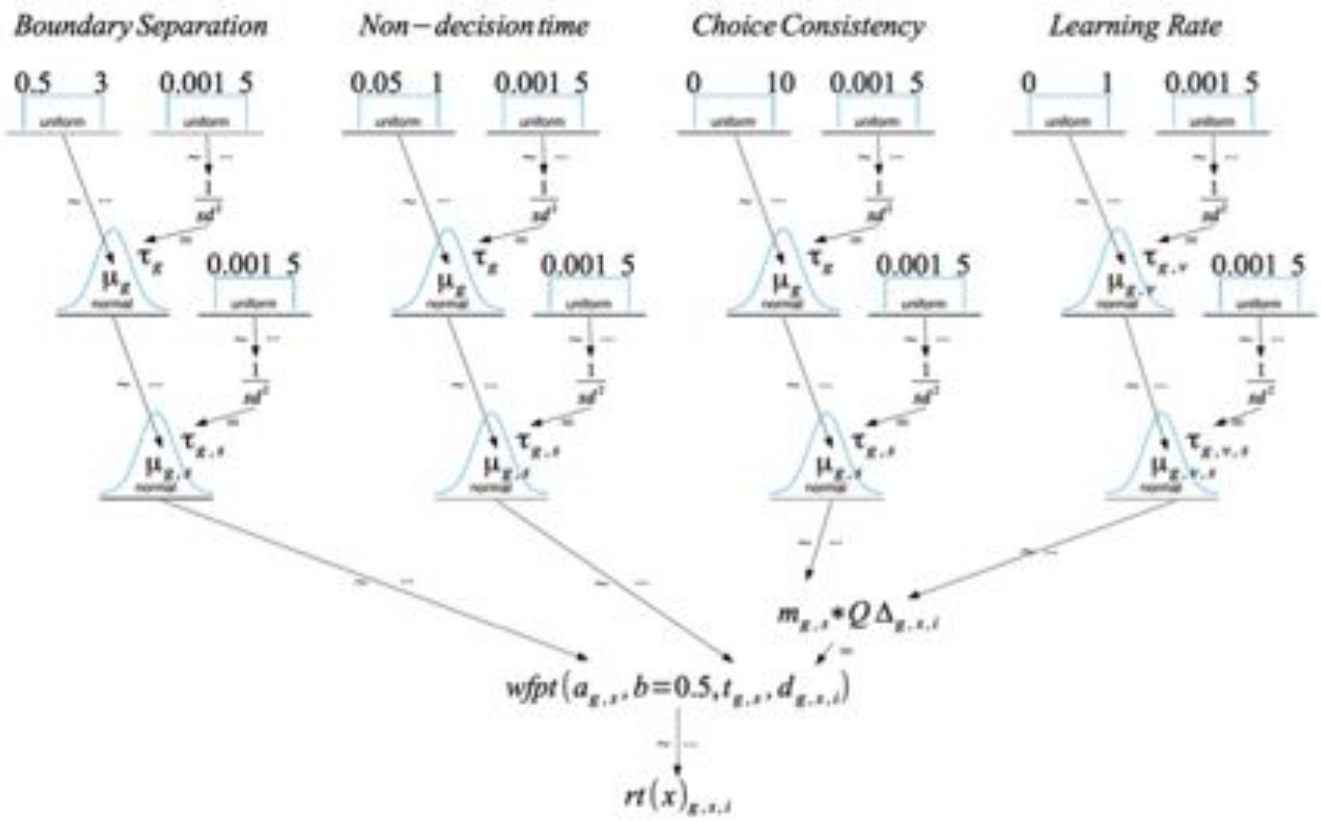
Real data: classification of DBS state



Wiecki, Poland & Frank 2013

Also classifies Huntington's disease before symptom onset! Wiecki,et al., in review

Simultaneous Estimation of RL and DDM



Pedersen, Frank & Biele, in prep

Summary: The good and the bad

- DDM useful for parsing out separate decision parameters
- Can be linked to neural mechanism via regression and model selection
- useful for classification of brain states

Look out for / be cautious about:

- model mimicry
- too much reliance on relative model fit (DIC etc). Use posterior predictive checks!
- convergence for complex models

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