Predicting Temporal Patterns In The Environment: Toward Primitive Mechanisms Of Learning, Memory, And Generalization

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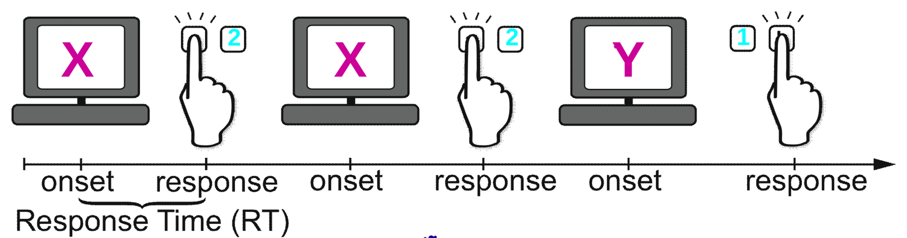
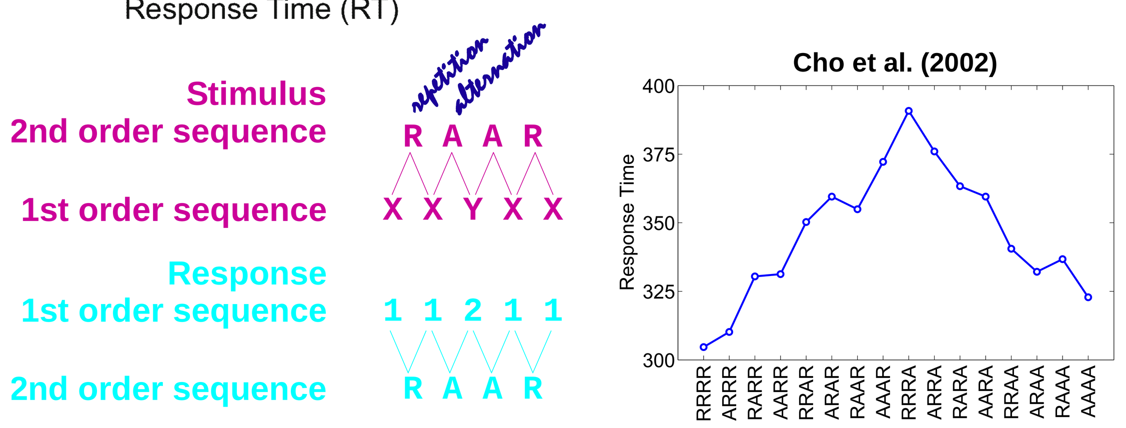
Predicting What Comes Next

Individuals develop strong expectations of upcoming events in environment based on recent experience.

Expectations illuminate brain's encoding of sequences.

E.g., two choice task





Dual Priming Model (Wilder, Jones, & Mozer, 2009)

Brain predicts what will happen next based on history, which is captured in two memory traces.

- First-order trace — YXXXY

$$w_1(t) = (1-\varphi)w_1(t-1) + \frac{\varphi}{2}S(t)$$

stimulus on trial t ($X = +1$, $Y = -1$)

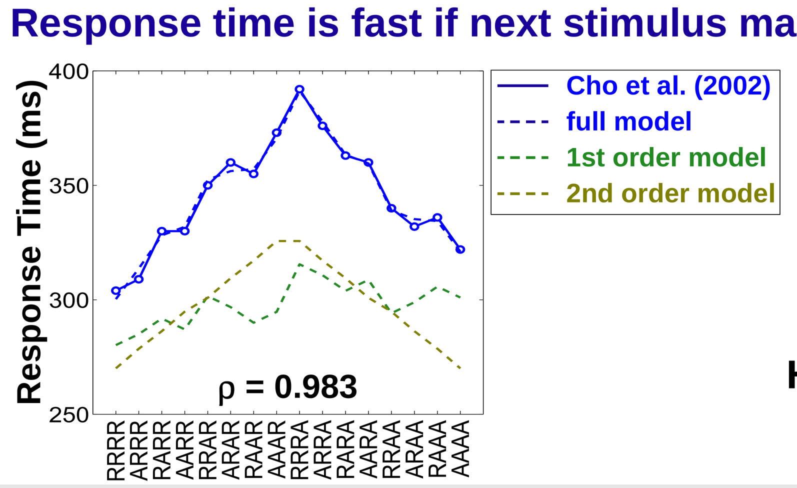
- Second-order trace — ARRA

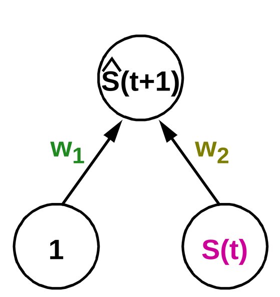
$$w_2(t) = (1-\gamma)w_2(t-1) + \frac{\gamma}{2}S(t)S(t-1)$$

Prediction combines both traces

$$\hat{S}(t+1) = w_1(t) + w_2(t)\,S(t)$$

Response time is fast if next stimulus matches prediction





Hebbian learning with decay

Experiment Objectives

- Further test dual priming model
- Use EEG to tease apart stimulus and response priming
- Examine long-term learning of environmental statistics via two conditions

positive autocorrelation (2/3 repetition rate)

X Y X X X X X X X X Y Y Y X X Y Y X X X

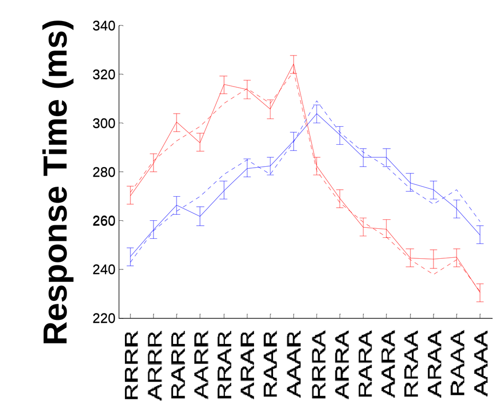
negative autocorrelation (1/3 repetition rate)

Y Y Y X Y X Y X Y X X Y X X Y X Y Y X Y

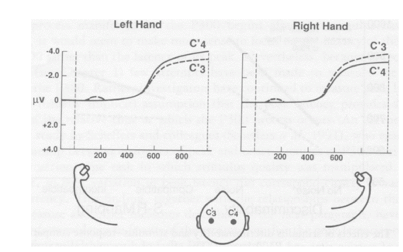
Reaction Time Analysis

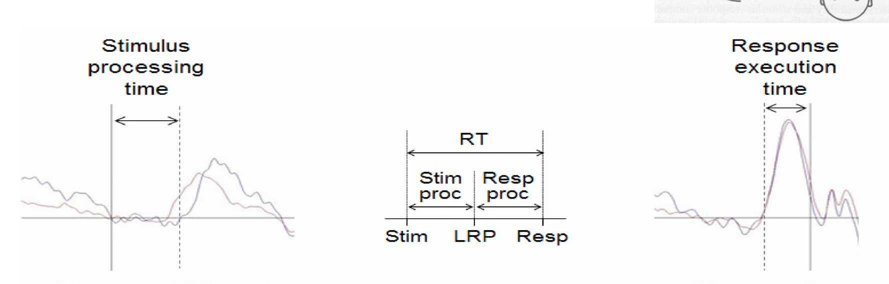
Dual-priming model predicts human RTs in the two autocorrelation conditions.

	model	data
positive	- - - -	——
negative	- - - -	——

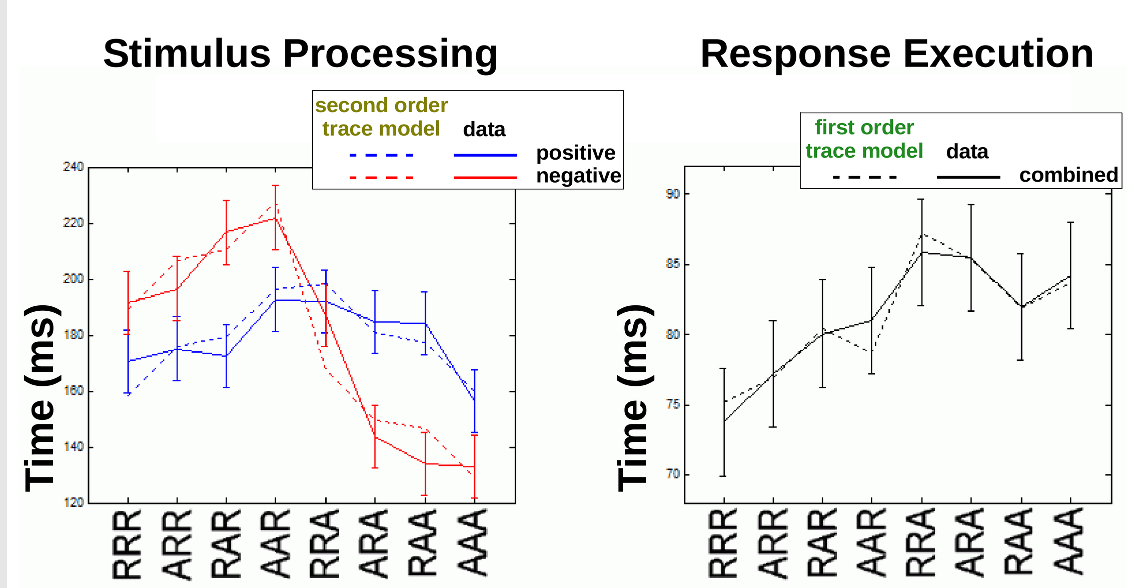


Lateralized readiness potential (LRP) can be used to decompose RT into stimulus processing time and response execution time.





Model's two memory traces dissociate into stimulus processing and response execution stages.



Priming of alternation/repetition of *stimulus* sequence

Priming of identities of *response* sequence

stimulus repetition sequence R A A R

~~stimulus identity sequence X X Y X X~~

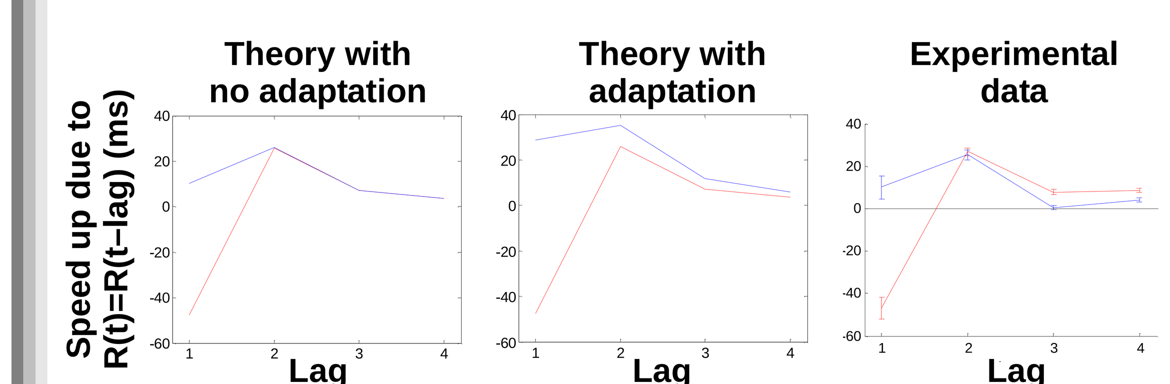
response identity sequence 1 1 2 1 1

~~response repetition sequence R A A R~~

Adaptation To Environment

If individuals adapt to long-term structure of environment, response identity priming should be stronger in positive autocorrelation condition than negative.

Positive	X	X	X	X	X
lag	4	3	2	1	
Negative	X	Y	X	Y	X



inverse adaptation effect

Cue Competition And Error-Correction Learning

Inverse adaptation effect is explained by replacing Hebbian learning with error-correction learning.

Model prediction as before

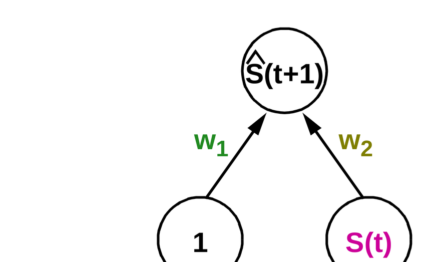
$$\hat{S}(t+1) = w_1(t) + w_2(t)\,S(t)$$

- First-order weight — YXXXY

$$\Delta w_1(t) = \varphi\,(\hat{S}(t) - S(t))$$

- Second-order weight — ARRA

$$\Delta w_2(t) = \gamma\,(\hat{S}(t) - S(t))S(t-1)$$



error-correction learning (Rescorla & Wagner, 1972)

Error contributed by $w_2(t)$ pushes $w_1(t+1)$ in opposite direction ⇒ inverse adaptation effect

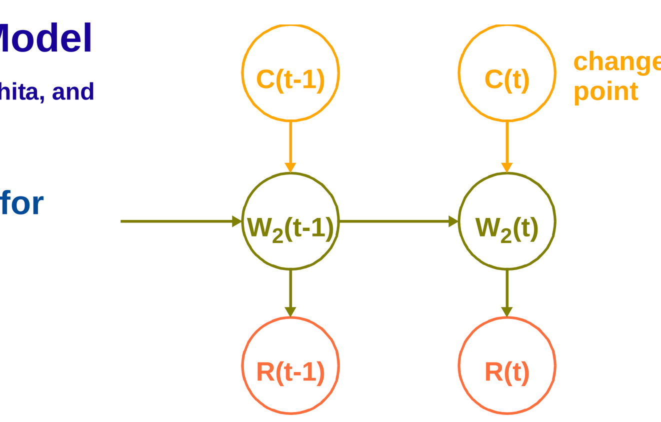
Toward A Normative Account

DBM: Dynamic Belief Model

Jones and Sieck (2003); Mozer, Kinoshita, and Shettel (2007); Yu and Cohen (2009)

Assumes repetition probability (W_2) is fixed for runs, with occasional changepoints (C)

Predicts repetition or alternation (R)



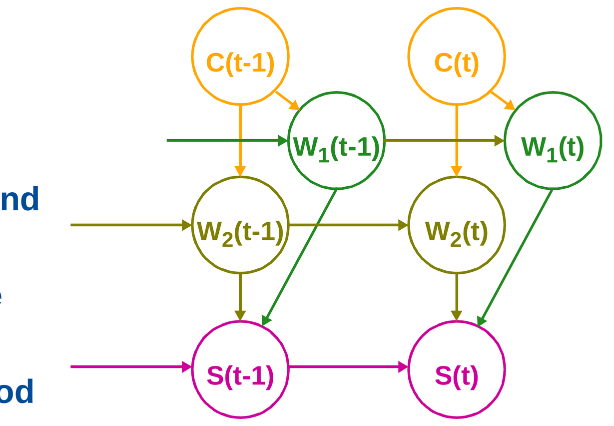
DBM2: Dynamic Belief Mixture Model

Wilder, Jones, and Mozer (2009)

Assumes stimulus (S) distribution is a Bernoulli mixture based on identity and repetition/alternation

Predicts stimulus/response identity

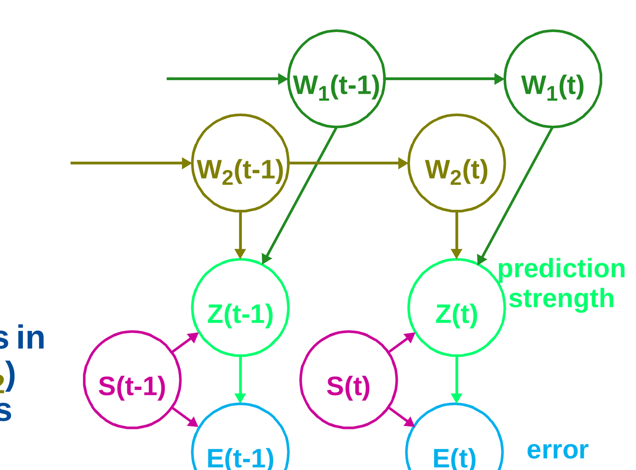
Dual priming model is a good approximation to DBM2



Kalman Filter Model

Instead of changepoint dynamics, assumes continuous fluctuation in first- and second-order probabilities

Produces produces updates in which the two cues (W_1, W_2) compete to predict stimulus

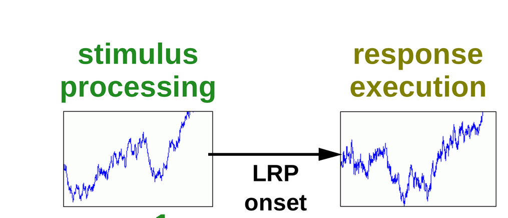


Toward A Neural Account

Cascaded diffusion processes

Relative processing speed of each stage can

- explain alternation bias
- amplify or attenuate first- and second-order effects



Tested in second experiment in which we manipulated

- ease of stimulus processing (random dot kinetogram coherence)
- ease of response processing (one button press vs. sequence)