A Bayesian Discrete-State Model for Working Memory

Eda Mızrak[1], Henrik Singmann[2], Ilke Öztekin[1]

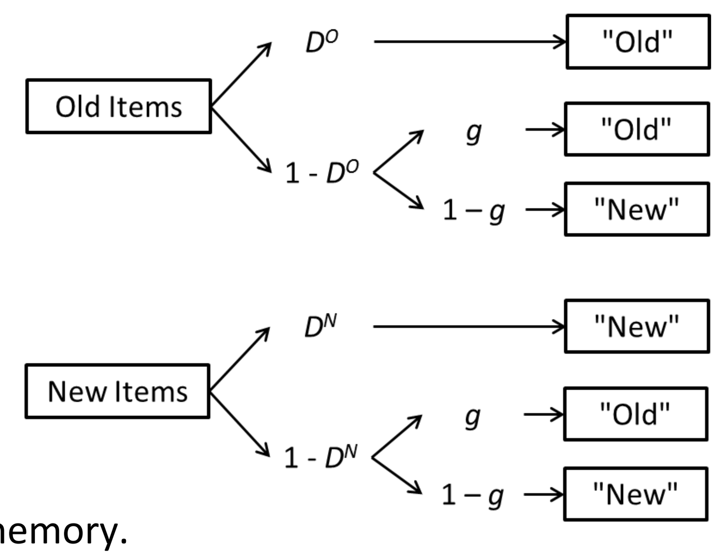
Koç University[1], University of Zurich[2]

emizrak@ku.edu.tr

singmann@psychologie.uzh.ch

Discrete-State Model

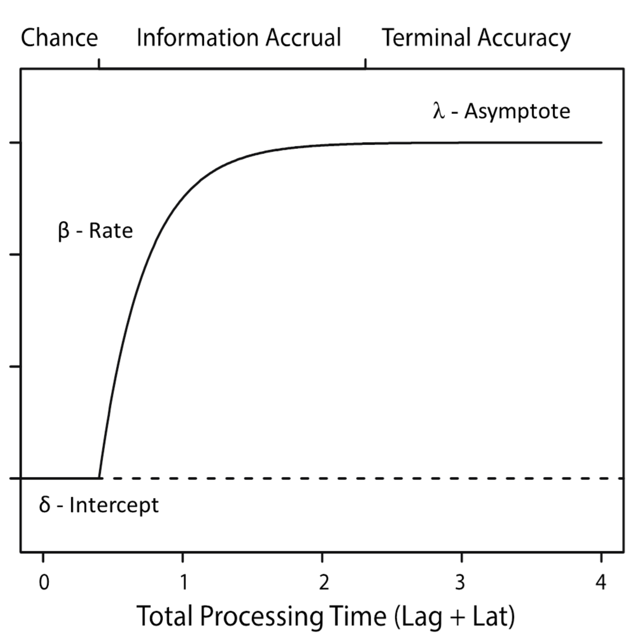
- In contrast to measurement models based on signal detection theory (e.g., *d'*), the *two-high-threshold model* (2HTM) assumes *discrete memory states* (detection and uncertainty) and distinguishes between a memory process for old items and a memory process for new items:
  - D^O: probability to correctly detect an old item as old (e.g., memory retrieval).
  - D^N: probability to detect a new item as new (i.e., rejection of lures).
  - *g*: measure of response bias (probability of responding "old" under uncertainty).



- **Goal:** Examine the time course of memory processes for old and new items in working memory.

Response Deadline Procedure

- We employ response-signal speed-accuracy trade-off procedure (SAT), which allows us to independently assess retrieval speed and retrieval accuracy.



- Data fitted by exponential approach to limit:

$$\lambda(1 - e^{-\beta(t-\delta)}), \quad t > \delta, \text{ or else } 0.$$

- SAT function reflects three phases:
  - Period where performance is at chance (departing point in time from chance is marked by *intercept parameter*)
  - Period of information accrual (rise of information accumulation is reflected by *rate parameter*)
  - Maximum level of accuracy is reached; performance does not improve any more (*asymptote parameter*).

- We model memory parameters D^O and D^N via independent SAT functions (i.e., completely independent sets of parameters). Additionally one *g* per participant.

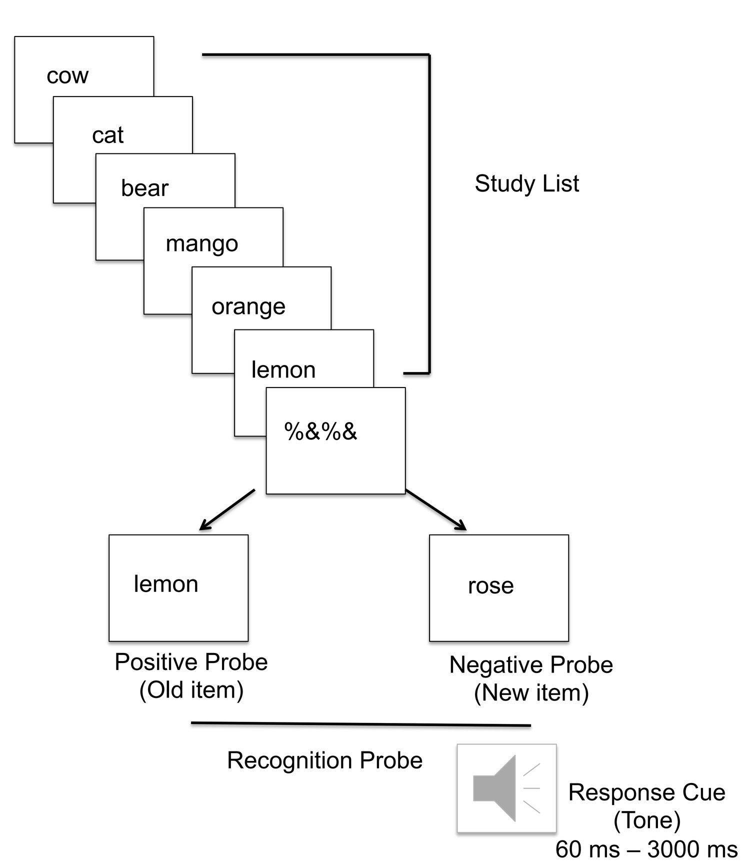
Experimental Procedure

Data Set 1- Visual Materials (Mizrak, & Öztekin, 2015):

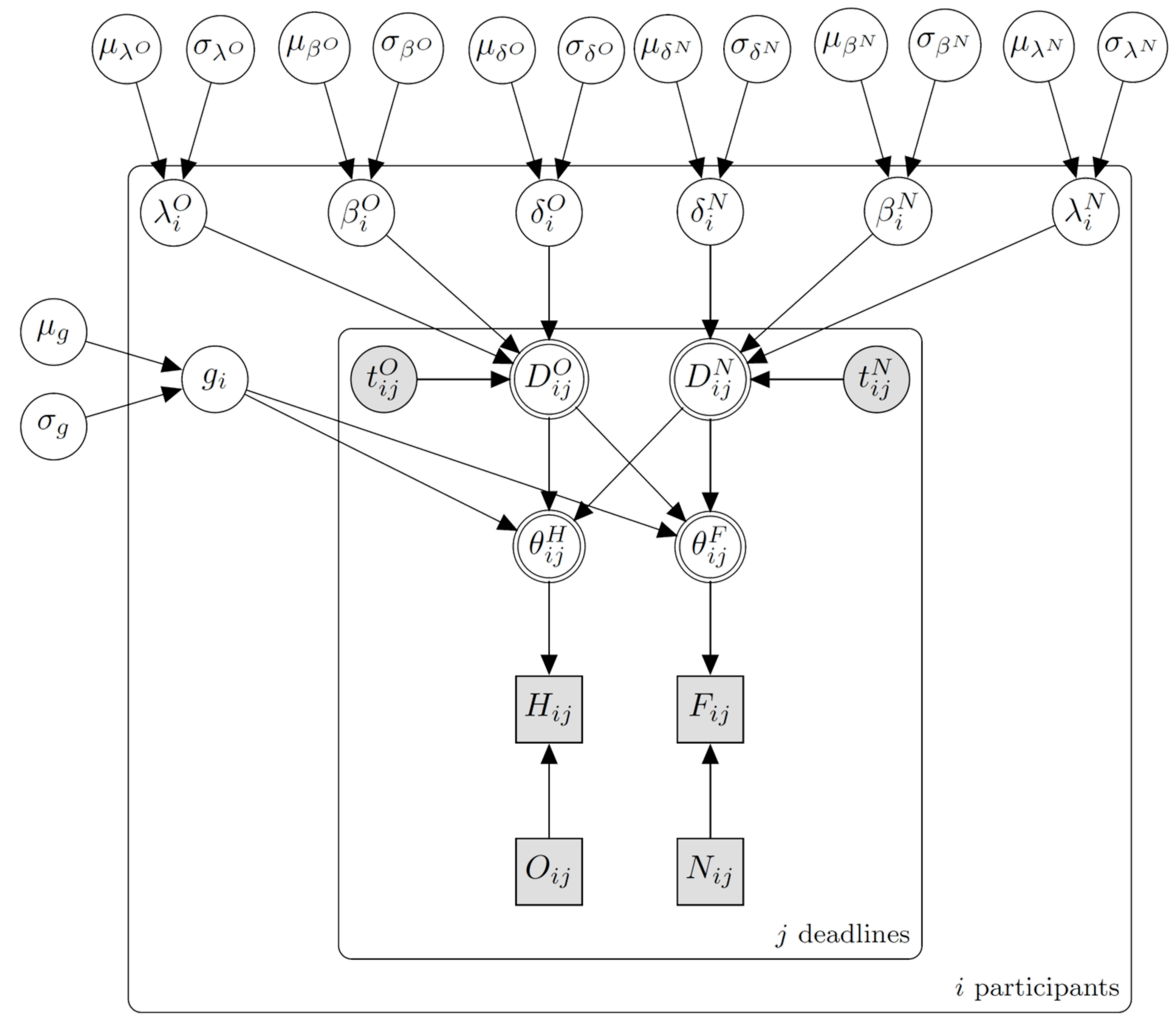
- Sternberg Recognition Memory Paradigm with response deadline procedure
- 3 item study list with neutral images from International Affective Picture System (Lang, Cuthbert, Bradley, 2005)
- 16 participants

Data Set 2- Verbal Materials (Öztekin, & McElree, 2010):

- Sternberg Recognition Memory Paradigm with response deadline procedure
- 6 item study list with neutral words
- 19 participants



Hierarchical Bayesian Model

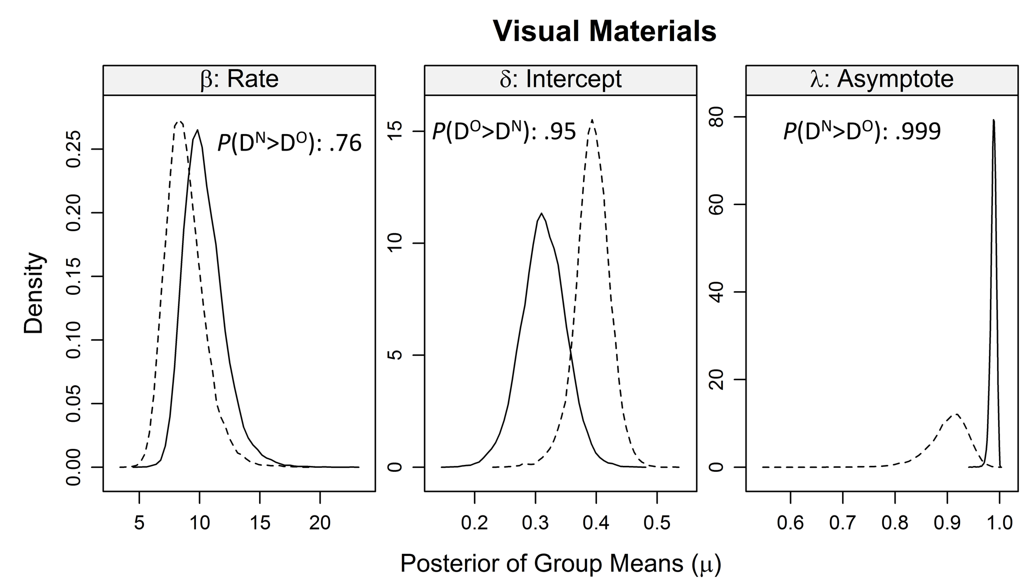


$$\mu_g, \mu_\lambda \sim \text{Gaussian}(0, 1)$$
$$\mu_\delta \sim \text{Cauchy}^+(0.4, 1)$$
$$\mu_\beta \sim \text{Cauchy}^+(5, 10)$$
$$\sigma \sim \text{Cauchy}^+(0, 10)$$
$$\lambda_i \sim \Phi(\text{Gaussian}(\mu_\lambda, \sigma_\lambda))$$
$$\beta_i \sim \text{Gaussian}^+(\mu_\beta, \sigma_\beta)$$
$$\delta_i \sim \text{Gaussian}^+(\mu_\delta, \sigma_\delta)$$
$$g_i \sim \Phi(\text{Gaussian}(\mu_g, \sigma_g))$$
$$H_{ij} \sim \text{Binomial}(\theta_{ij}^H, O_{ij})$$
$$F_{ij} \sim \text{Binomial}(\theta_{ij}^F, N_{ij})$$

Bayesian estimation via STAN

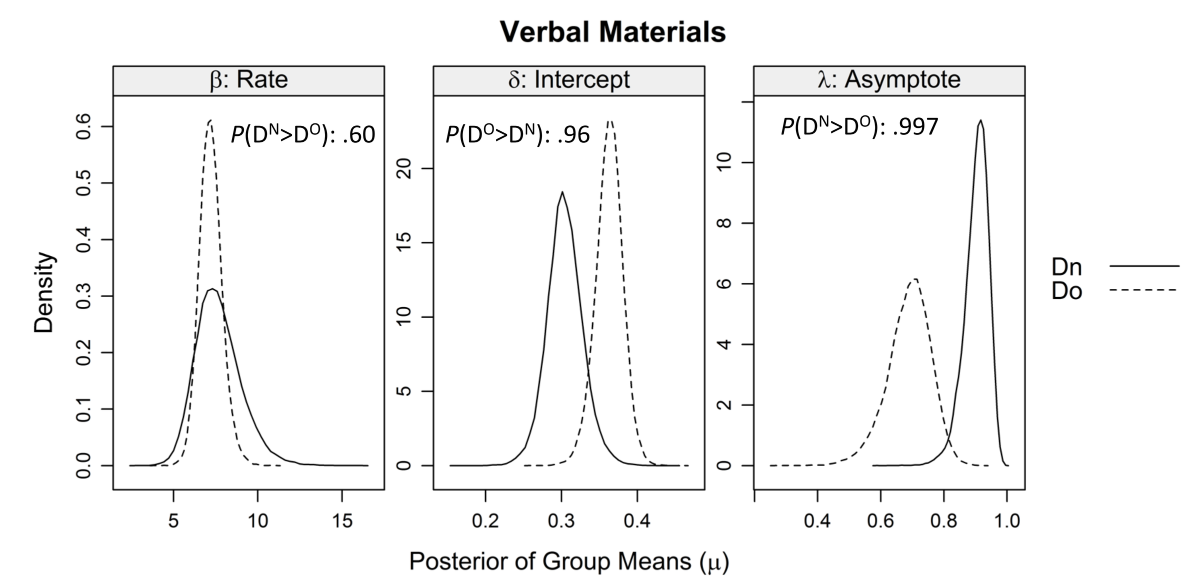
Results

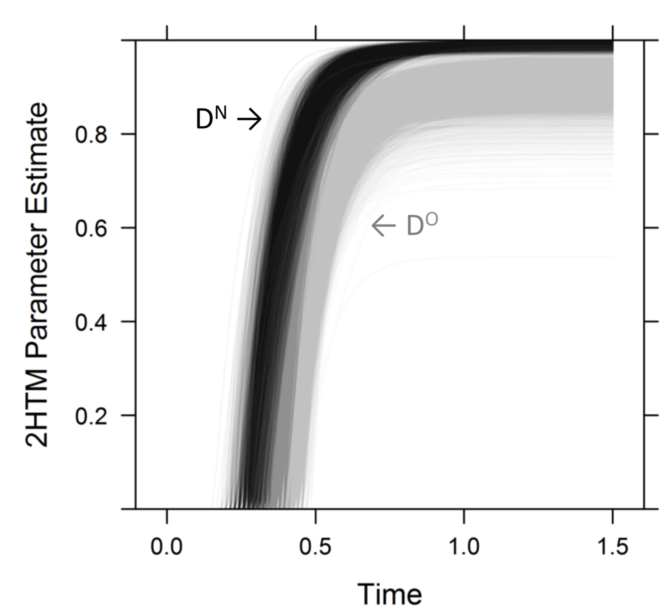
Data Set 1 (3-item Study list)



Kernel density estimates from posterior distributions of hyperparameters (distribution means)

Data Set 2 (6-item Study list)

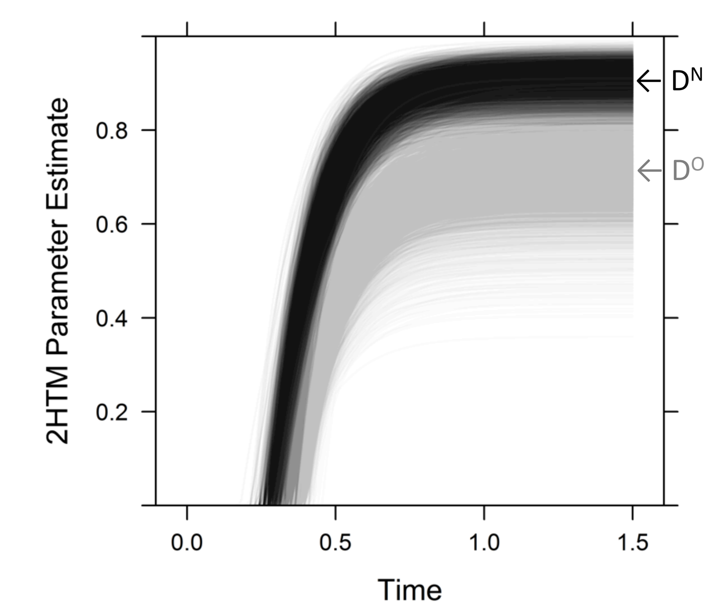




Predicted SAT curves from group means (5000 random draws from posterior, plotted with 98% transparency)

Posterior distribution hyperparameters: means and SDs

	Visual			Verbal		
	mean	2.50%	97.50%	mean	2.50%	97.50%
μ:						
β_{old}	8.78	6.18	12.55	7.21	5.96	8.64
β_{new}	10.37	7.74	14.16	7.67	5.37	10.69
δ_{old}	0.39	0.33	0.45	0.36	0.33	0.40
δ_{new}	0.31	0.24	0.39	0.30	0.26	0.35
λ_{old}	0.90	0.81	0.96	0.69	0.54	0.81
λ_{new}	0.99	0.98	1.00	0.90	0.81	0.96
g	0.64	0.48	0.77	0.42	0.29	0.55
σ:						
β_{old}	3.02	0.67	6.31	1.81	0.87	3.25
β_{new}	3.04	0.48	6.91	3.69	1.82	6.64
δ_{old}	0.07	0.02	0.13	0.06	0.03	0.10
δ_{new}	0.13	0.08	0.20	0.06	0.01	0.12
λ_{old}	0.79	0.47	1.30	0.82	0.55	1.25
λ_{new}	0.38	0.03	1.03	0.91	0.58	1.44
g	0.74	0.49	1.16	0.72	0.50	1.04



Conclusion

- **Findings suggest different time course for memory for old items versus new items:** evidence for rejecting lures becomes available earlier than evidence for detecting old items.
- Findings incompatible with exhaustive memory search (McElree, & Dosher, 1989).
- Findings consistent with novelty gated encoding (Oberauer et al., 2012), suggesting that the more novel the incoming item is, the more strongly it will be encoded. It is possible that participants reject lures by assessing their novelty strength instead of comparing the memory strength.
- Using discrete-state model promising approach to model SAT data as it allows to separately measure memory processes for old and new items.

References

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