Modeling lexical access in ACT-R

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1. Frequency effects in ACT-R

Modeling lexical decision (LD) tasks in ACT-R
the effect of frequency on reaction times & accuracies

- data: experiment reported in [2]
- explained in [2] in terms of the Rank hypothesis; they note that the effect of frequency on RTs could also be modeled by a power function

  $P = At^{-d}$ (P – performance; t – time; A, d – free params)

- power function model implemented in ACT-R, so: could ACT-R model the LD data?

Why relevant?

- ACT-R models linguistic processing & lexical retrieval during processing ([1, 3, 4])
- these are complex models, but lexical retrieval is simply power law with standard values for free parameters
- our contributions:

- a more direct test of the ACT-R declarative memory retrieval model for language
- direct evidence for *which free parameters* should be used and *what values* they have; our results differ from previous assumptions

2. Data: Murray et al. (2004)

LD task for 5-7 letter words from 16 frequency bands:

- highest frequency – 315 per 1 million
- lowest frequency – 1 per 1 million

Best fit: Power law, Rank hypothesis

3. Lexical decision and frequency effects in ACT-R

The models

- Bayesian modeling using general-purpose tools (Python and pymc3)
- accuracy and RTs for LD derived from the same unobserved variable – activation (see box)
- evaluated directly against the data, various free parameters estimated
- also evaluated in a full ACT-R model that simulates a participant completing an LD task, including visual and motor interfaces

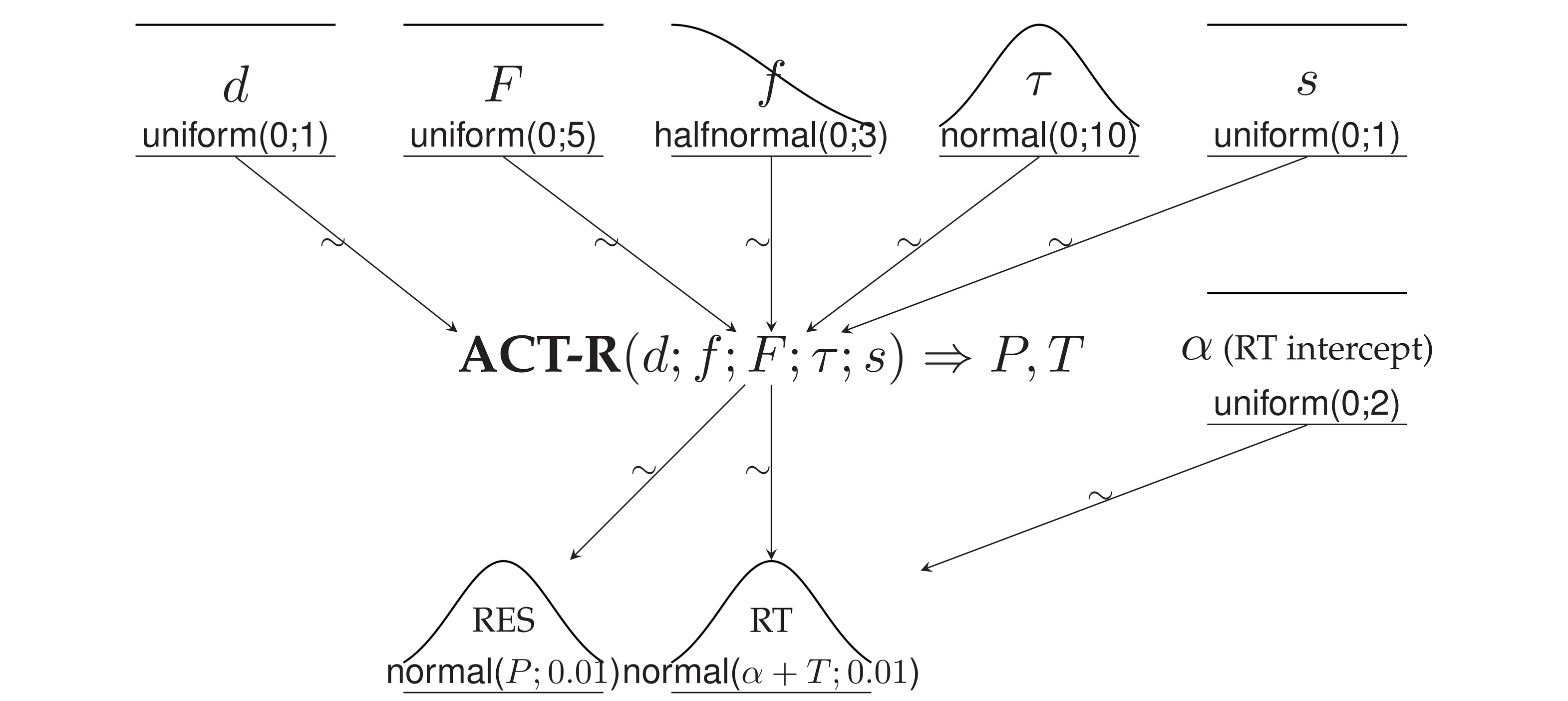
The ACT-R model of lexical retrieval

$$\text{Activation: } A_i = \log\left(\sum_{k=1}^{n} t_k^{-d}\right) \; (d: \text{decay}; n: \text{rehearsals}) \quad (1)$$

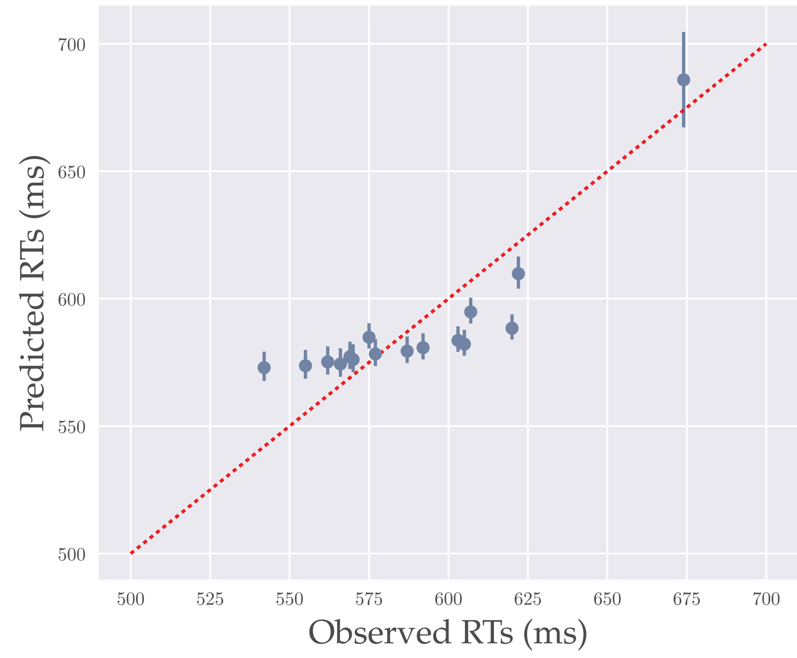
$$\text{Retrieval prob.: } P_i = \frac{1}{1+e^{-\frac{A_i-\tau}{s}}} \; (s: \text{noise}, \tau: \text{threshold}) \quad (2)$$

$$\text{Latency: } T_i = Fe^{-fA_i} \; (F, f: \text{latency factor and exp.}) \quad (3)$$

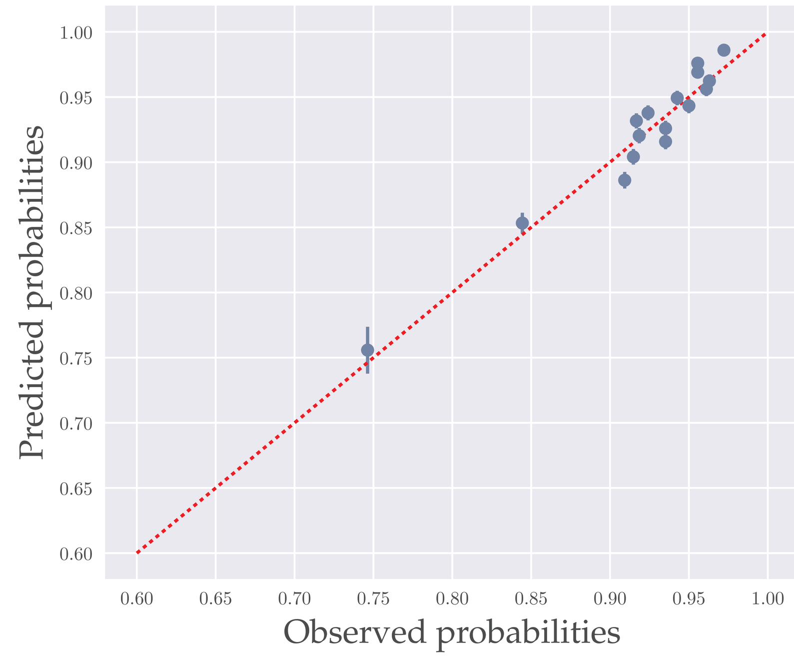
Full Bayesian models (model with f shown)



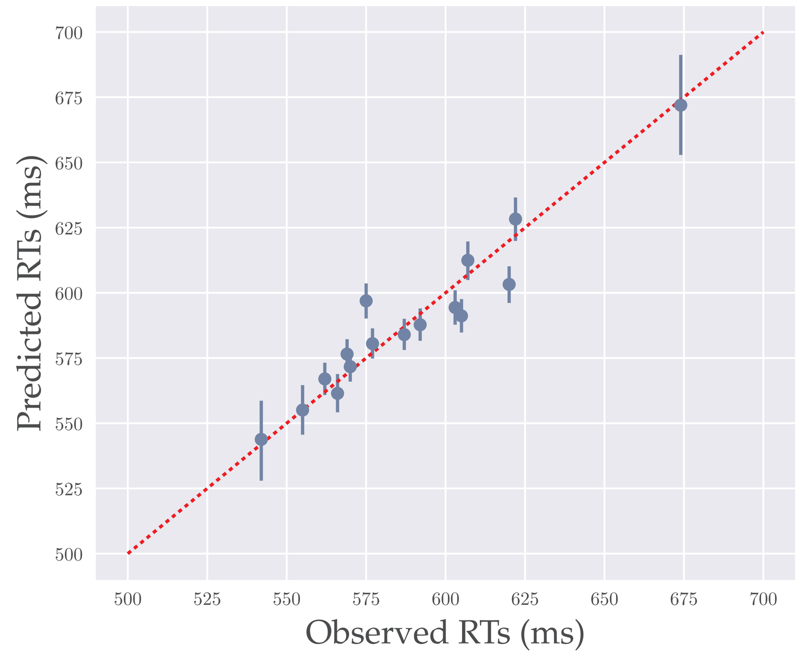
Reaction times (without f)



Accuracies (with/without f)



Reaction times (with f)



Estimates

- $f = 0.28[0.06 - 0.48]$
- $F = 0.45[0.1 - 0.86]$
- $d = 0.1[1e^{-6} - 0.24]$
- $\alpha = 0.5[0.3 - 0.56]$
- $\tau = 0.9[-1.9 - 2.9]$
- $s = 1.77[1.6 - 1.9]$

Conclusions

- ACT-R can model role of frequency in LD tasks very well
- the params d, τ, s needed to model accuracies
- latency exponent f essential for modeling RTs, but psycholinguistic ACT-R models disregard it ([1, 3, 4]; cf. [5])
- crucial to estimate ACT-R model params by embedding them in (Bayesian) statistical models
- we can do systematic quantitative model comparison, in contrast to standard practice (default values for params, or manually changing the values)

[1] Lewis, R., and S. Vasishth. 2005. An activation-based model of sentence processing as skilled memory retrieval. *CogSci* 29:1–45. ∗ [2] Murray, W. S, and K. I Forster. 2004. Serial mechanisms in lexical access: the rank hypothesis. *Psychological Review* 111:721. ∗ [3] Reitter, D., F. Keller, and J. D. Moore. 2011. A computational cognitive model of syntactic priming. *CogSci* 35:587–637. ∗ [4] van Rij, J. 2012. *Pronoun processing: Computational, behavioral, and psychophysiological studies in children and adults*. Groningen. ∗ [5] West, R., A. Pyke, M. Rutledge-Taylor, and H. Lang. 2010. Interference and ACT-R: New evidence from the fan effect. In *Proceedings of the 10th International Conference on Cognitive Modeling*, ed. D. D. Salvucci and G. Gunzelmann, 211–216. Philadelphia, PA: Drexel University.