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Modeling the development of cognitive abilities over time

Jessica Schaaf, Jessica.Schaaf@radboudumc.nl, @JessicaVSchaaf

Using psychometrics to improve cognitive models–and theory

Cognition as dynamic process

HEALTH

Joe Biden's 'Cognitive Fluctuations'

Which version of the president will show up next?

COGSCI2024
DYNAMICS OF COGNITION
July 24-27 • Rotterdam

Slip-ups like Joe Biden's misnaming of Trump and Harris

https://www.theatlantic.com/health/archive/2024/07/science-joe-bidens-cognitive-fluctuations/678900/
https://www.abc.net.au/news/2024-07-14/us-president-joe-biden-slip-ups-trump-misnaming-are-common/104092304

Cognition as dynamic process

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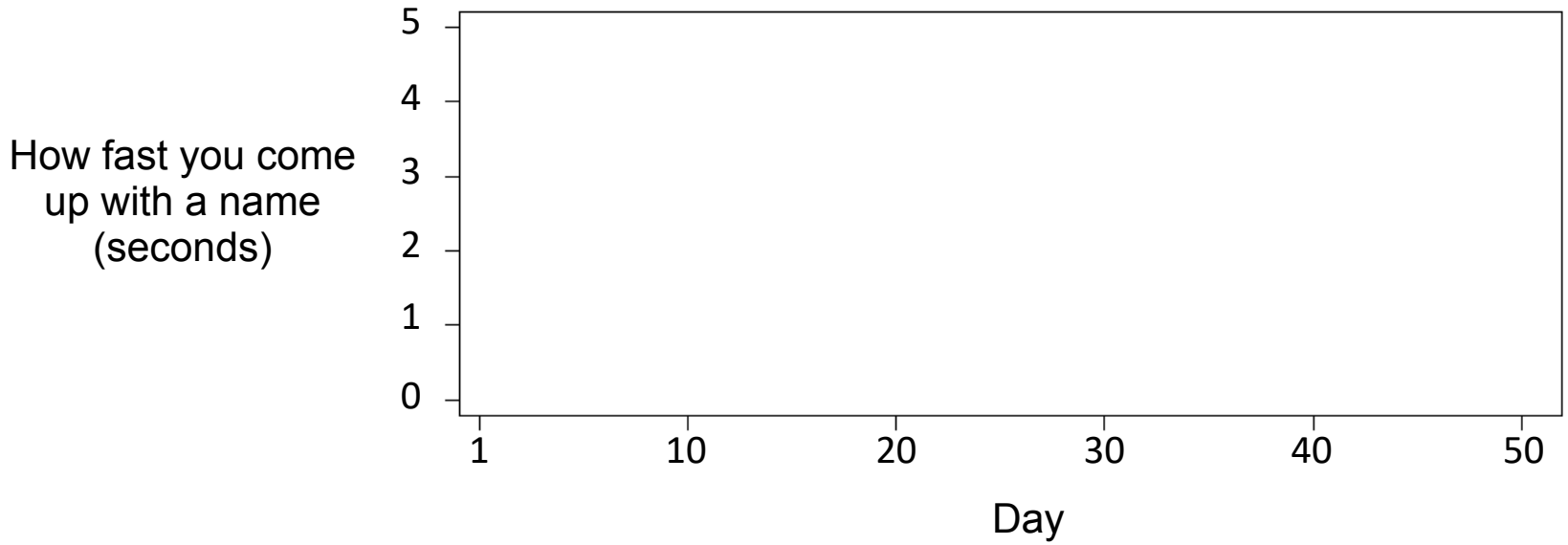

Cognition as dynamic process

HEALTH

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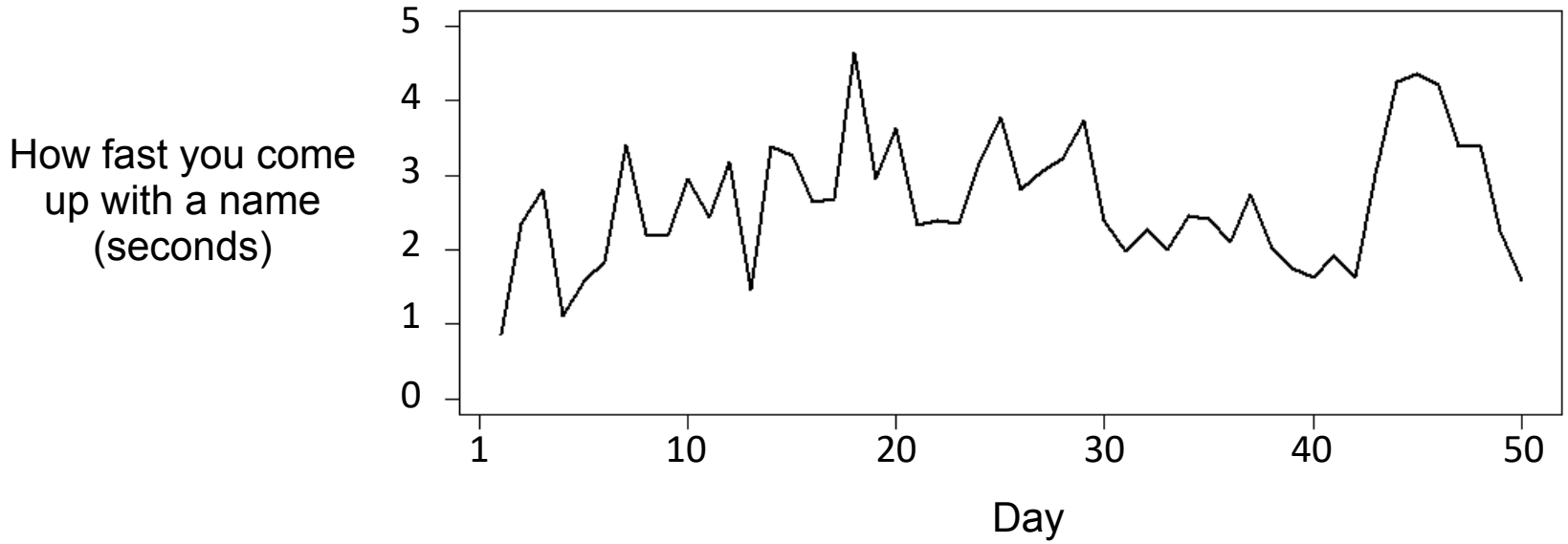
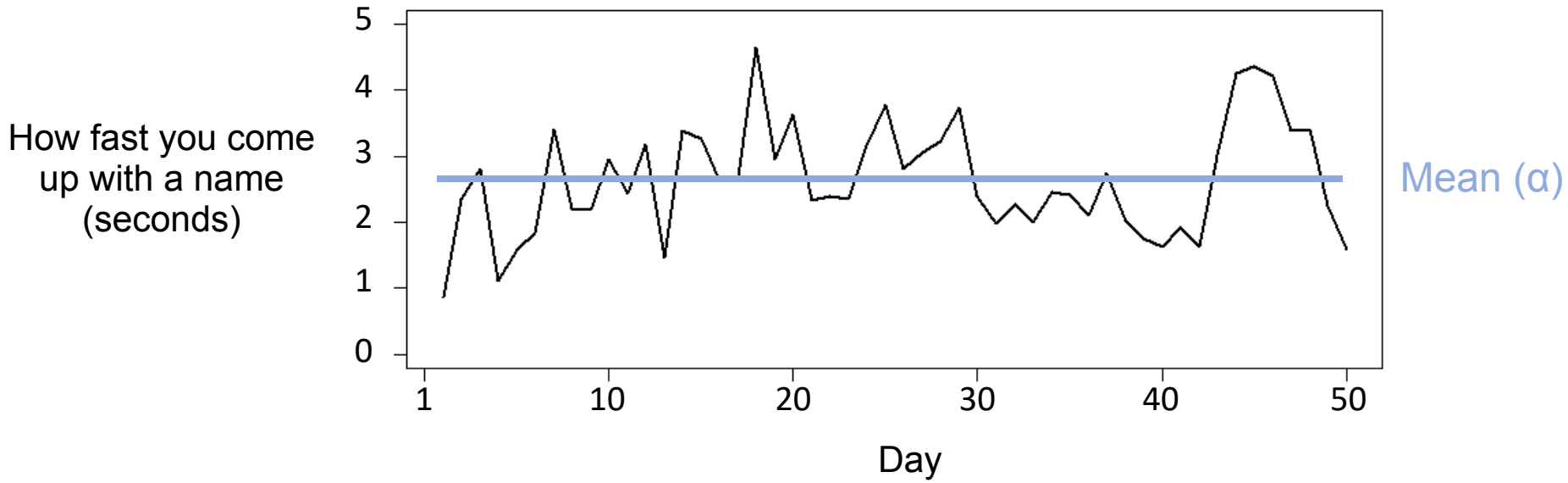


Cognition as dynamic process

HEALTH

Joe Biden's ~~'Cognitive Fluctuations'~~ Noise

Which version of the president will show up next?



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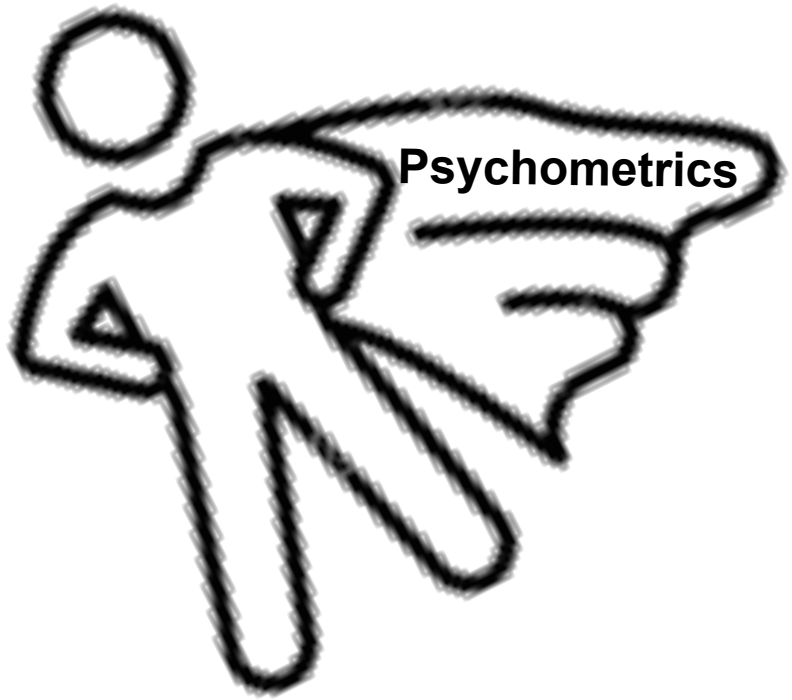
Modelling cognitive fluctuations

Detailed description of fluctuations

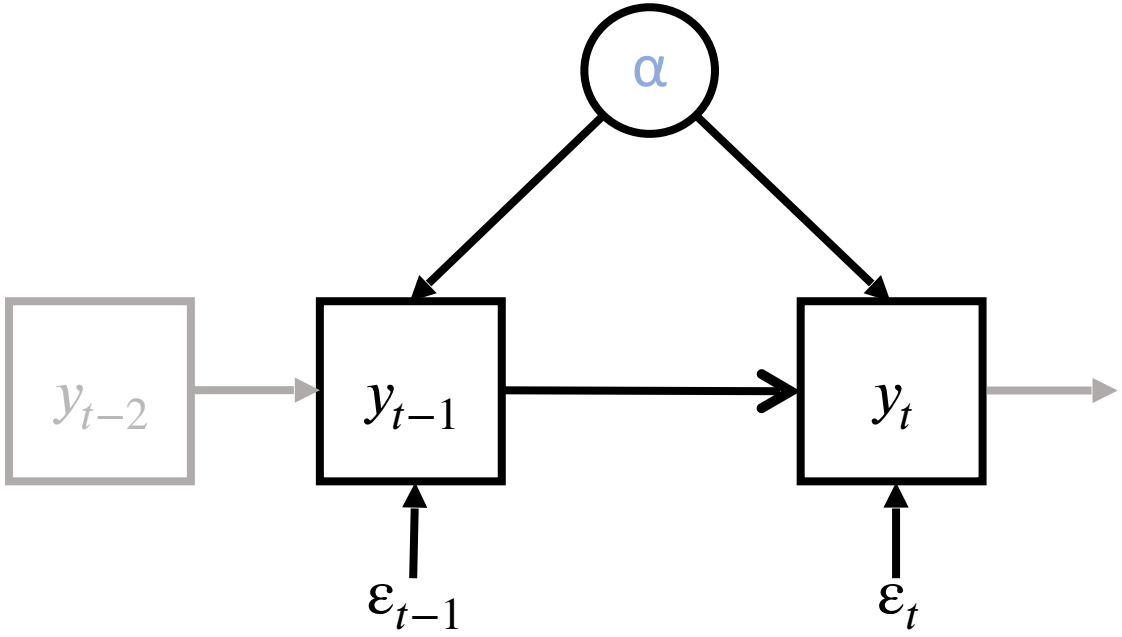
- ➢ On which time scales do cognitive fluctuations occur?
- ➢ Can we relate cognitive fluctuations to external variables?

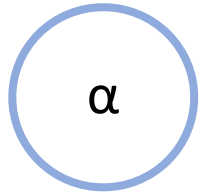


Slip-ups like Joe Biden's misnaming of Trump and Harris are common, and usually caused by lack of sleep or stress, experts say

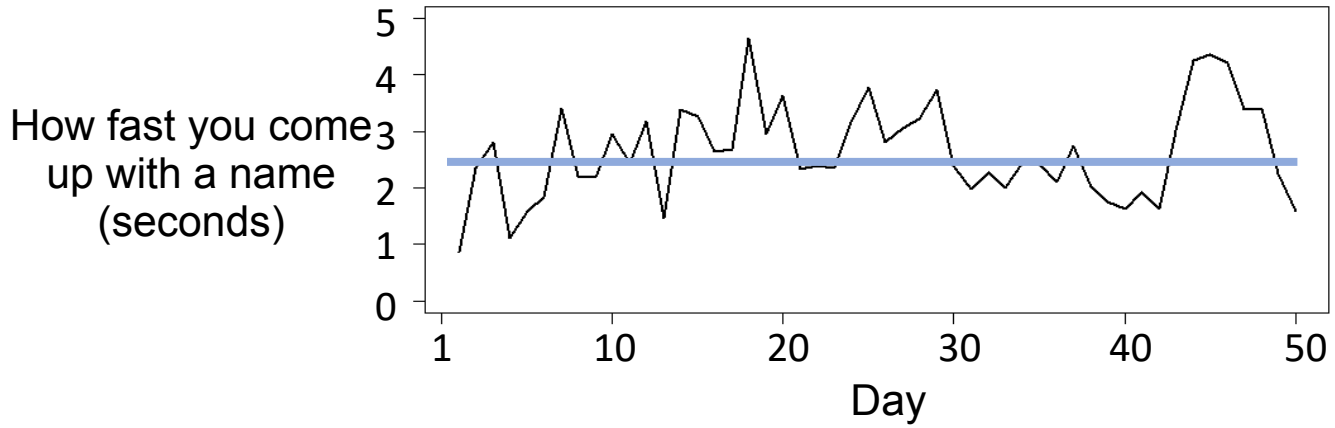
https://www.abc.net.au/news/2024-07-14/us-president-joe-biden-slip-ups-trump-misnaming-are-common/104092304

Modelling cognitive fluctuations **as noise**

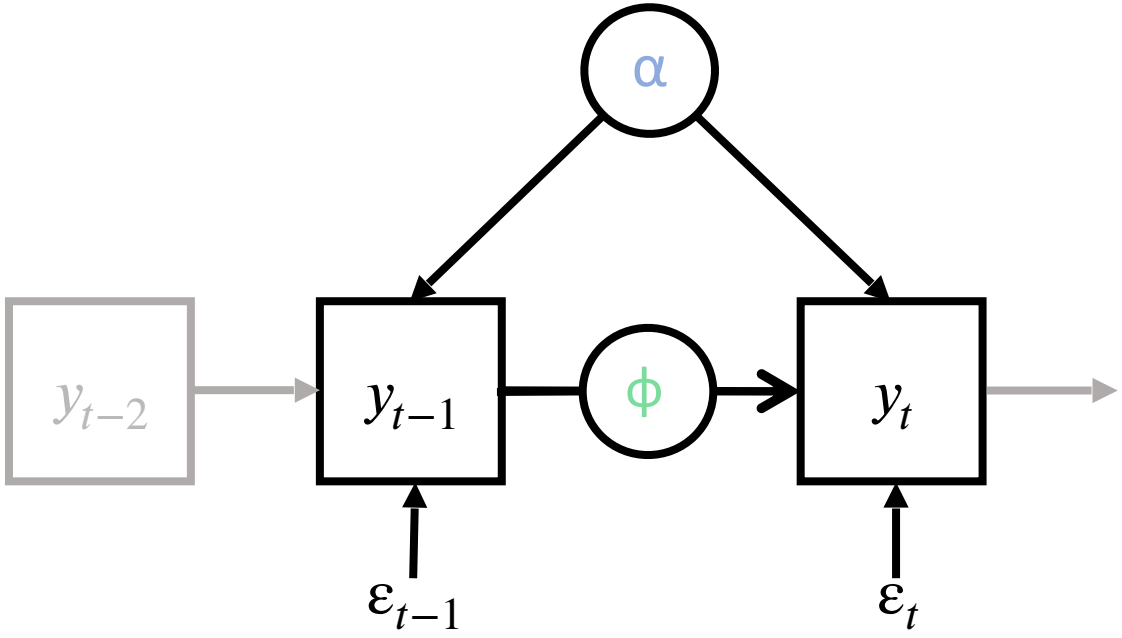




mean



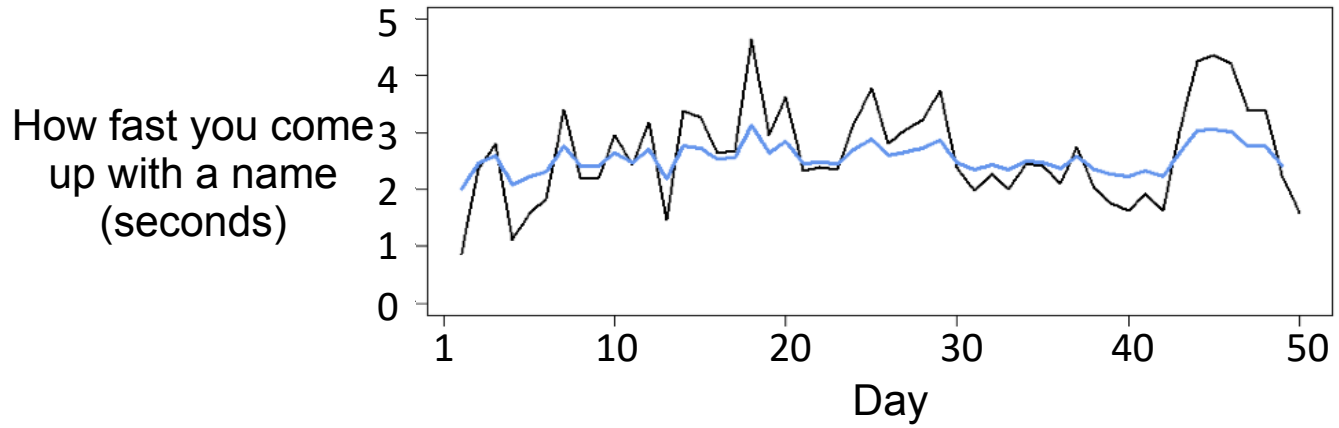
Modelling cognitive fluctuations **as something of interest**



α mean

ϕ inertia

Interpretation: the tendency of a person/ system to persist in deviations from their mean



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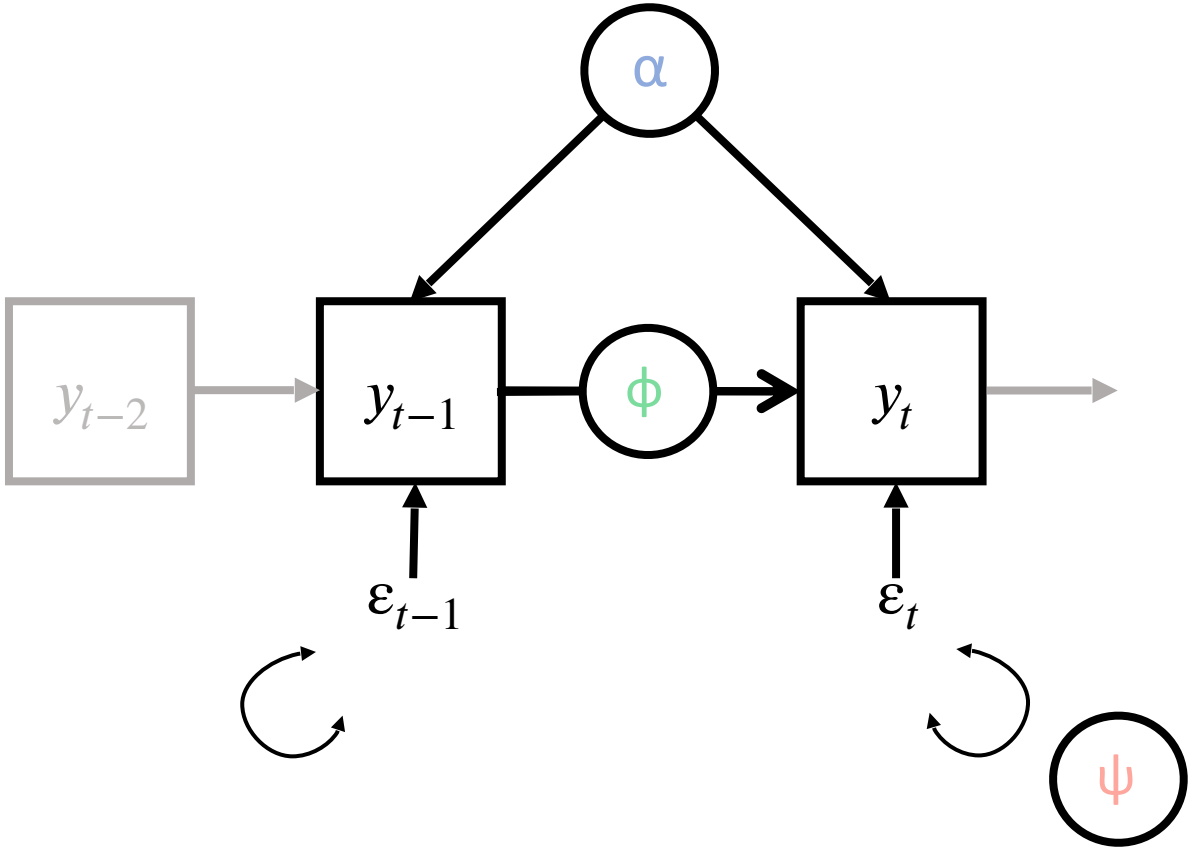
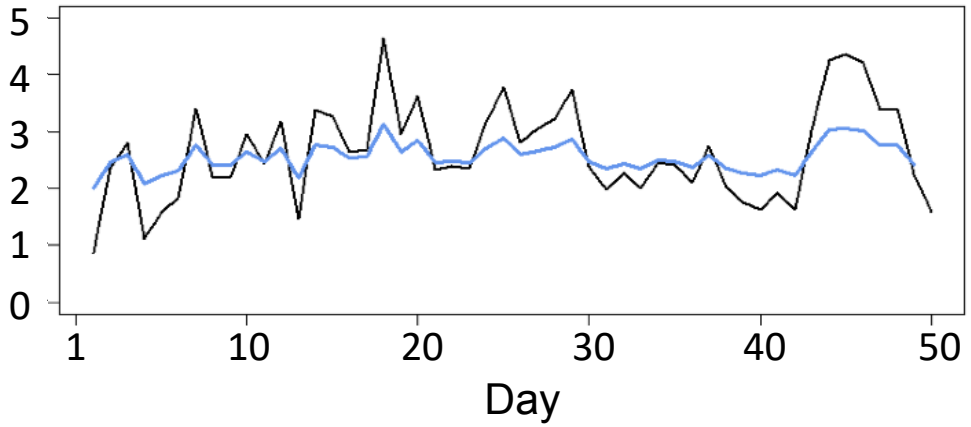


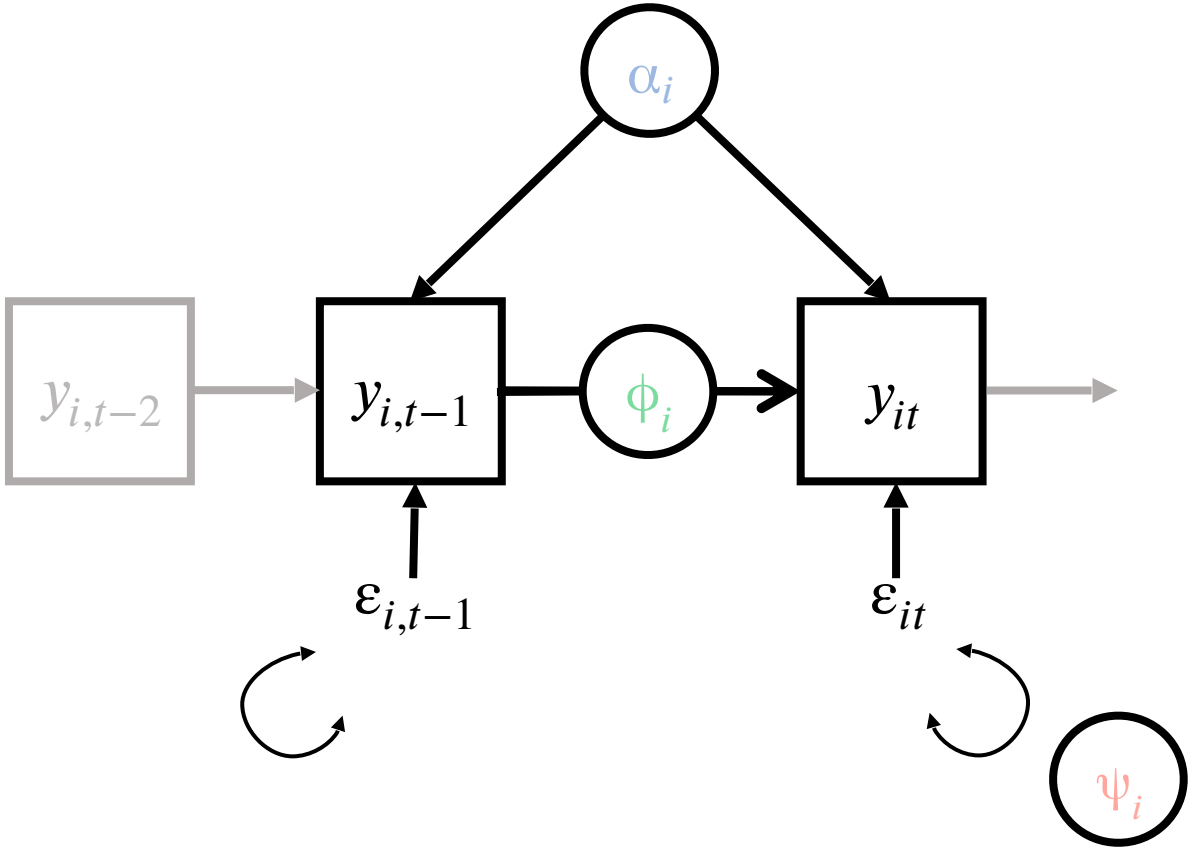
α mean

ϕ inertia

ψ residual variance



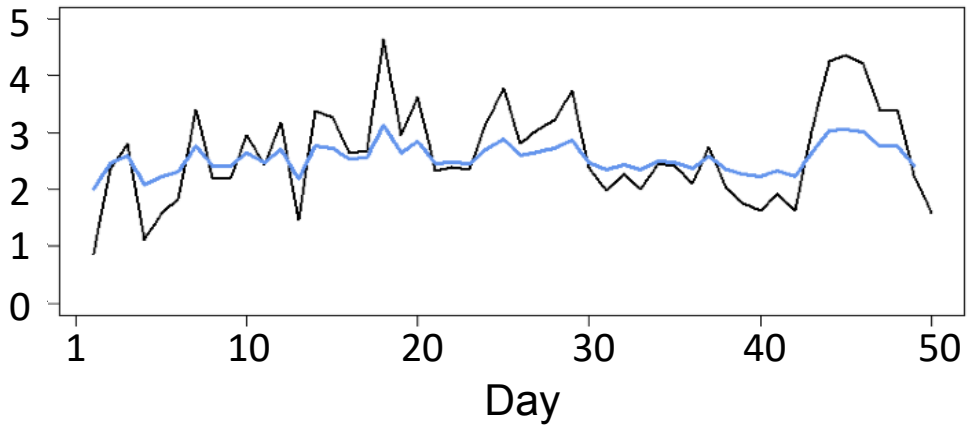
Hierarchical modelling of cognitive fluctuations



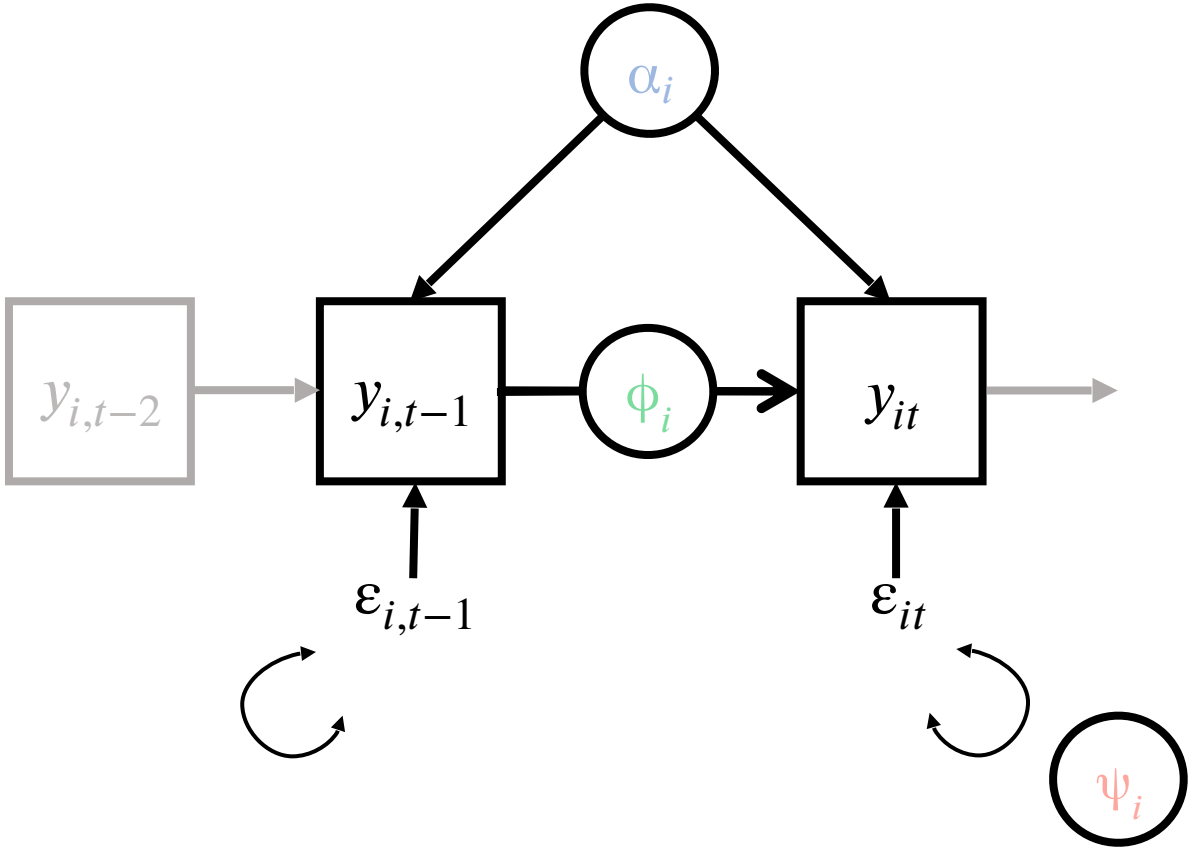
α_i mean

ϕ_i inertia

ψ_i residual variance



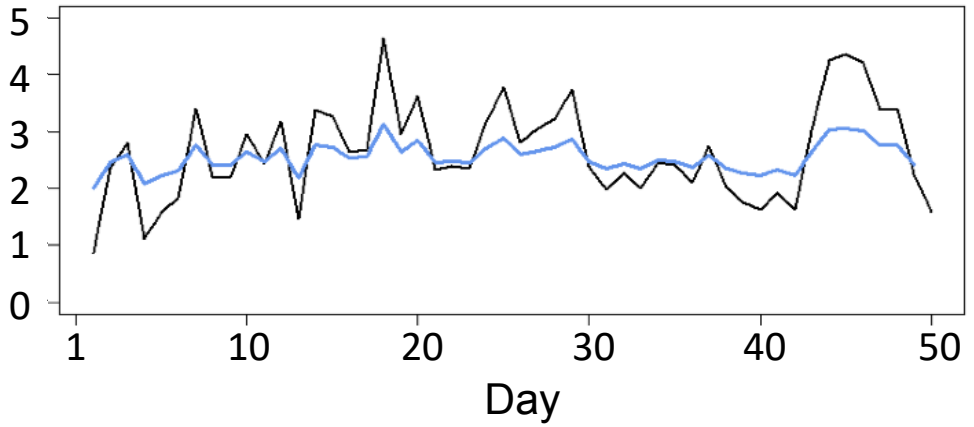
Dynamic Structural Equation Model



$$\alpha_i = \alpha + u_{\alpha i}$$

$$\phi_i = \phi + u_{\phi i}$$

$$\psi_i = \psi + u_{\psi i}$$



Asparouhov et al. (2018). *Structural Equation Modeling: A Multidisciplinary Journal*; Jongerling et al. (2015). *Multivariate Behavior Research*; McNeish et al. (2020). *Psychological Methods*.

Applications

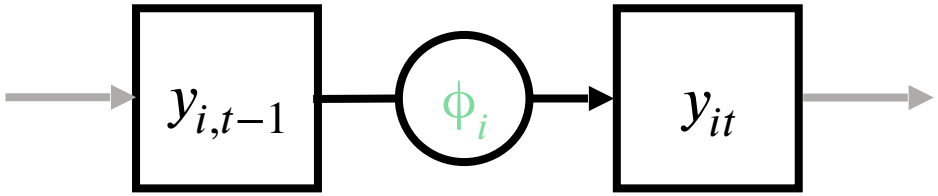
Emotional/affective inertia (Koval & Kuppens, 2012, 2024; Kuppens et al, 2012; Suls et al., 1998)

Stress inertia (Ekuni et al., 2022; Sperry & Kwapil, 2022)

Solitude inertia (Elmer et al., 2020)

RT inertia (Aristodemou et al., 2024)

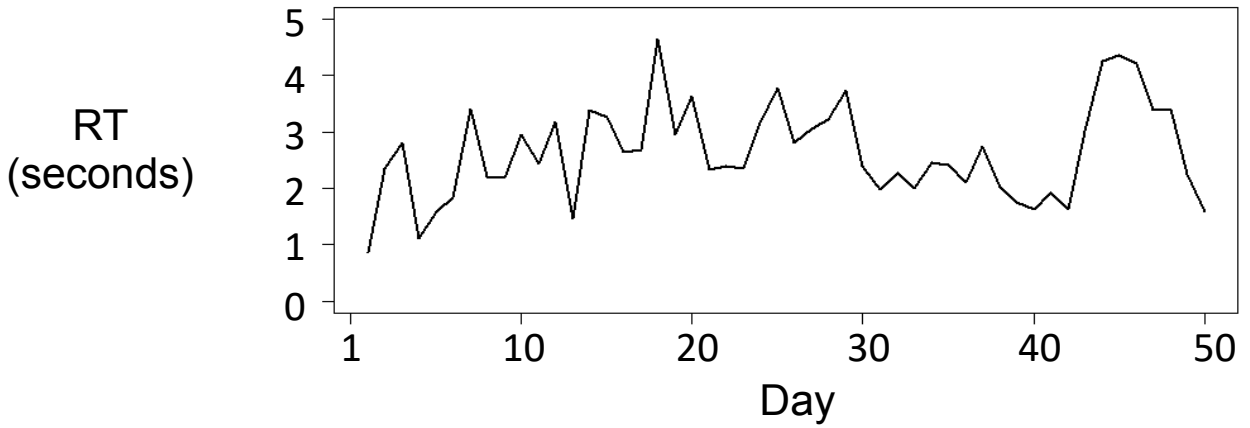
…



Aristodemou et al. (2024). *Collabra*; Ekuni et al. (2022). *Sleep Health*; Elmer et al. (2020). *Journal of Abnormal Psychology*; Koval & Kuppens (2012). *Emotion*; Koval & Kuppens (2024). *Changes in Emotion and Mental Health;* Kuppens et al. (2010). *Psychological Science*; Sperry & Kwapil (2022). *Behavioral Sleep Medicine*; Suls et al. (1998). *Personality and Social Psychology Bulletin.*

Challenges in standard DSEM

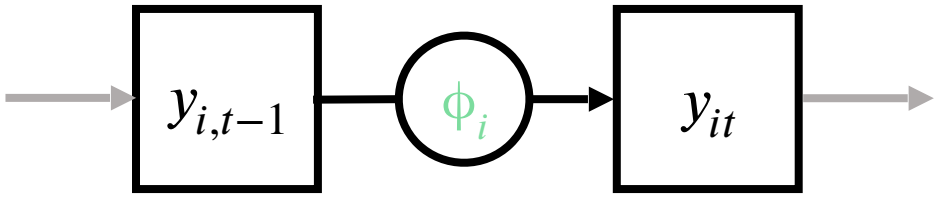
- Default inertia parameter is *symmetric*
- Inertia of deviations above and below the mean treated equally
- Responding faster than average equally likely to persist as responding slower than average
- Probably not true
  - post-error slowing
  - any measure with ceiling effects (e.g., intelligence or memory)



Asymmetric variant of DSEM

Solution: *Threshold AR*

➢ Estimate two inertia parameters, above and below the mean



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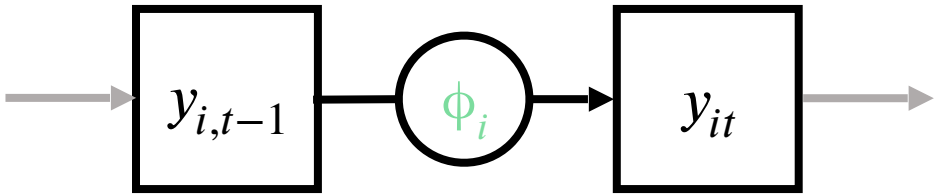


$$\alpha_i = \alpha + u_{\alpha i}$$

$$\phi_i^+ = \phi^+ + u_{\phi_i^+}$$

$$\phi_i^- = \phi^- + u_{\phi_i^-}$$

$$\psi_i = \psi + u_{\psi i}$$

De Haan-Rietdijk et al. (2016). *Psychometrika*; Tong & Lim (1980). *Journal of Royal Statistical Society: Series B (Methodological)*.

Using psychometrics to improve cognitive models–and theory

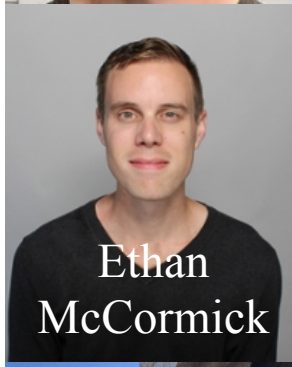
DYNamics of Asymmetric Timeseries (DYNASTI)

Implemented in Stan: free, flexible, updates, community

Univariate and bivariate examples

Workshop on basics of DSEM in Stan: https://github.com/mearistodemou/DSEM_workshop

Stan models and simulation code: https://osf.io/hwmgk/



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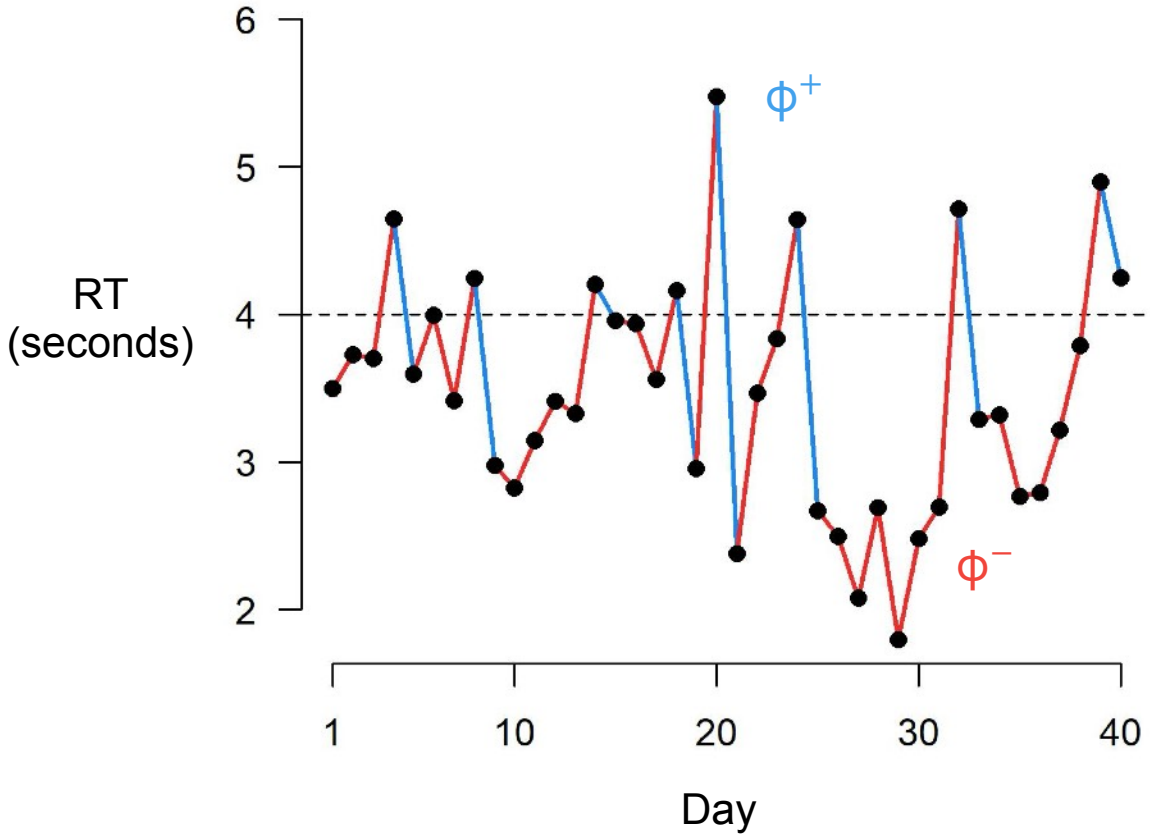


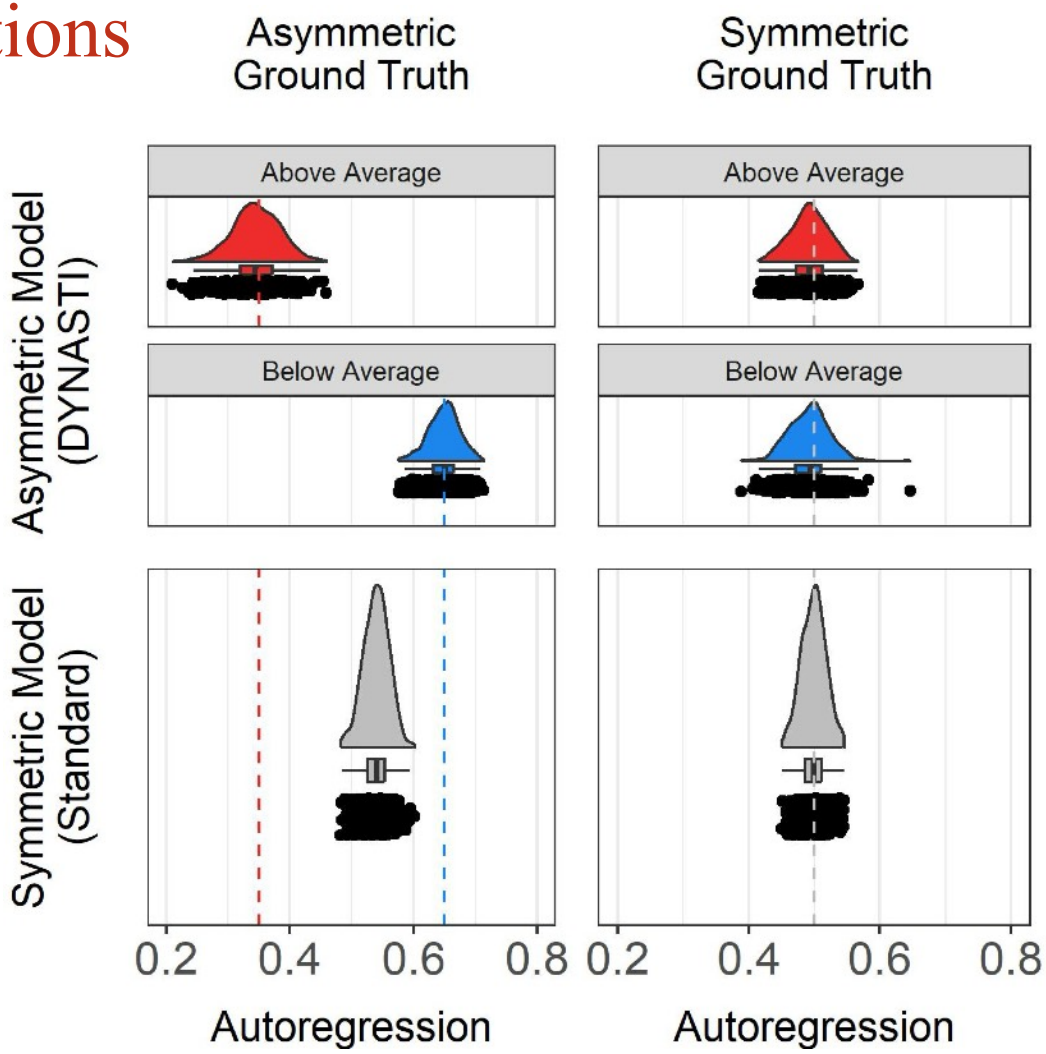
Using psychometrics to improve cognitive models–and theory

DYNASTI DSEM simulations

500 datasets

N = 50 subjects

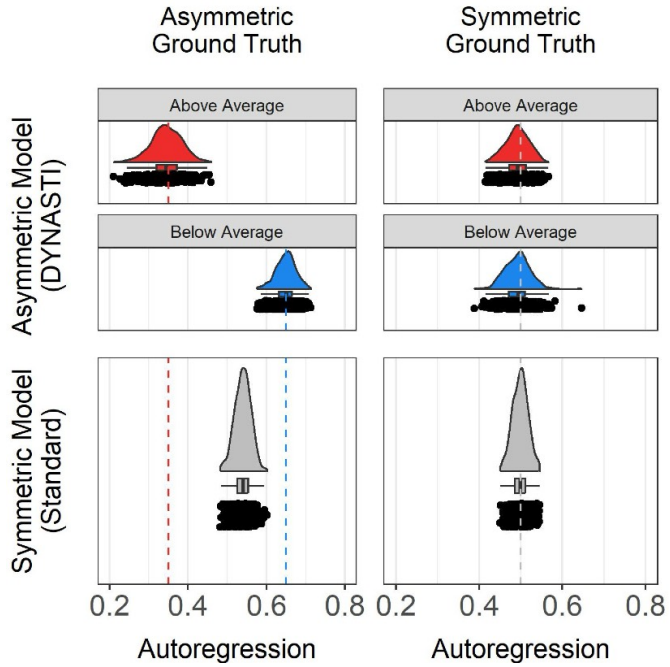
T = 100 time points



All code is openly available at https://osf.io/hwmgk/

DYNASTI DSEM simulations – summary

1. DYNASTI model adequately captures asymmetric dynamics
2. Standard model returns incorrect estimate in case of asymmetric dynamics
3. Both models adequately capture symmetric dynamics



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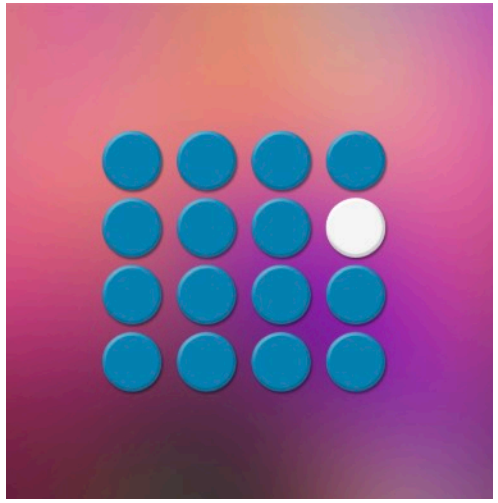
Empirical DYNASTI example

Vektor platform

WM grid (~corsi block tapping)



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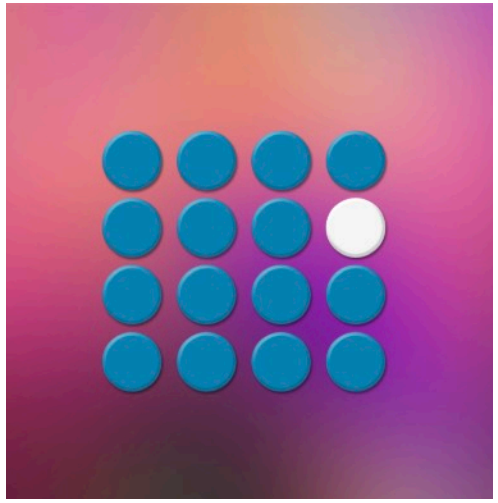
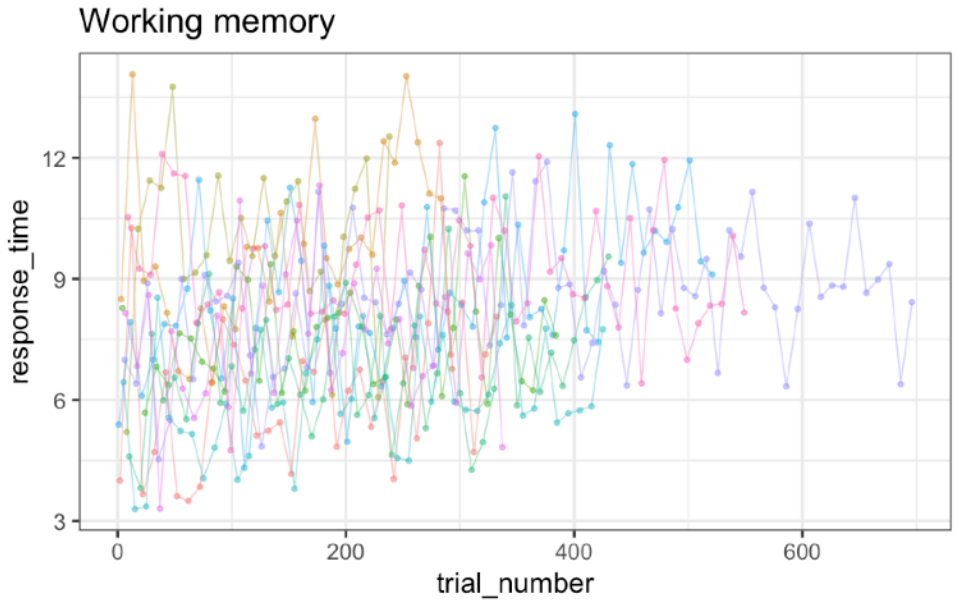


Vektor platform

WM grid (~corsi block tapping)

RTs (all trials), N = 71, T = 502

Detrended



Standard vs DYNASTI model

Are temporal dynamics for fast trials the same for slow trials?

Empirical DYNASTI example

DYNASTI model is preferred (by a lot)

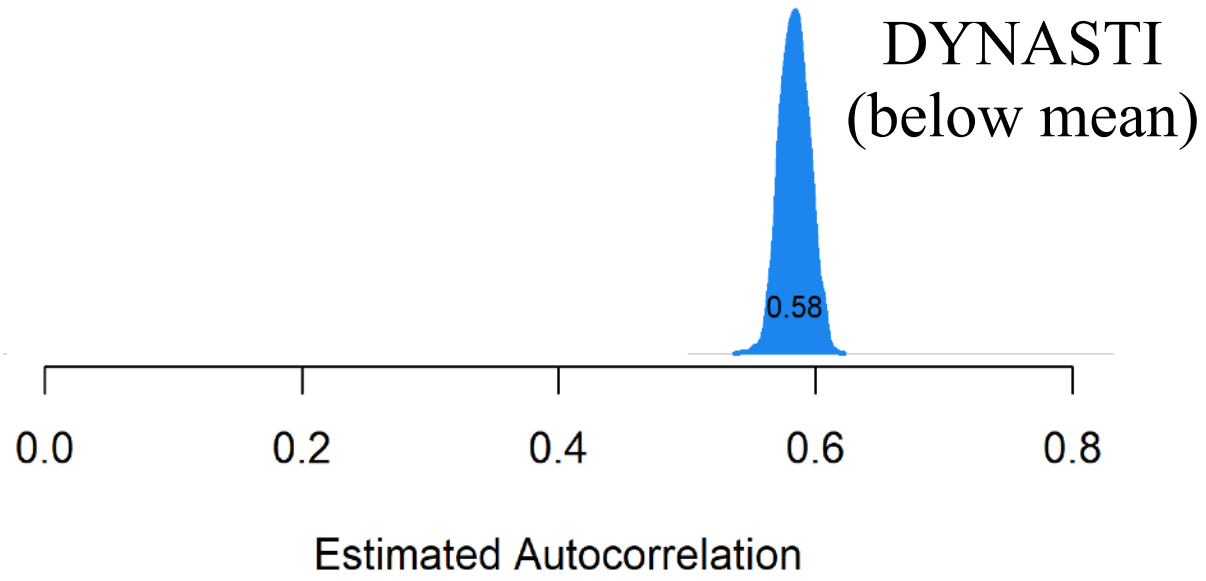
Model	-2LL	AIC	BIC
Standard	-6330	-6310	-6287
DYNASTI	**-7243**	**-7213**	**-7179**

Empirical DYNASTI example

DYNASTI model is preferred (by a lot)

Inertia is considerable below mean RT

- Faster than average trials come in streaks
- Concentration?



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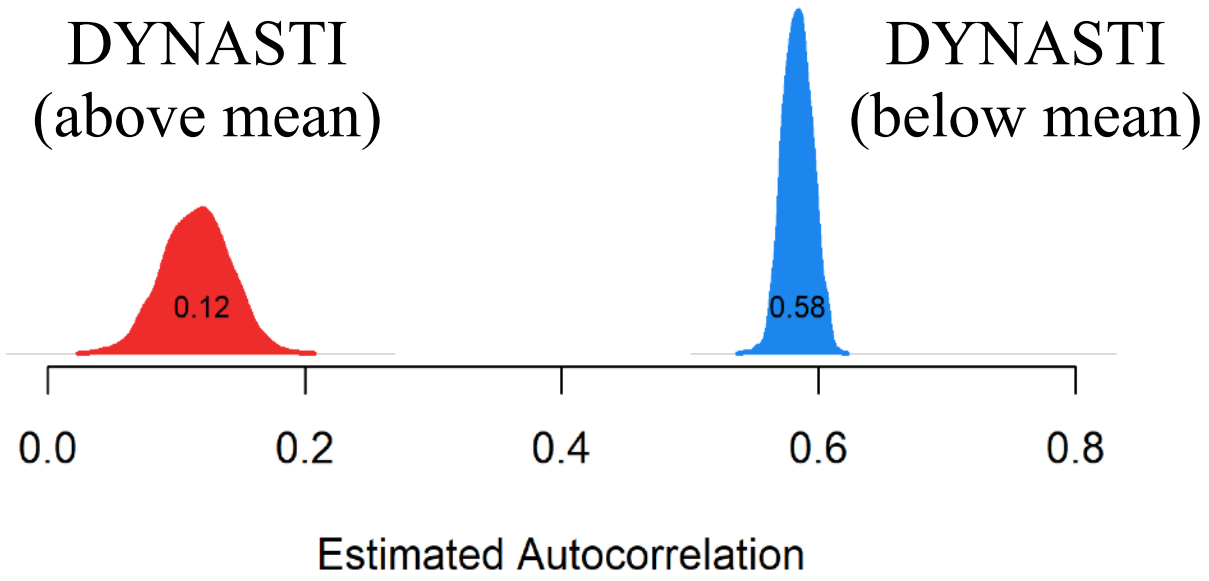
But inertia is *negligible* above the mean

- Attentional lapses show swift mean reversion



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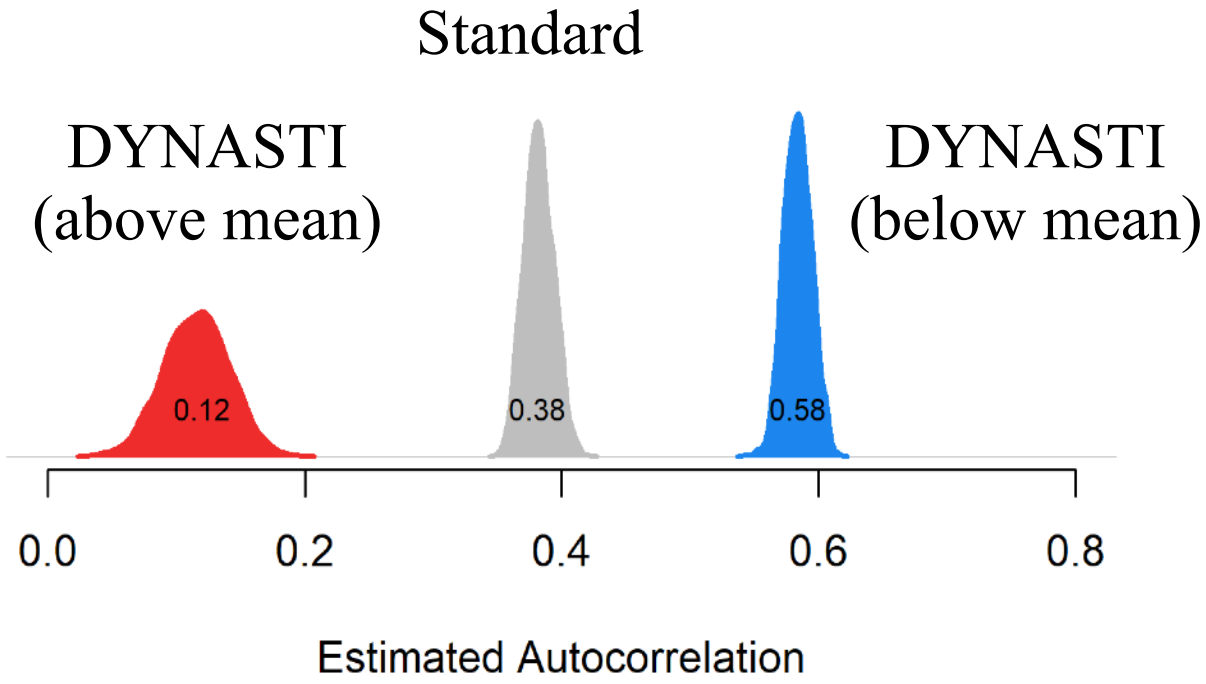
- Attentional lapses show swift mean reversion

Standard model would be wrong about both



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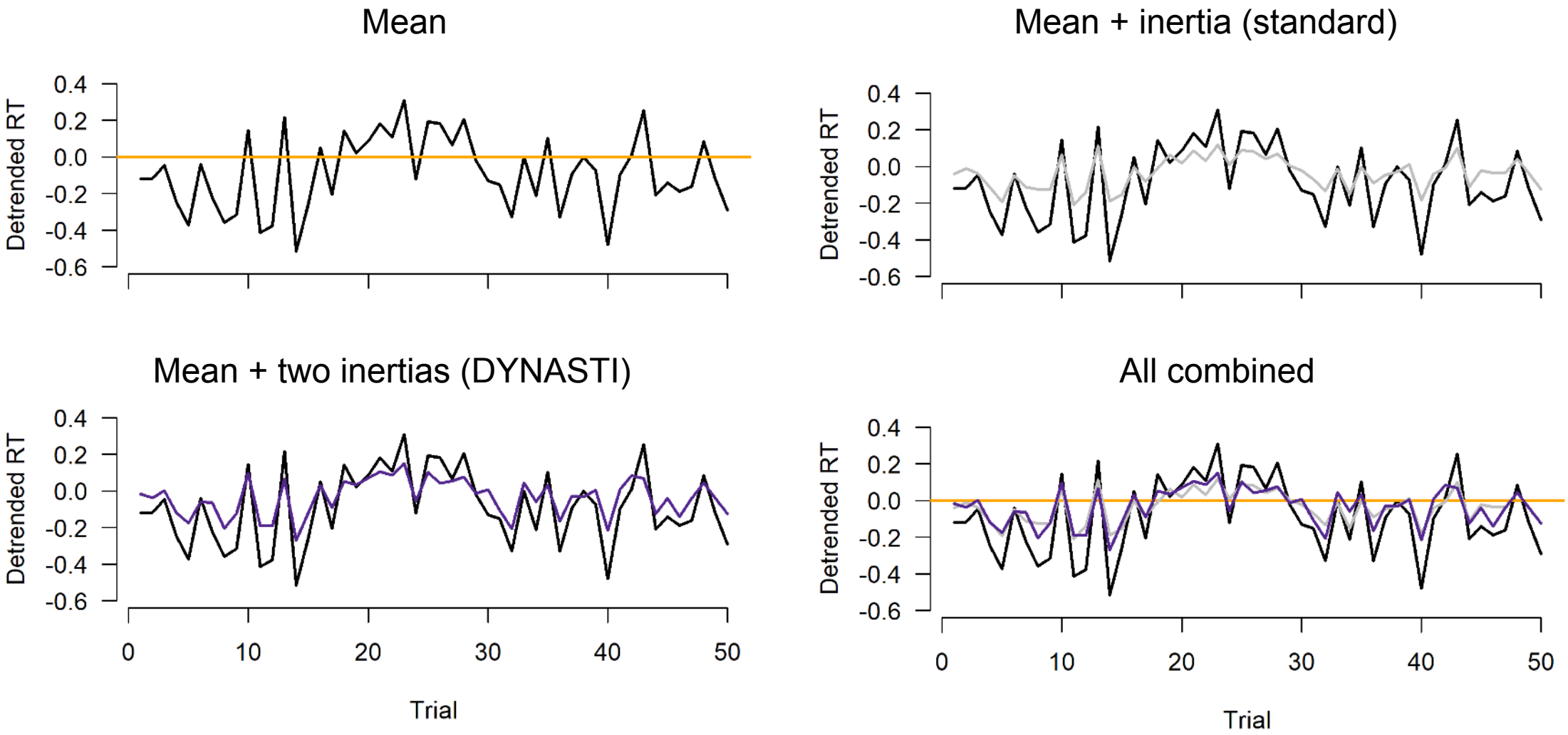

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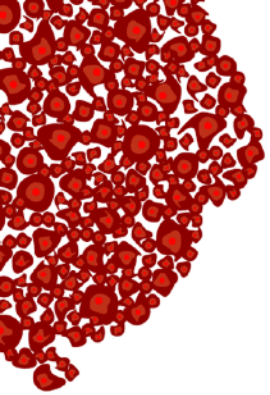
To take home

- Many cognitive processes plausibly have asymmetric dynamics
- Fitting DYNASTI implementations doesn't hurt! Try it out.
- Keep it maximal: estimation comes at negligible costs.
- Flexible framework to fit your specific RQ.

Barr et al (2013). *Journal of Memory of Language.*



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Thank you!

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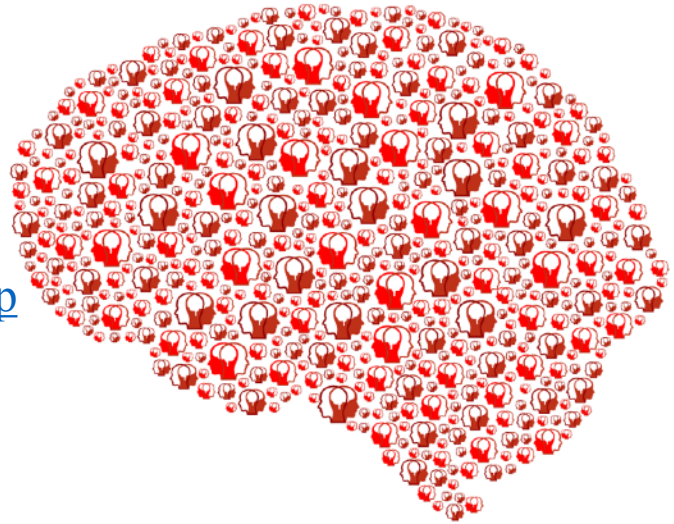


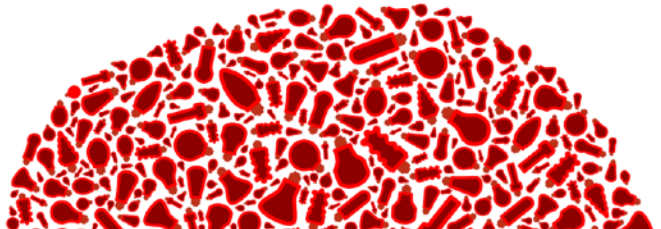

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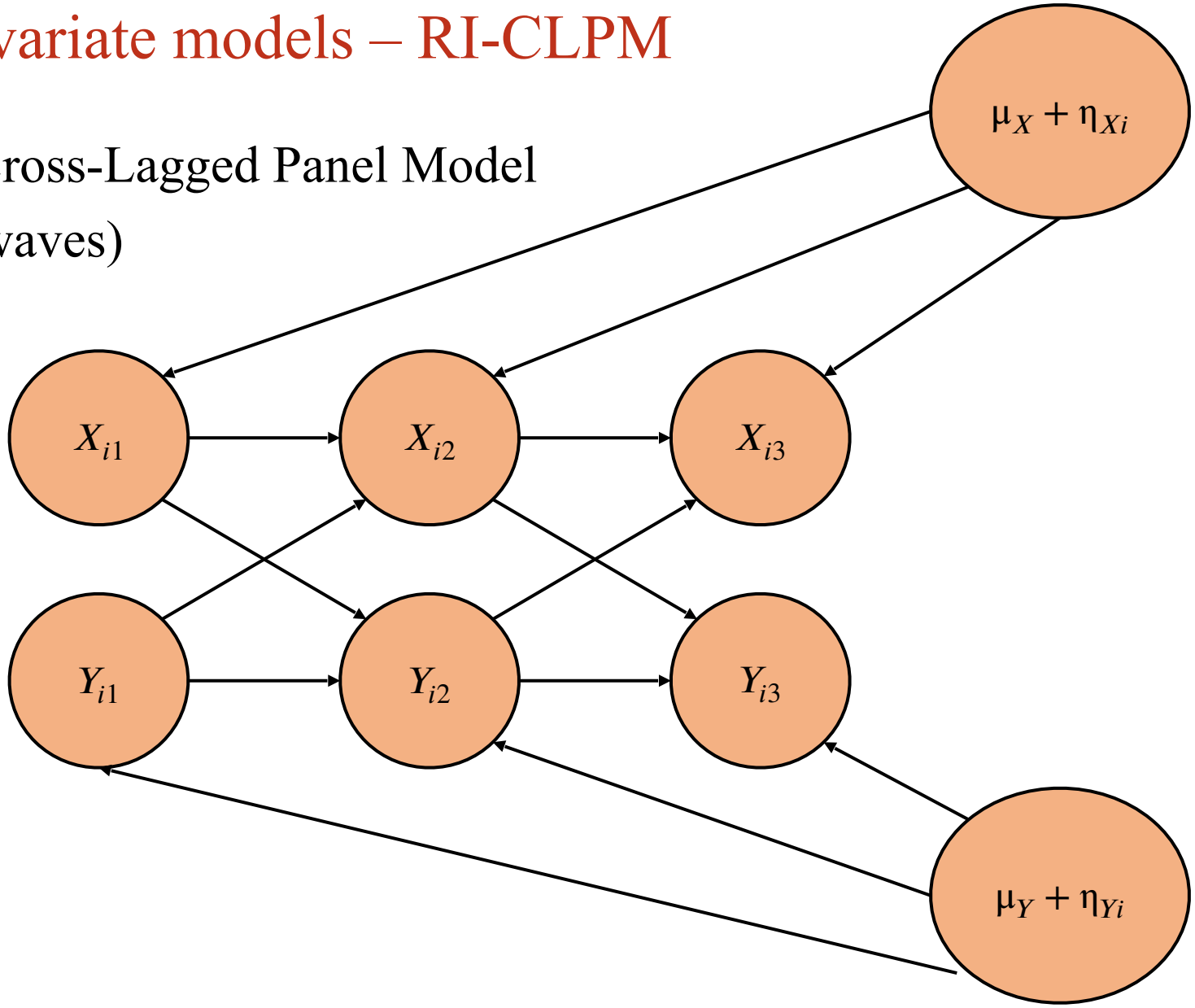
DYNASTI in bivariate models – RI-CLPM

Random Intercept Cross-Lagged Panel Model

Panel data (± 3-10 waves)

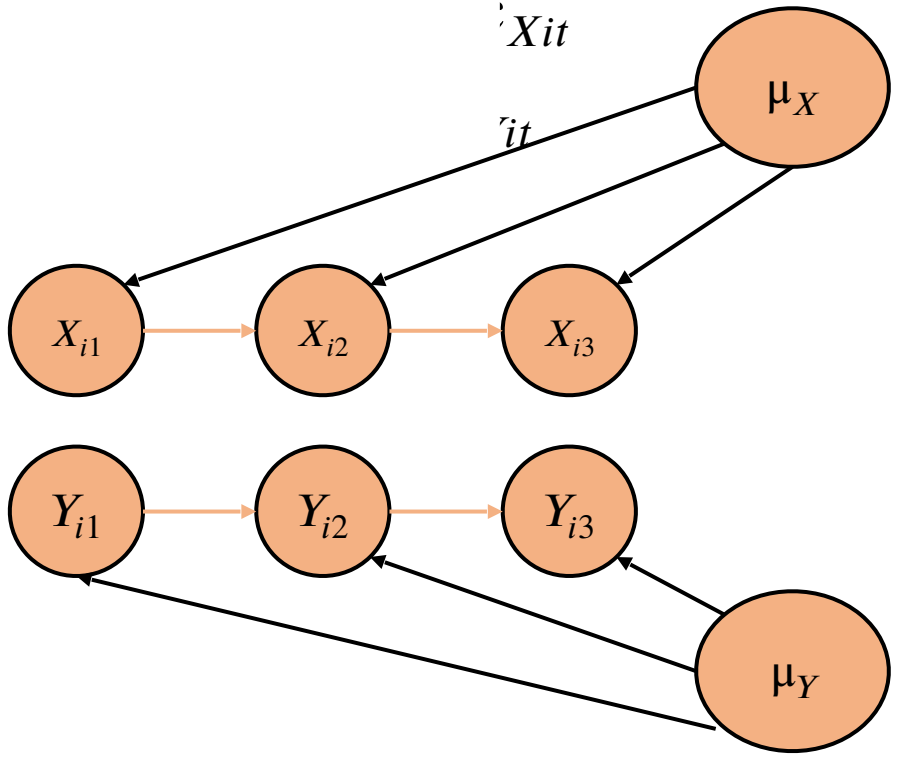


DYNASTI in bivariate models – RI-CLPM

Very similar to the DSEM, you explain the time series of X and Y with a mean (α) and inertia (φ). For subject *i* across trials *t* :

$$X_{it} = \alpha_X \quad + \varphi_{XX}\left(X_{i,t-1} - \alpha_X - \right. \quad + \quad \text{Xit}$$

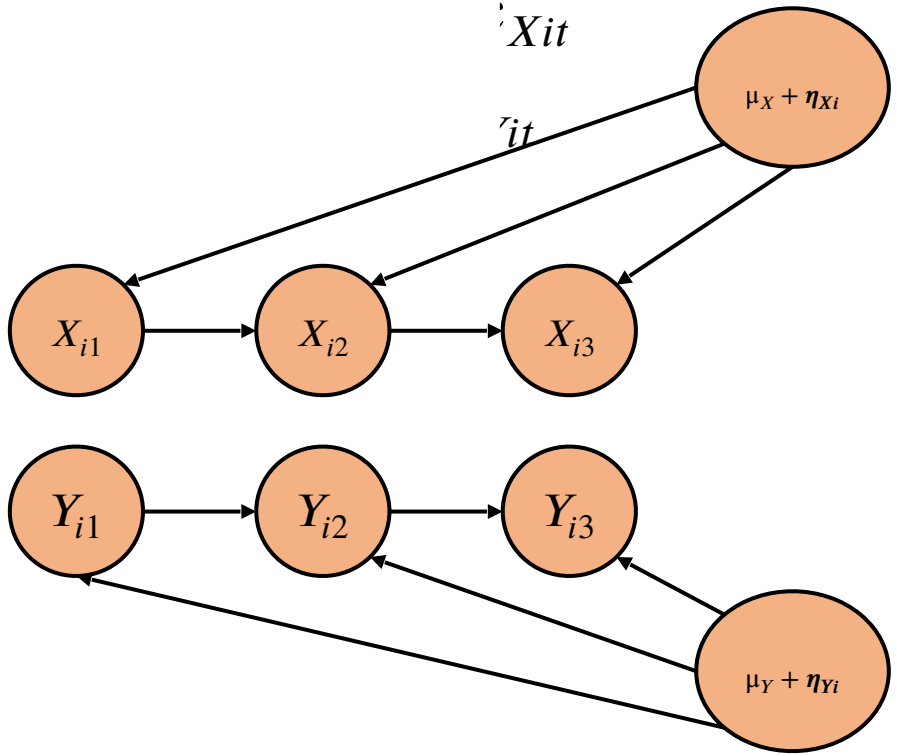
$$Y_{it} = \alpha_Y \cdot \quad + \varphi_{YY}\left(Y_{i,t-1} - \alpha_Y - \text{ιιYi} \right) + \quad \text{it}$$



DYNASTI in bivariate models – RI-CLPM

You allow individuals to have different means with η (the "random intercept")
For subject *i* across trials *t* :

$$X_{it} = \mu_X + \boldsymbol{\eta_{Xi}} + \varphi_{XX}\left(X_{i,t-1} - \mu_X - \boldsymbol{\eta_{Xi}}\right) +$$
$$Y_{it} = \mu_Y + \boldsymbol{\eta_{Yi}} + \varphi_{YY}\left(Y_{i,t-1} - \mu_Y - \boldsymbol{\eta_{Yi}}\right) +$$

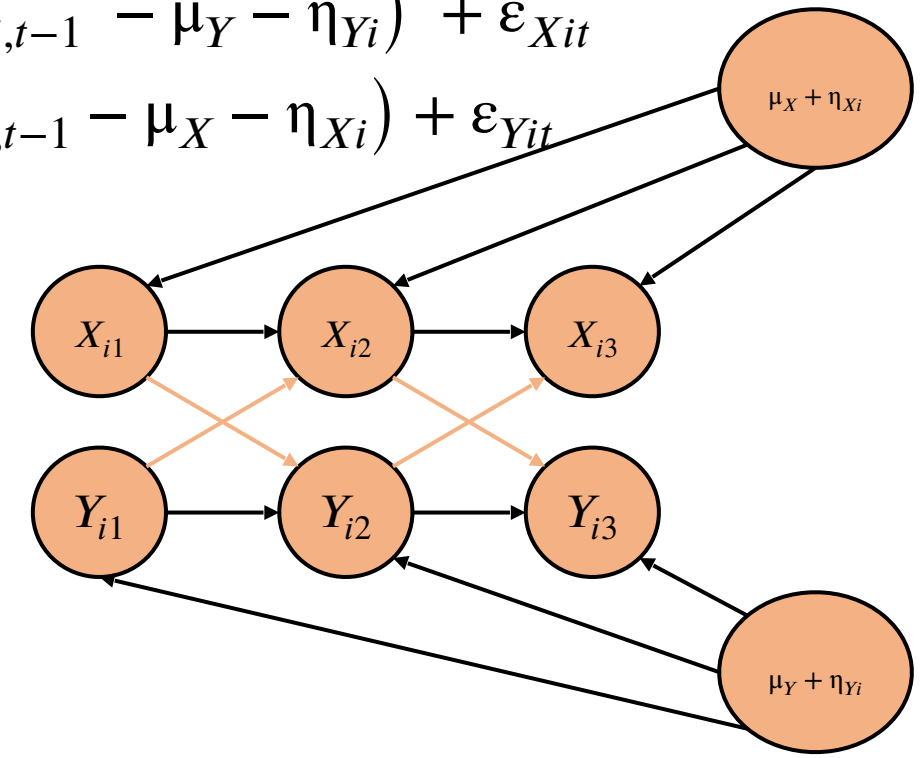


DYNASTI in bivariate models – RI-CLPM

And you add cross-lagged parameters (β), that is, effects from X on Y and the other way around. For subject *i* across trials *t* :

$$X_{it} = \mu_X + \eta_{Xi} + \varphi_{XX}\left(X_{i,t-1} - \mu_X - \eta_{Xi}\right) + \beta_{YX}\left(Y_{i,t-1} - \mu_Y - \eta_{Yi}\right) + \varepsilon_{Xit}$$

$$Y_{it} = \mu_Y + \eta_{Yi} + \varphi_{YY}\left(Y_{i,t-1} - \mu_Y - \eta_{Yi}\right) + \beta_{XY}\left(X_{i,t-1} - \mu_X - \eta_{Xi}\right) + \varepsilon_{Yit}$$



DYNASTI in bivariate models – RI-CLPM

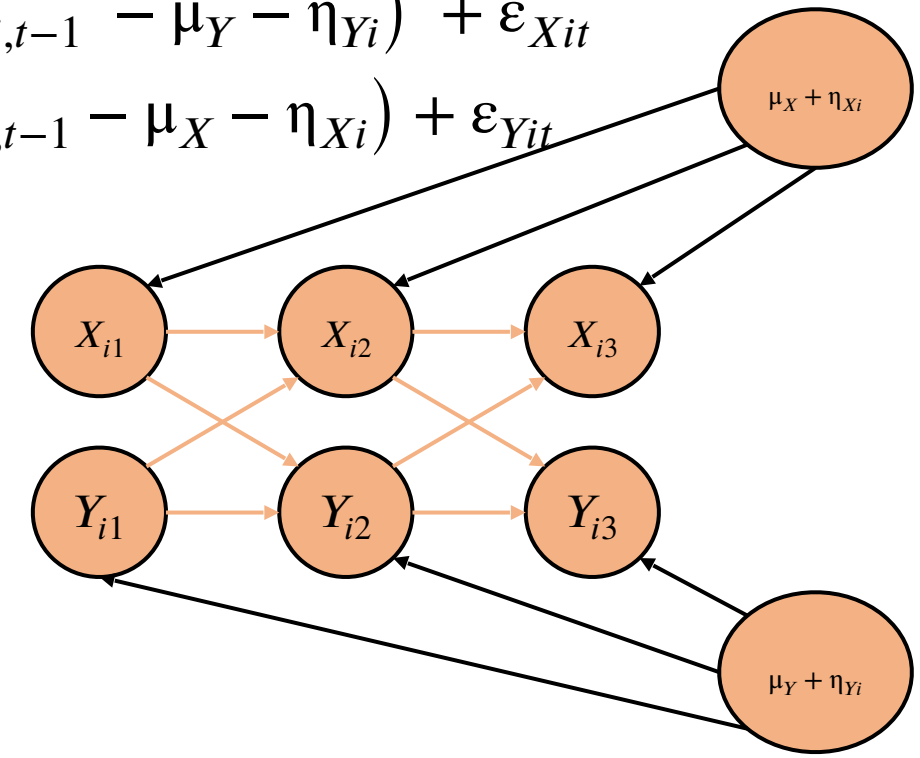
Both inertia and cross-lagged parameters can be allowed to differ for above- and below-mean values. For subject i across trials t :

$$X_{it} = \mu_X + \eta_{Xi} + \varphi_{XX}\left(X_{i,t-1} - \mu_X - \eta_{Xi}\right) + \beta_{YX}\left(Y_{i,t-1} - \mu_Y - \eta_{Yi}\right) + \varepsilon_{Xit}$$

$$Y_{it} = \mu_Y + \eta_{Yi} + \varphi_{YY}\left(Y_{i,t-1} - \mu_Y - \eta_{Yi}\right) + \beta_{XY}\left(X_{i,t-1} - \mu_X - \eta_{Xi}\right) + \varepsilon_{Yit}$$

$$\varphi_{XX} = \begin{cases} \varphi_{XX}^{\text{above}}, & X_{i,t-1} - \mu_X - \eta_{Xi} > 0 \\ \varphi_{XX}^{\text{below}}, & X_{i,t-1} - \mu_X - \eta_{Xi} \le 0 \end{cases}$$

$$\beta_{YX} = \begin{cases} \beta_{YX}^{\text{above}}, & Y_{i,t-1} - \mu_Y - \eta_{Yi} > 0 \\ \beta_{YX}^{\text{below}}, & Y_{i,t-1} - \mu_Y - \eta_{Yi} \le 0 \end{cases}$$



DYNASTI in bivariate models – Simulations