MAX PLANCK UCL CENTRE
for Computational Psychiatry and Ageing Research

Continuous Time Modeling:
On the role of time in the search for mechanisms of the human mind, brain, and behavior

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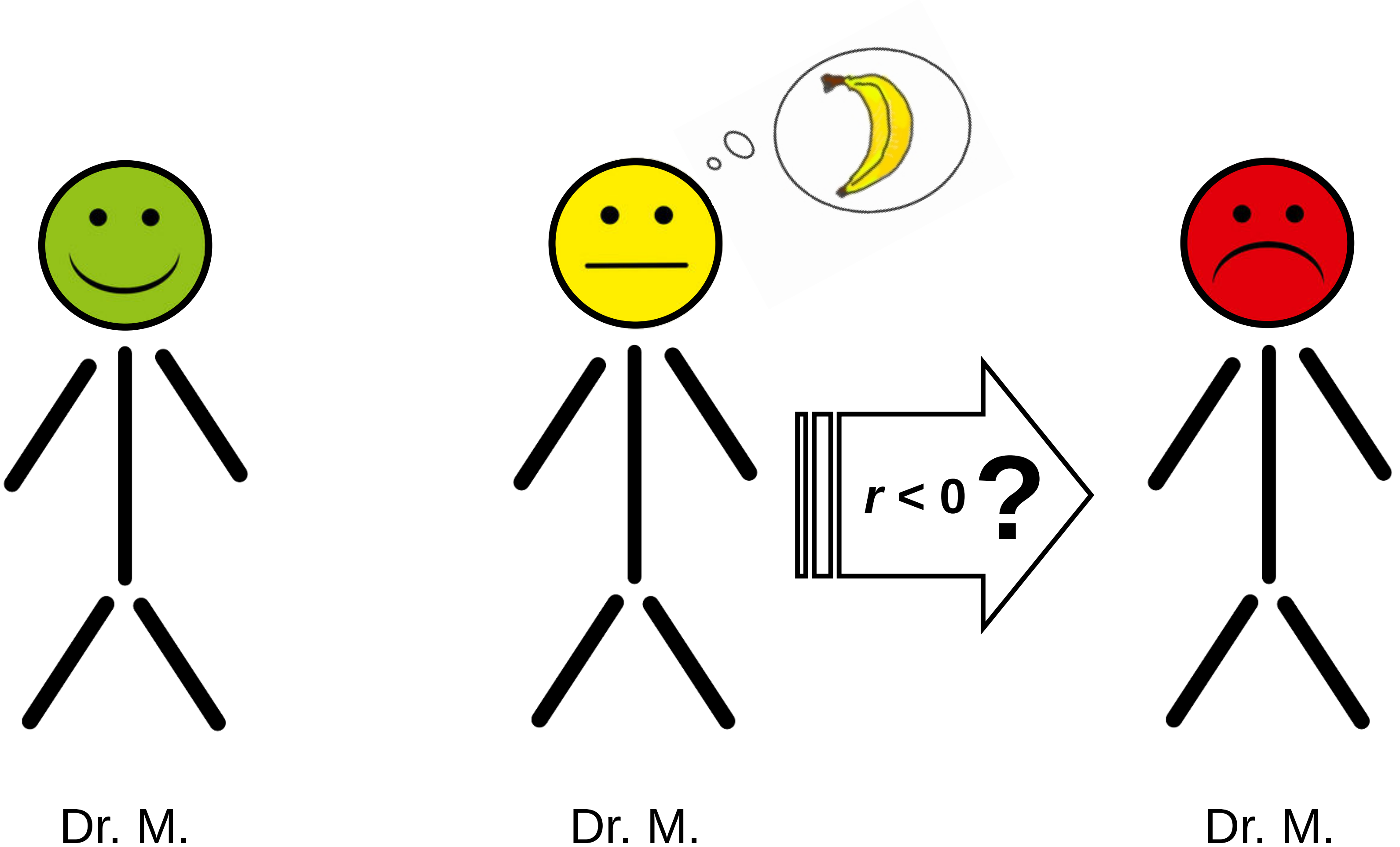
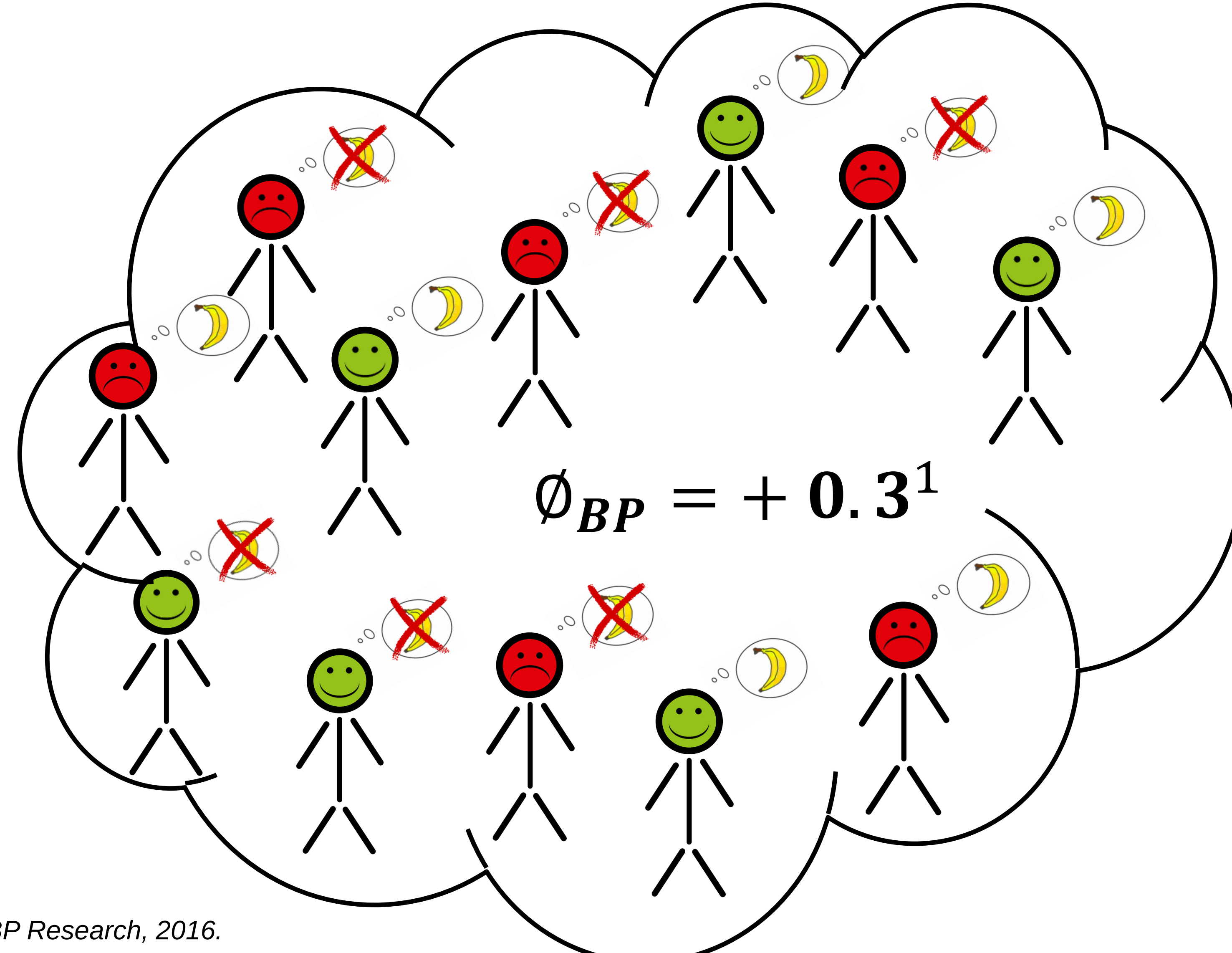
An Example: The Case of Dr. M.



The Case of Dr. M. Act 1: Consulting the Literature

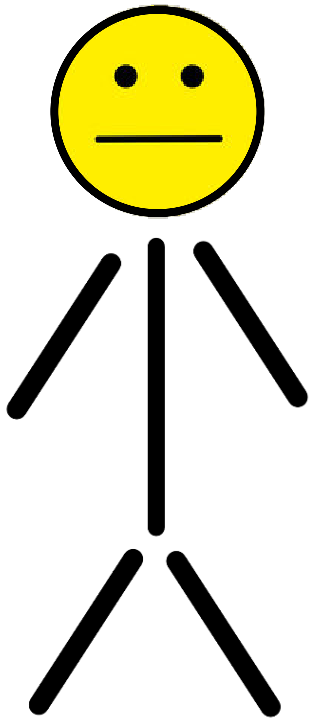
Between-Person (BP) correlation:



[1] *Journal for BP Research, 2016.*

The Case of Dr. M. Act 1: Consulting the Literature

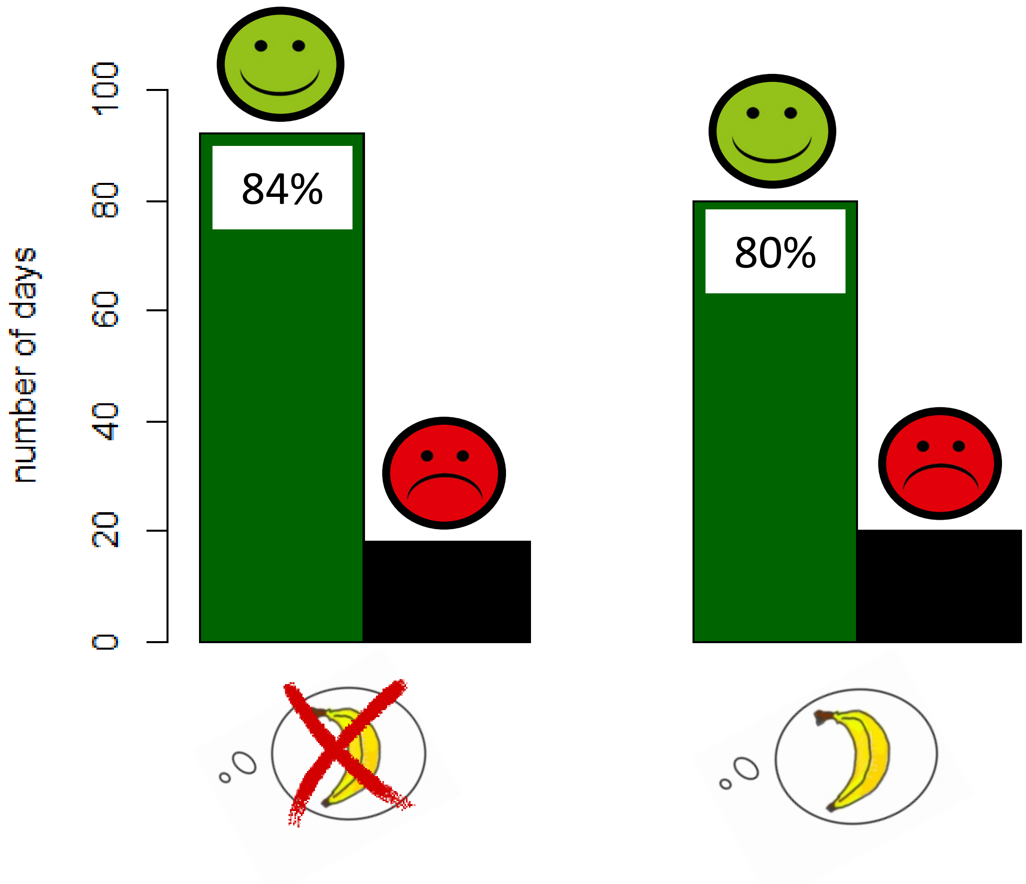
$$\emptyset_{WP} = \textbf{?}$$



Dr. M.

The Case of Dr. M. Act 2: Running a WP Study

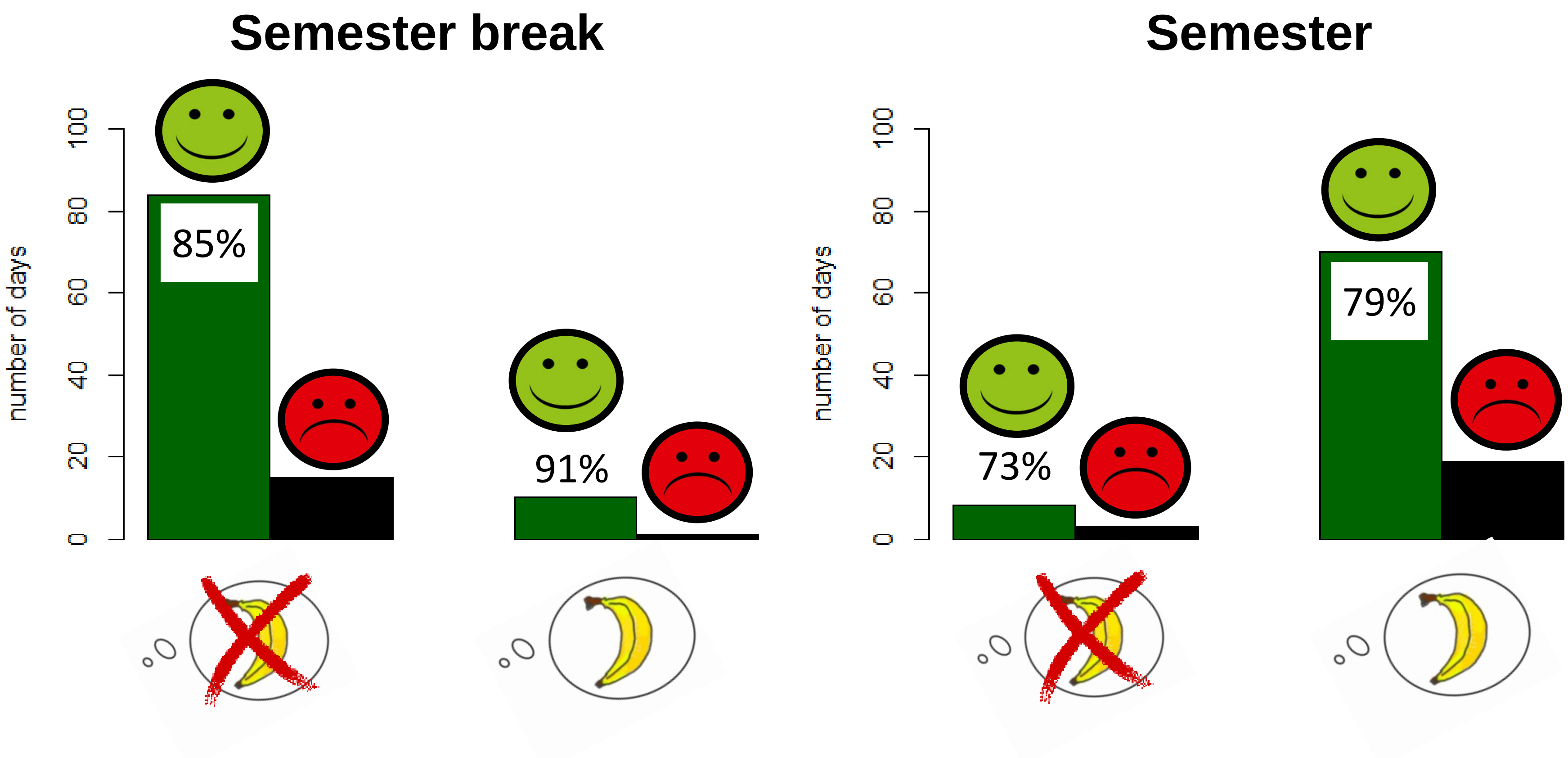
Within-Person (WP) correlation (T = 210 days):



$$\emptyset_{WP} = -.05$$

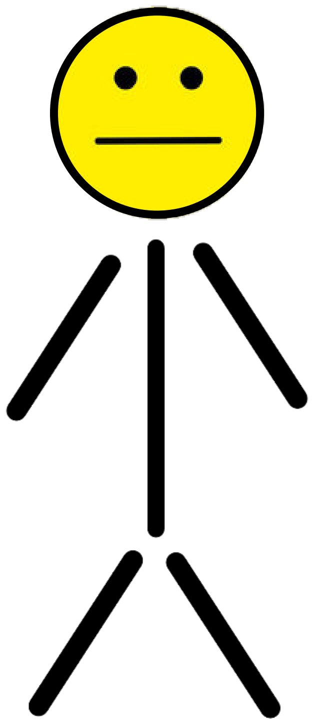
The Case of Dr. M. Act 2: Running a WP Study

Within-Person (WP) correlation (T = 210 days):



$$\phi_{WP} = +.05 \qquad \phi_{WP} = +.04$$

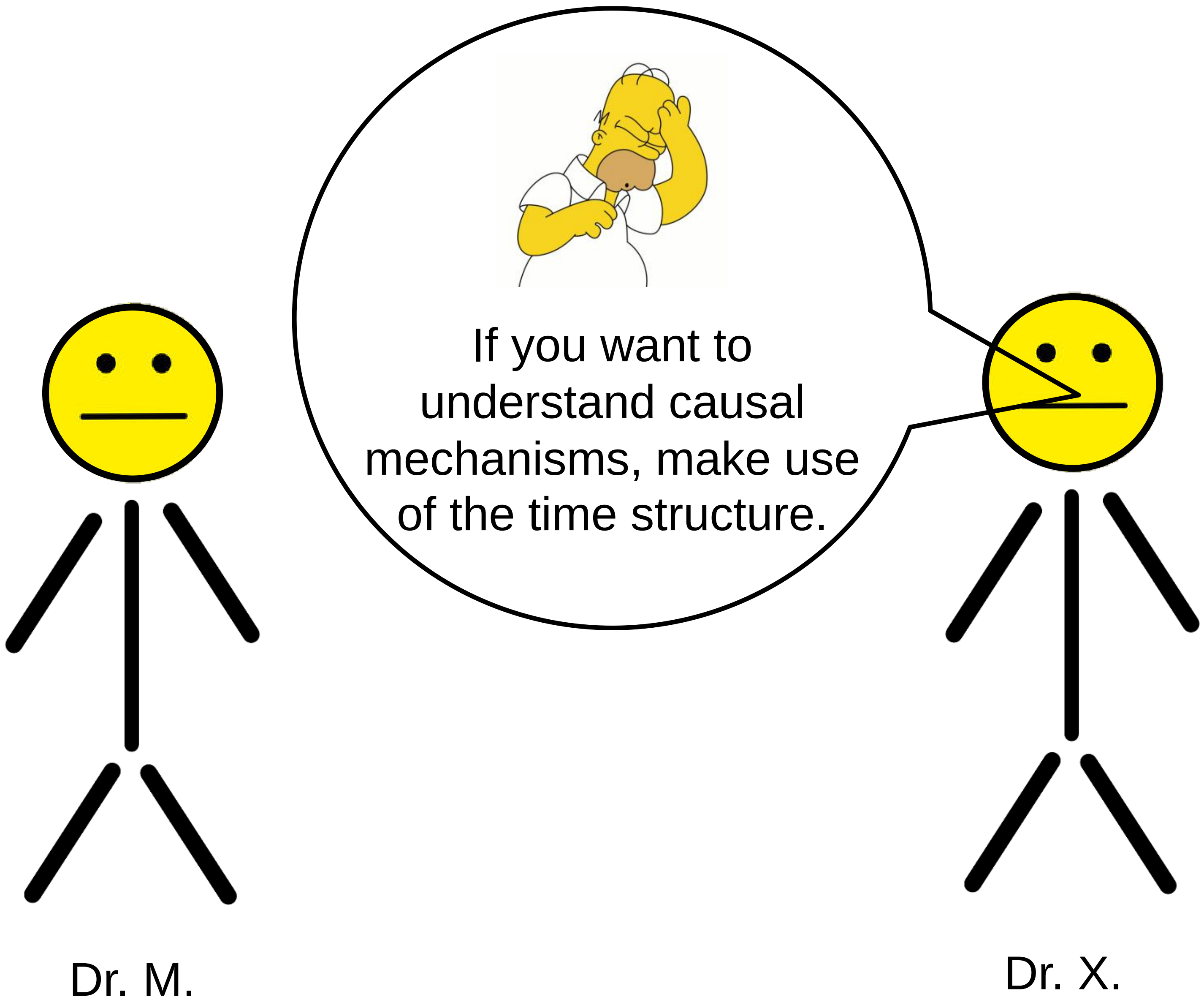
The Case of Dr. M. Act 2: Running a WP Study



Dr. M.

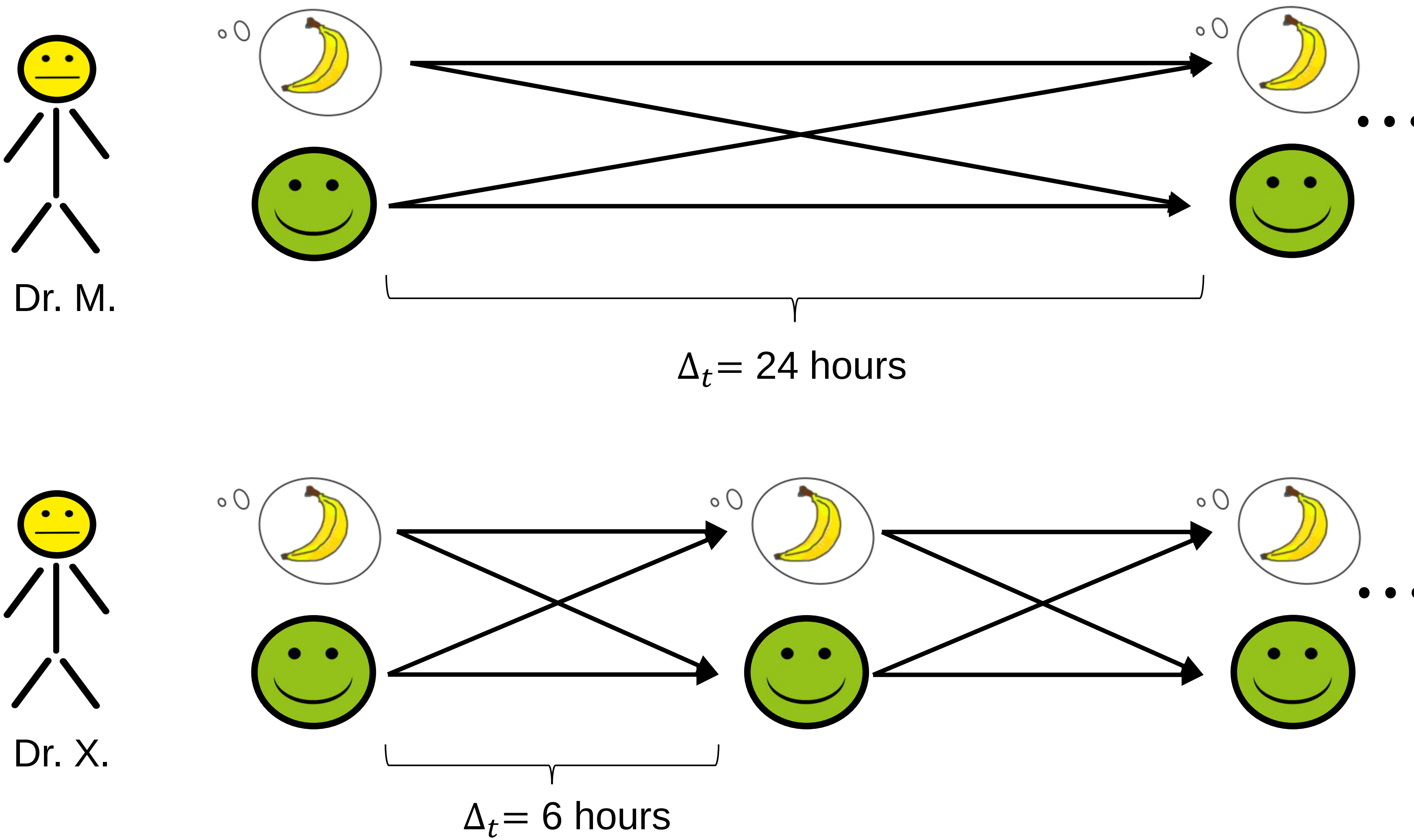
?

The Case of Dr. M. Act 3: Studying Lead-Lag Dynamics



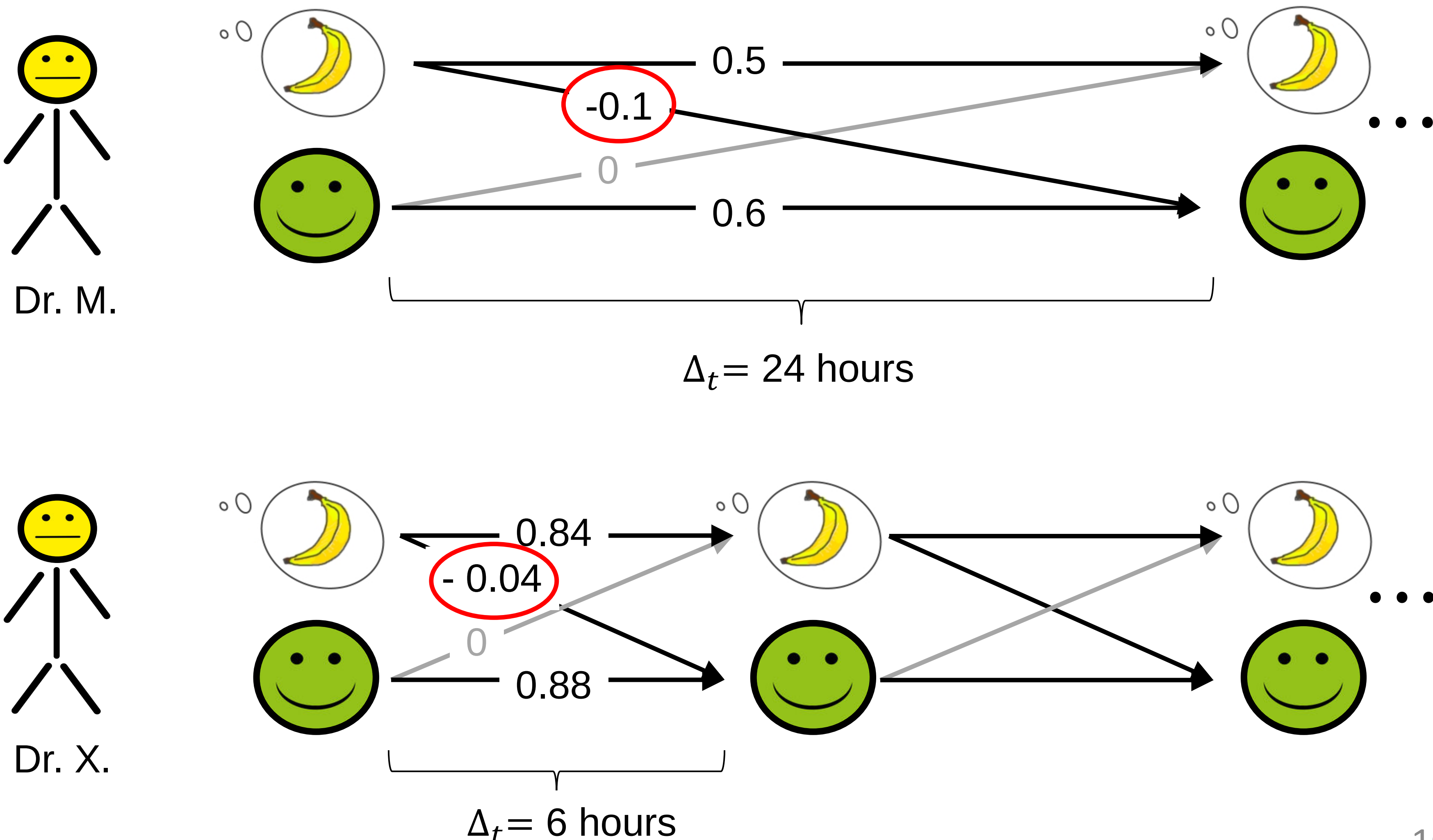
The Case of Dr. M. Act 3: Studying Lead-Lag Dynamics

Dynamic Within-Person (WP) Models:



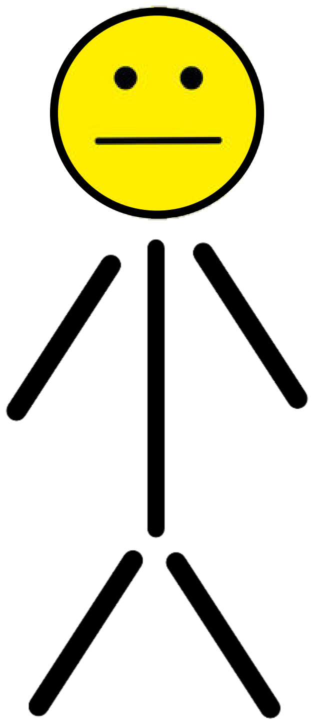
The Case of Dr. M. Act 3: Studying Lead-Lag Dynamics

Dynamic Within-Person (WP) Models:

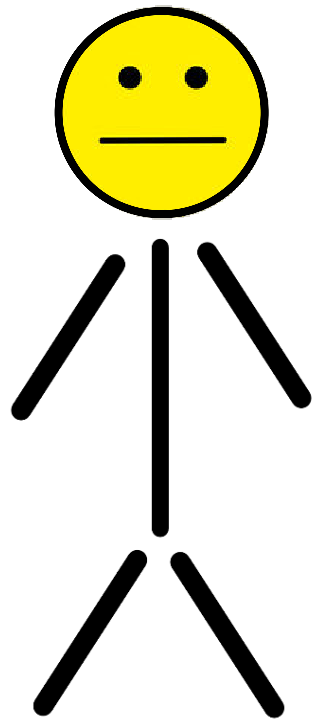


The Case of Dr. M. Act 3: Studying Lead-Lag Dynamics

-0.1 ($p < .01$) -0.04 ($p > .01$)



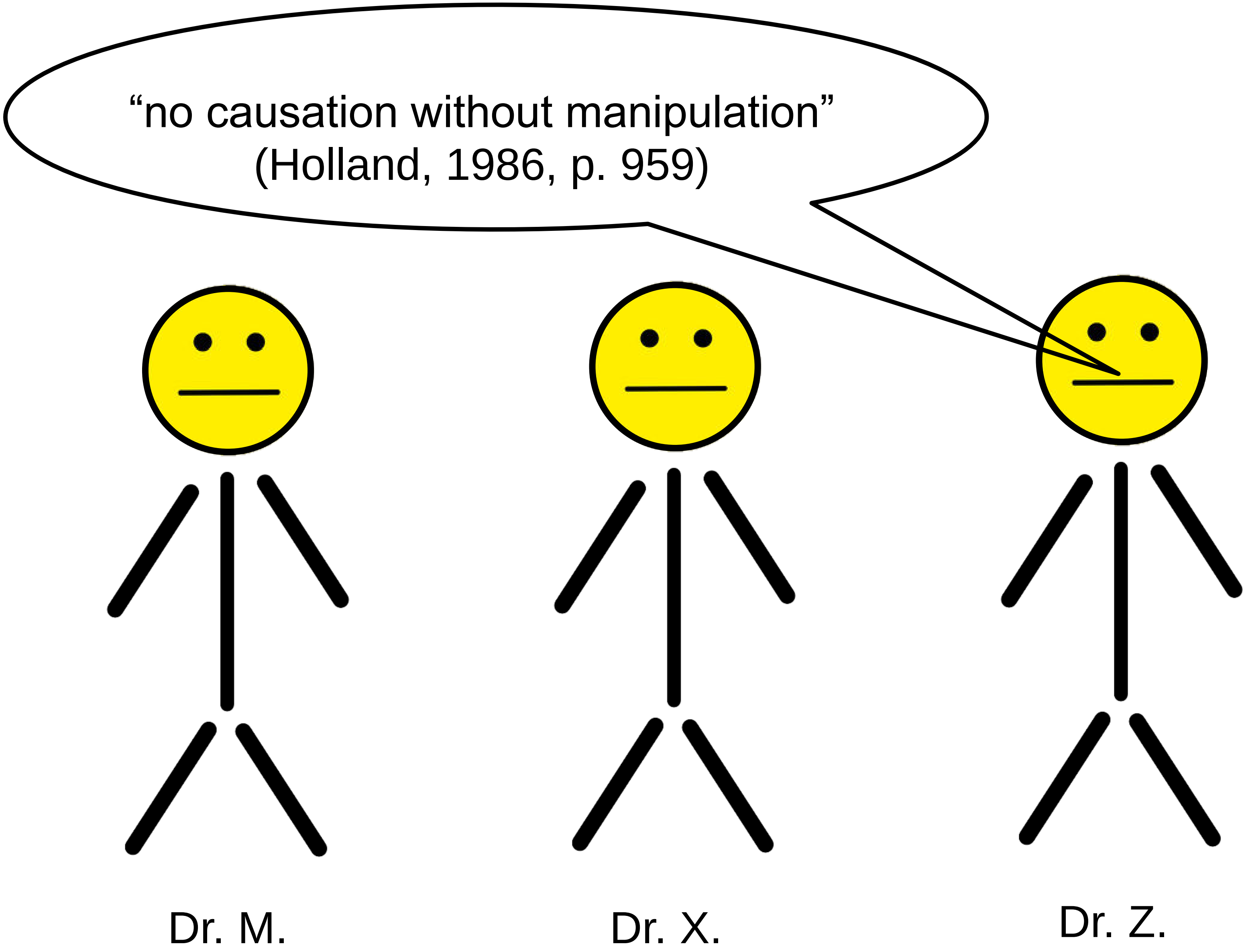
Dr. M.



Dr. X.

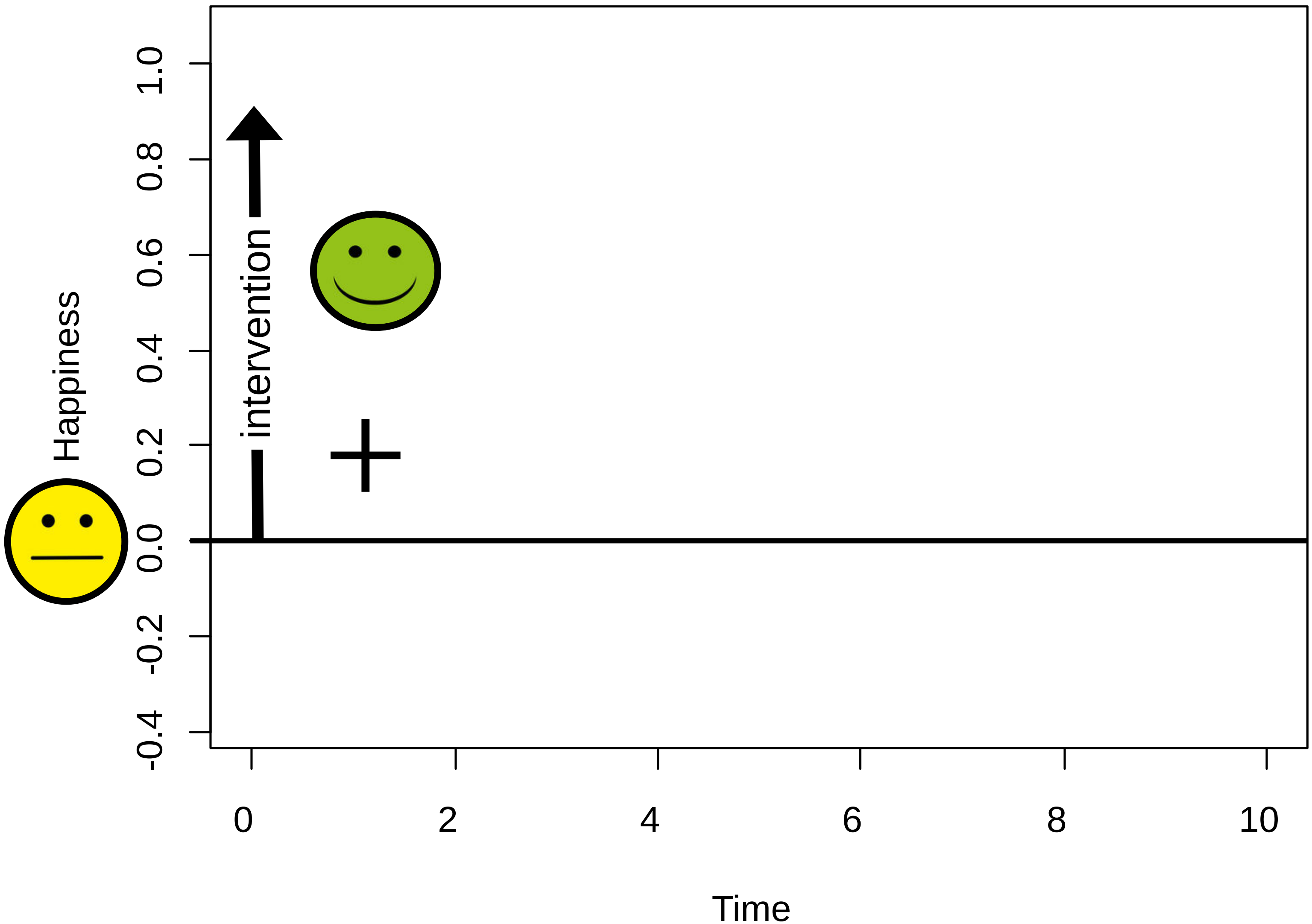
?

The Case of Dr. M. Act 4: Interventions



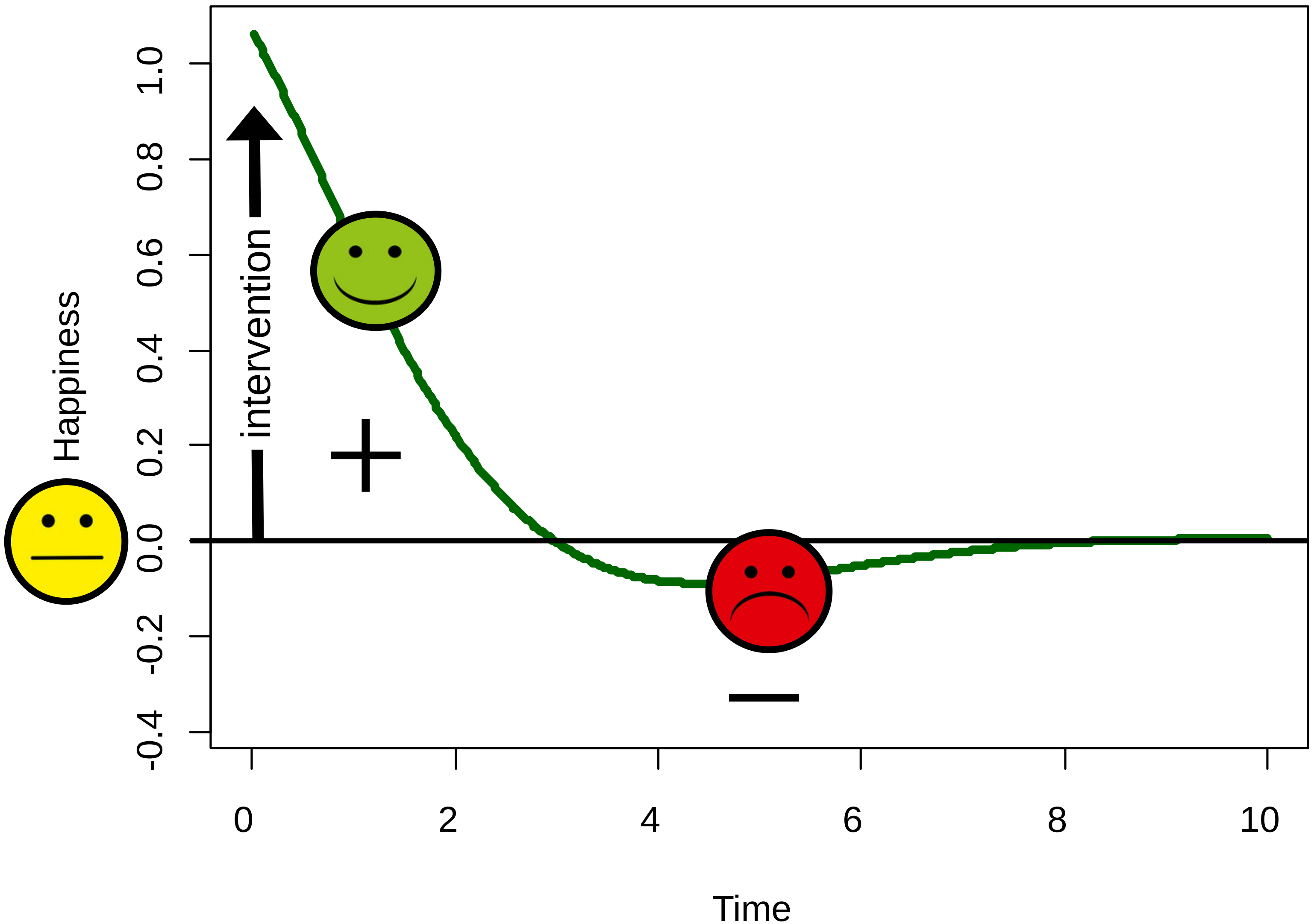
The Case of Dr. M. Act 4: Interventions

Interventions:

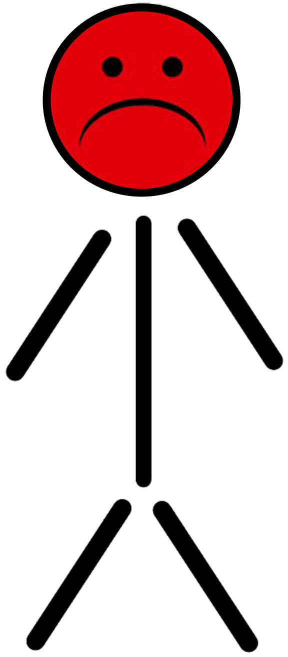


The Case of Dr. M. Act 4: Interventions

Interventions and Time:



The Case of Dr. M. Act 4: Interventions



The end

The Case of Dr. M.: A Summary

- BP and WP effects, obtained from repeatedly assessing the same individual over **time** need not be the same.

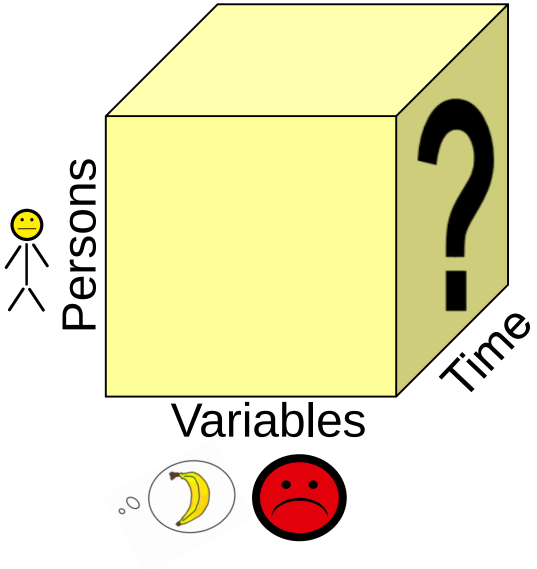
- While WP research eliminates the problem of heterogeneity across individuals, it introduces the problem of heterogeneity in **time**.

- While dynamic (lead-lag) models help in the identification of causal mechanisms, results are difficult to interpret and compare without explicit reference to **time**.

- (WP) effects due to interventions are difficult to interpret and compare without considering the **time** course.

Time: The Unknown Third Dimension?

Part I. Another dimension, another scientific paradigm?

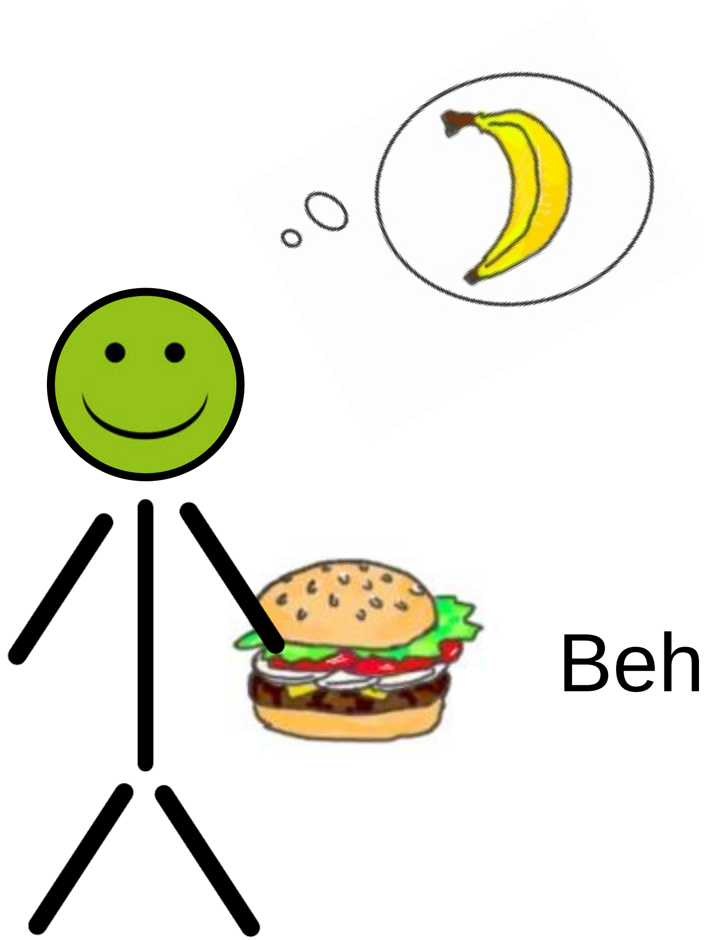


Part II. Another dimension or another variable?

Part III. Another dimension, many complexities?

The Goal

…is to understand the mechanisms of the human mind, brain, and behavior.



A Quick Note on Causality

- Following Pearl (2009), I will define a causal effect as:

$$P(Y = y|do(x))$$

- Via

$$E(Y|do(x')) - E(Y|do(x''))$$

this may be linked to Rubin's model for causal inference.

- While the link to inference is obvious, note the difference in in the definition

$$Y_{i|d=1} - Y_{i|d=0}$$

- However, in this presentation a pragmatic approach to causality is taken, with potential differences between theoretical approaches being irrelevant to all main arguments.

(Pearl, 2009; Holland, 1986, Halaby, 2004)

Another dimension, another scientific paradigm?

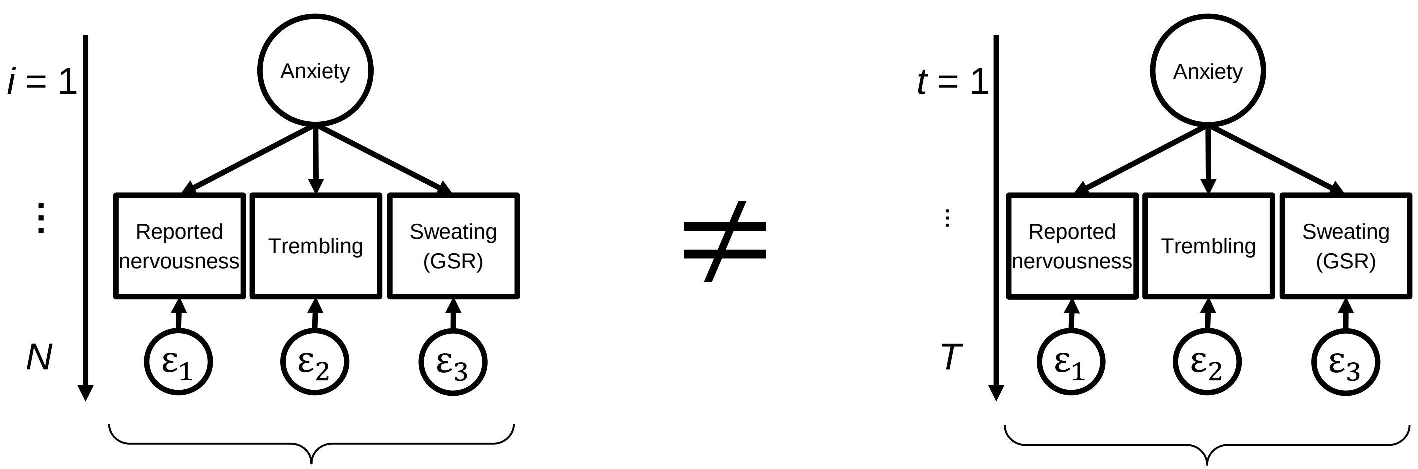
Another dimension, another scientific paradigm?

1. The statistical perspective:

- Usually $\emptyset_{BP} \neq \emptyset_{WP}$

$$\emptyset_{BP} = +0.3 \text{ vs. } \emptyset_{WP} = -0.05$$

- Usually BP models will differ from WP models:



1. Another dimension, another scientific paradigm?

1. The statistical perspective:

- In case of a saturated model, unconditional structural equivalence ("ergodicity") is given if

$$\boldsymbol{\theta}_i = \boldsymbol{\theta}_t$$

for all possible combinations of *t* and *i* (e.g., with $\boldsymbol{\theta}_i = \{\boldsymbol{\mu}_i, \boldsymbol{\Sigma}_i\}$ and $\boldsymbol{\theta}_t = \{\boldsymbol{\mu}_t, \boldsymbol{\Sigma}_t\}$)

Homogeneity

Stationarity

Molenaar (2004). *Measurement.*

Another dimension, another scientific paradigm?

1. The statistical perspective:

„only under very strict conditions—which are hardly obtained in real psychological processes—can a generalization be made from a structure of interindividual variation to the analogous structure of intraindividual variation”. (Molenaar, 2004, p. 201)

The New Person-Specific Paradigm in Psychology

Peter C.M. Molenaar and Cynthia G. Campbell

Current Directions in Psychological Research (2009)

1. Another dimension, another scientific paradigm?

2. The causal perspective:

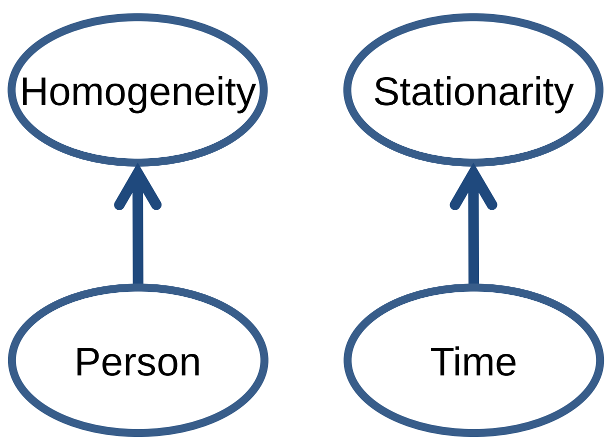
- What *caused* the data?

- Common causes (what leads to “ergodicity”)?

$$P_{\theta_i}(Y = y|do(x)) = P_{\theta_t}(Y = y|do(x))$$

$$\boldsymbol{\theta}_i = \boldsymbol{\theta}_t$$

- Unique causes (what destroys “ergodicity”)?



1. Another dimension, another scientific paradigm?

3. The concept of conditional (BP/WP) equivalence:

Unique

$$(\boldsymbol{\theta}_{ic} | \boldsymbol{\theta}_{iu}) = (\boldsymbol{\theta}_{tc} | \boldsymbol{\theta}_{tu})$$

Common

Voelkle, Brose, Schmiedek, & Lindenberger (2014). *Multivariate Behavioral Research.*

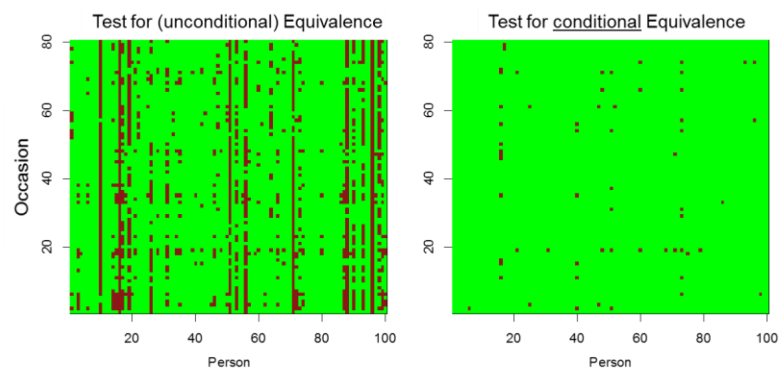
Another dimension, another scientific paradigm?

3. The concept of conditional (BP/WP) equivalence:

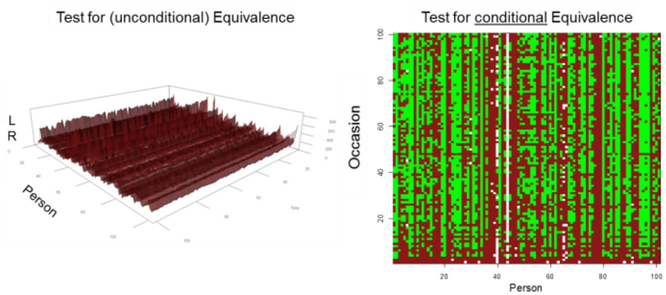
$$H_0: \quad (\boldsymbol{\theta}_{ic}|\boldsymbol{\theta}_{iu}) = (\boldsymbol{\theta}_{tc}|\boldsymbol{\theta}_{tu})$$

$$H_1: \quad (\boldsymbol{\theta}_{ic}|\boldsymbol{\theta}_{iu}) \neq (\boldsymbol{\theta}_{tc}|\boldsymbol{\theta}_{tu})$$

Statistical basis: Conditional equivalence comparisons by means of likelihood ratio tests



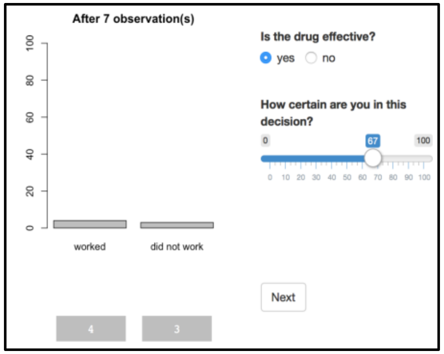
Proof of concept using simulated data

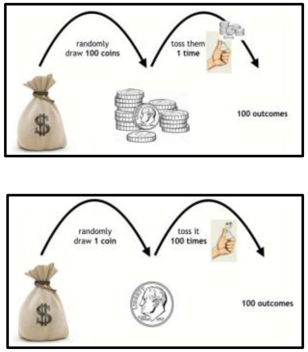


0.02 Percent n.s.
(2 out of 10,100)

42.24 Percent n.s.

Empirical application using data from the COGITO study



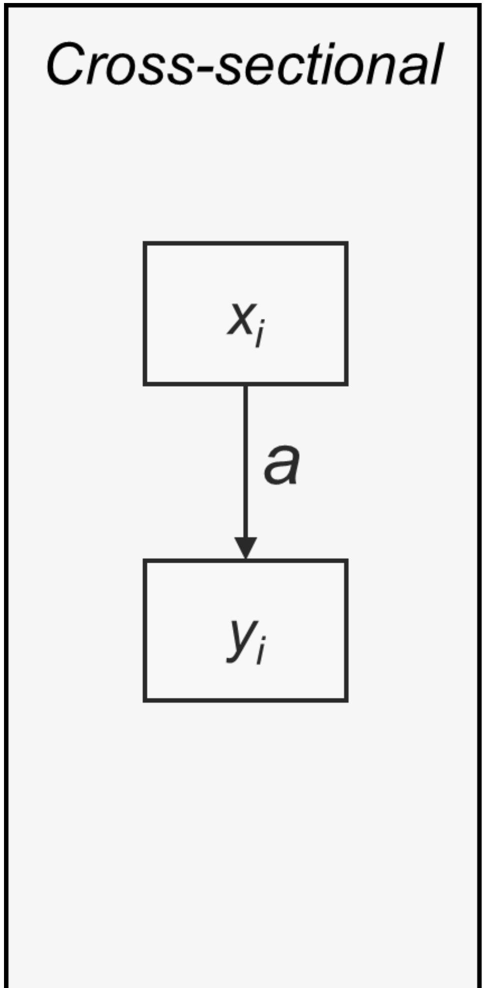


Perceived ergodicity and decision making

Voelkle, Brose, Schmiedek, & Lindenberger (2014). *Multivariate Behavioral Research.*
Voelkle, Oud, von Oertzen, & Lindenberger (2012). *Structural Equation Modeling.*

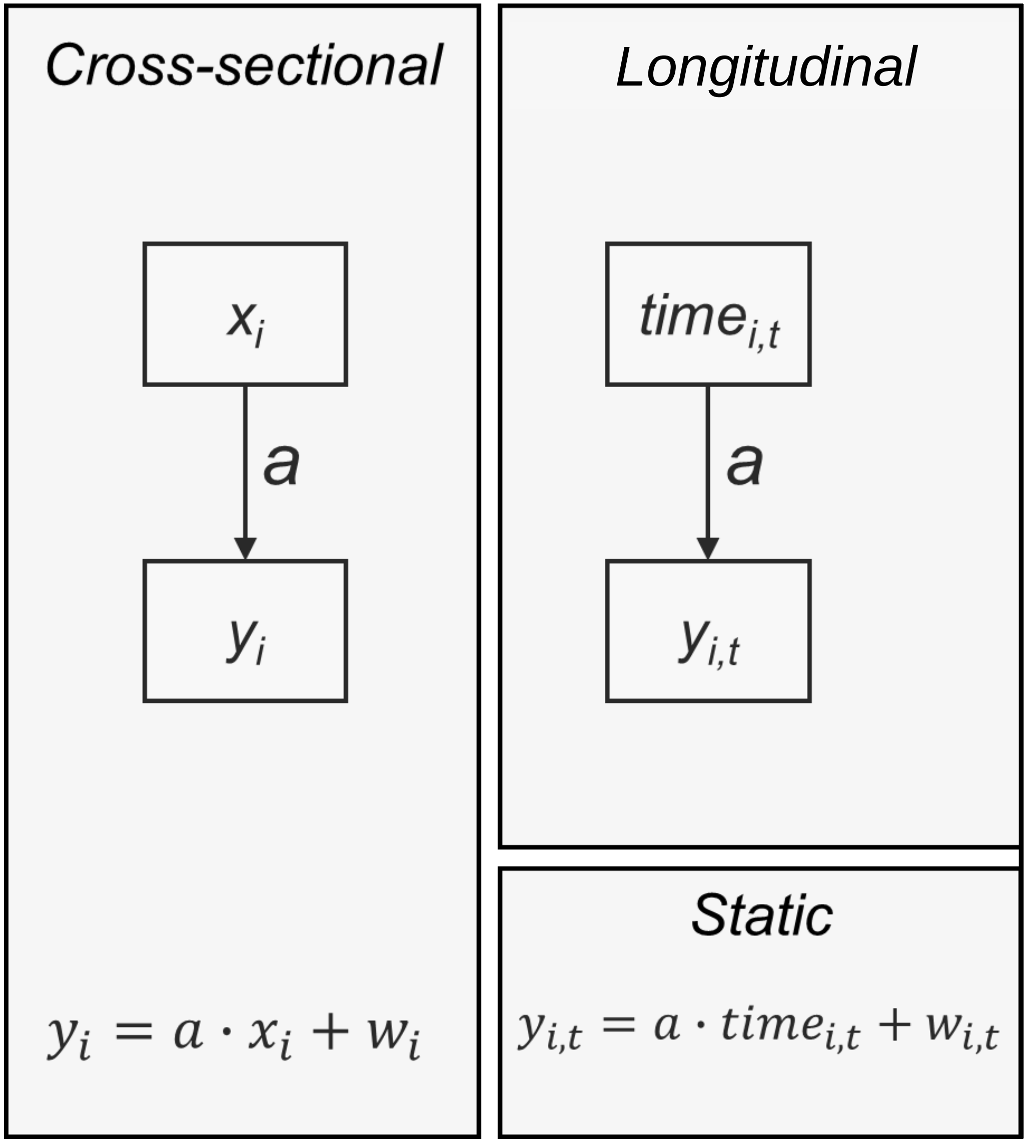
Another Dimension or Another Variable?

2. Another Dimension or Another Variable?



$$y_i = a \cdot x_i + w_i$$

Another Dimension or Another Variable?



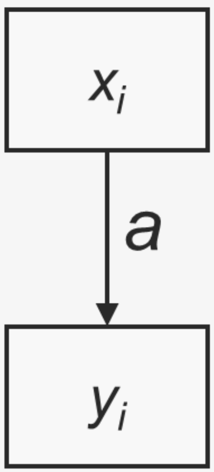
"…although time is inextricably linked to the concept of development, in itself it cannot explain any aspect of developmental change….

Time, rather like the theatrical stage upon which the processes of development are played out, provides a necessary base upon which the description, explanation, and modification of development proceed."

(Baltes et al. 1988, p. 108)

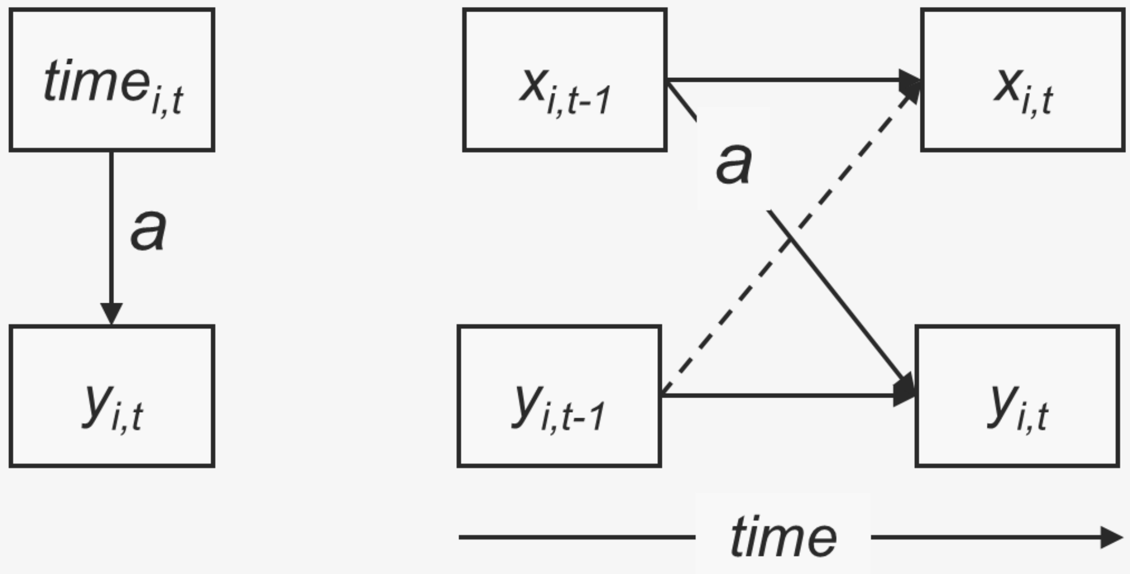
2. Another Dimension or Another Variable?

Cross-sectional



$$y_i = a \cdot x_i + w_i$$

Longitudinal



Static

$$y_{i,t} = a \cdot time_{i,t} + w_{i,t}$$

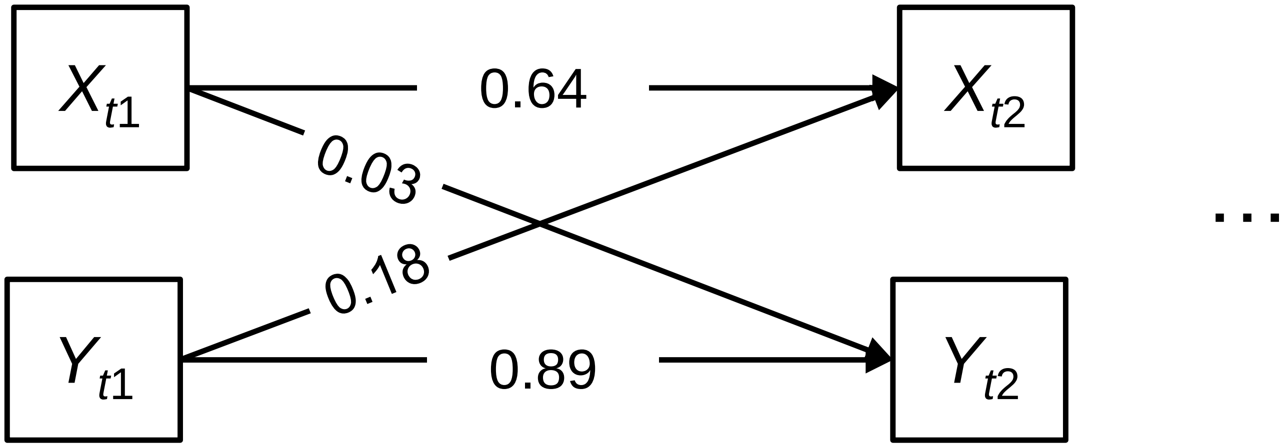
Dynamic

$$\mathbf{x}_{i,t} = \mathbf{A}\mathbf{x}_{i,t-1} + \mathbf{w}_{i,t}$$

2. Another Dimension or Another Variable?

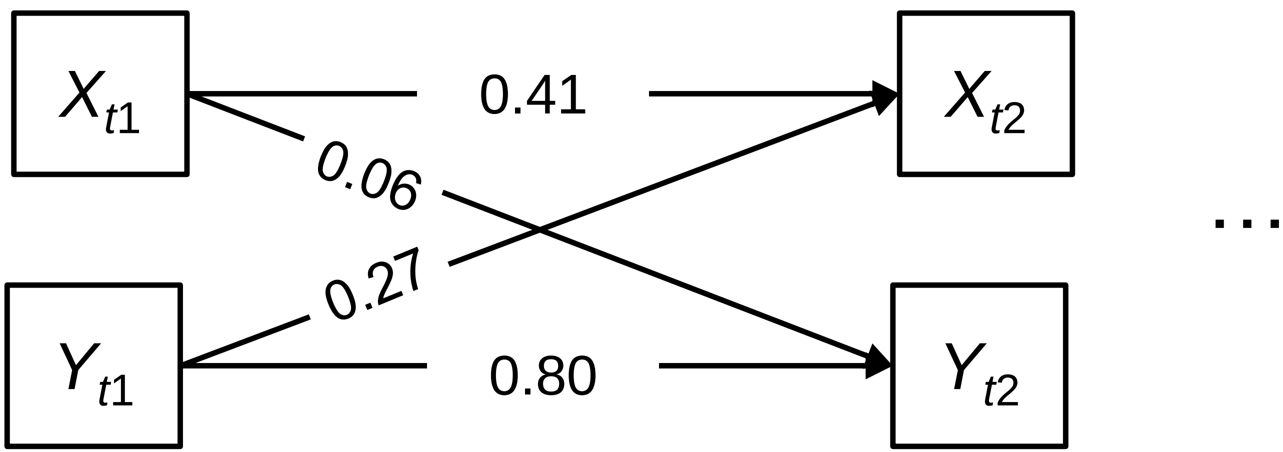
Researcher 1:

$\Delta t = 1$



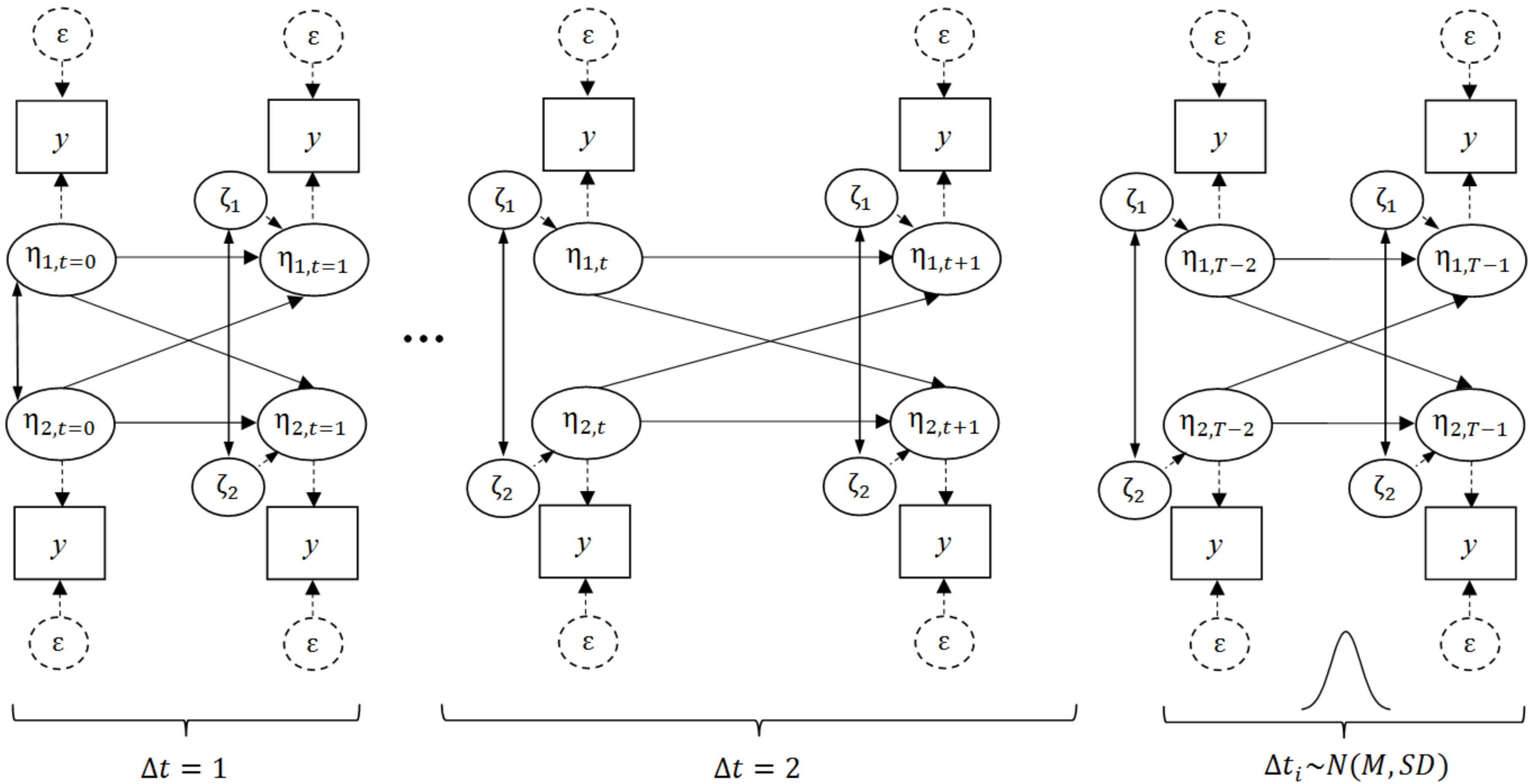
Researcher 2:

$\Delta t = 2$



2. Another Dimension or Another Variable?

- (Latent) Cross-Lagged Panel Designs With Different Intervals:



2. Another Dimension or Another Variable?

- The Problem:

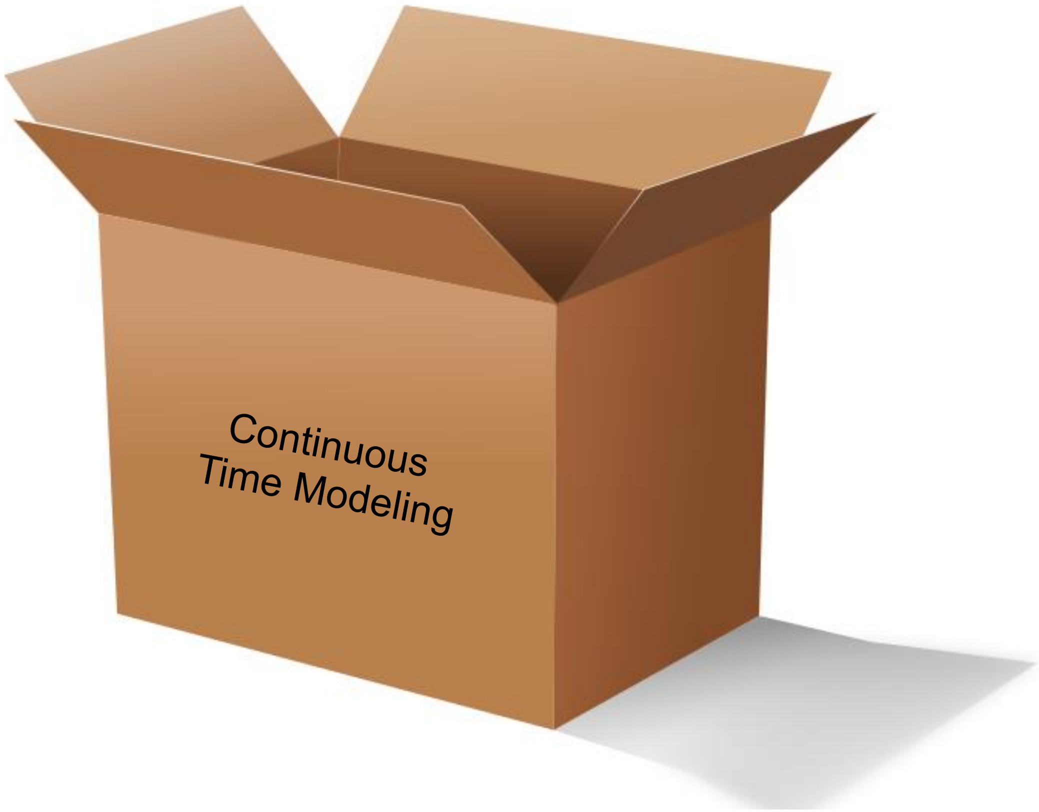
$$\boldsymbol{\eta}_u = \mathbf{A}\boldsymbol{\eta}_{u-1} + \mathbf{b}_u + \mathbf{M}\mathbf{x}_u + \boldsymbol{\zeta}_u$$

- The Solution:

$$\mathrm{d}\boldsymbol{\eta}(t) = (\mathbf{A}\boldsymbol{\eta}(t) + \mathbf{b} + \mathbf{M}\mathbf{x}(t))\mathrm{d}t + \mathbf{G}\mathrm{d}\mathbf{W}(t)$$

Continuous Time Models

2. A Super-Quick Introduction to CT Models



Voelkle, Oud, Davidov, & Schmidt (2012). *Psychological Methods.*

2. A Super-Quick Introduction to CT Models

1. The complete discrete time model:

$$\mathbf{x}(t_i) = \mathbf{A}(\Delta t_i)\mathbf{x}(t_i - \Delta t_i) + \mathbf{b}(\Delta t_i) + \mathbf{w}(\Delta t_i)$$

2. Take the derivative with respect to time:

$$\frac{\mathrm{d}\mathbf{x}(t)}{\mathrm{d}t} = \mathbf{A}\,\mathbf{x}(t) + \mathbf{b} + \mathbf{G}\frac{\mathrm{d}\mathbf{W}(t)}{\mathrm{d}t}$$

3. Solve (2) for initial time point and given time interval:

$$\mathbf{x}(t) = \mathrm{e}^{\mathbf{A}\cdot(t-t_0)}\mathbf{x}(t_0) + \mathbf{A}^{-1}\left[\mathrm{e}^{\mathbf{A}\cdot(t-t_0)} - \mathbf{I}\right]\mathbf{b} + \int_{t_0}^{t} \mathrm{e}^{\mathbf{A}\cdot(t-s)}\mathbf{G}\mathrm{d}\mathbf{W}(s)$$

$$\text{with } cov\left[\int_{t_0}^{t} \mathrm{e}^{\mathbf{A}\cdot(t-s)}\mathbf{G}\mathrm{d}\mathbf{W}(s)\right] = \int_{t_0}^{t} \mathrm{e}^{\mathbf{A}\cdot(t-s)}\mathbf{Q}\mathrm{e}^{\mathbf{A}'\cdot(t-s)}\mathrm{d}s = irow\left\{\mathbf{A}_{\#}^{-1}\left[\mathrm{e}^{\mathbf{A}_{\#}\cdot(t-t_0)} - \mathbf{I}\right]row\mathbf{Q}\right\}$$

$$\text{for } \mathbf{Q} = \mathbf{G}\mathbf{G}' \text{ and } \mathbf{A}_{\#} = \mathbf{A}\otimes\mathbf{I} + \mathbf{I}\otimes\mathbf{A}$$

4. Impose constraints between discrete and continuous time parameters

$$\mathbf{x}(t_i) = \mathbf{e}^{\mathbf{A}\cdot\Delta t_i}\mathbf{x}(t_i - \Delta t_i) + \mathbf{A}^{-1}[\mathbf{e}^{\mathbf{A}\cdot\Delta t_i} - \mathbf{I}]\mathbf{b} + \mathbf{w}(\Delta t_i)$$

2. A Super-Quick Introduction to CT Models

5. Put (e.g.) into SEM format with:

$\mathbf{y} = \mathbf{\Lambda\eta} + \boldsymbol{\varepsilon}$ with $cov(\boldsymbol{\varepsilon}) = \mathbf{\Theta}$ representing the usual measurement equation, and

$\boldsymbol{\eta} = \mathbf{B}\boldsymbol{\eta} + \boldsymbol{\zeta}$ with $cov(\boldsymbol{\zeta}) = \Psi.$ with

$$\boldsymbol{\eta}' = (\mathbf{x}(t_0)' \quad \mathbf{x}(t_1)' \quad \mathbf{x}(t_i)' \quad \cdots \quad \mathbf{x}(t_{i=T})' \quad 1)'$$

$$\boldsymbol{\zeta}' = ([\boldsymbol{x}(t_0) - \boldsymbol{\mu}_{\boldsymbol{x}(t_0)}]' \quad [\boldsymbol{w}(t_1 - \Delta t_1)]' \quad [\boldsymbol{w}(t_i - \Delta t_i)]' \quad \cdots \quad [\boldsymbol{w}(t_{i=T} - \Delta t_{i=T})]' \quad 1)'$$

$$\mathbf{B} = \begin{pmatrix} \mathbf{0} & \mathbf{0} & \cdots & \mathbf{0} & \mathbf{0} & \boldsymbol{\mu}_{\mathbf{x}(t_0)} \\ e^{\mathbf{A}\cdot\Delta t_1} & \mathbf{0} & & \mathbf{0} & \mathbf{0} & \mathbf{A}^{-1}[e^{\mathbf{A}\cdot\Delta t_1} - \mathbf{I}]\mathbf{b} \\ \mathbf{0} & e^{\mathbf{A}\cdot\Delta t_i} & & \mathbf{0} & \mathbf{0} & \mathbf{A}^{-1}[e^{\mathbf{A}\cdot\Delta t_i} - \mathbf{I}]\mathbf{b} \\ \vdots & & \ddots & & & \\ \mathbf{0} & \mathbf{0} & & e^{\mathbf{A}\cdot\Delta t_{i=T}} & \mathbf{0} & \mathbf{A}^{-1}[e^{\mathbf{A}\cdot\Delta t_{i=T}} - \mathbf{I}]\mathbf{b} \\ \mathbf{0} & \mathbf{0} & \cdots & \mathbf{0} & \mathbf{0} & 0 \end{pmatrix} \quad \boldsymbol{\Psi} = \begin{pmatrix} \boldsymbol{\Phi}_{\mathbf{x}(t_0)} & & & & & \\ \mathbf{0} & \mathbf{Q}_{\Delta t_1} & & & & \\ \mathbf{0} & \mathbf{0} & \mathbf{Q}_{\Delta t_i} & & & \\ \vdots & & & \ddots & & \\ \mathbf{0} & \mathbf{0} & \mathbf{0} & & \mathbf{Q}_{\Delta t_{i=T}} & \\ \mathbf{0} & \mathbf{0} & \mathbf{0} & & \mathbf{0} & 1 \end{pmatrix}$$

6. Estimate parameters (e.g. via ML):

$$LL = \frac{-Nm}{2}\log(2\pi) - \frac{N}{2}\log|\boldsymbol{\Sigma}| - \frac{1}{2}\sum_{i=1}^{N}(\boldsymbol{y}_i - \boldsymbol{\mu})'\,\boldsymbol{\Sigma}^{-1}(\boldsymbol{y}_i - \boldsymbol{\mu})$$

2. A Super-Quick Introduction to CT Models

Voelkle, Oud, Davidov, & Schmidt (2012). *Psychological Methods.*

A Super-Quick Introduction to CT Models

- To deal with the math behind continuous time modeling, we developed *ctsem*:

Driver, Oud, & Voelkle (in press). *Journal of Statistical Software.*

2. A Super-Quick Introduction to CT Models

Output: Continuous time parameter estimates & standard errors

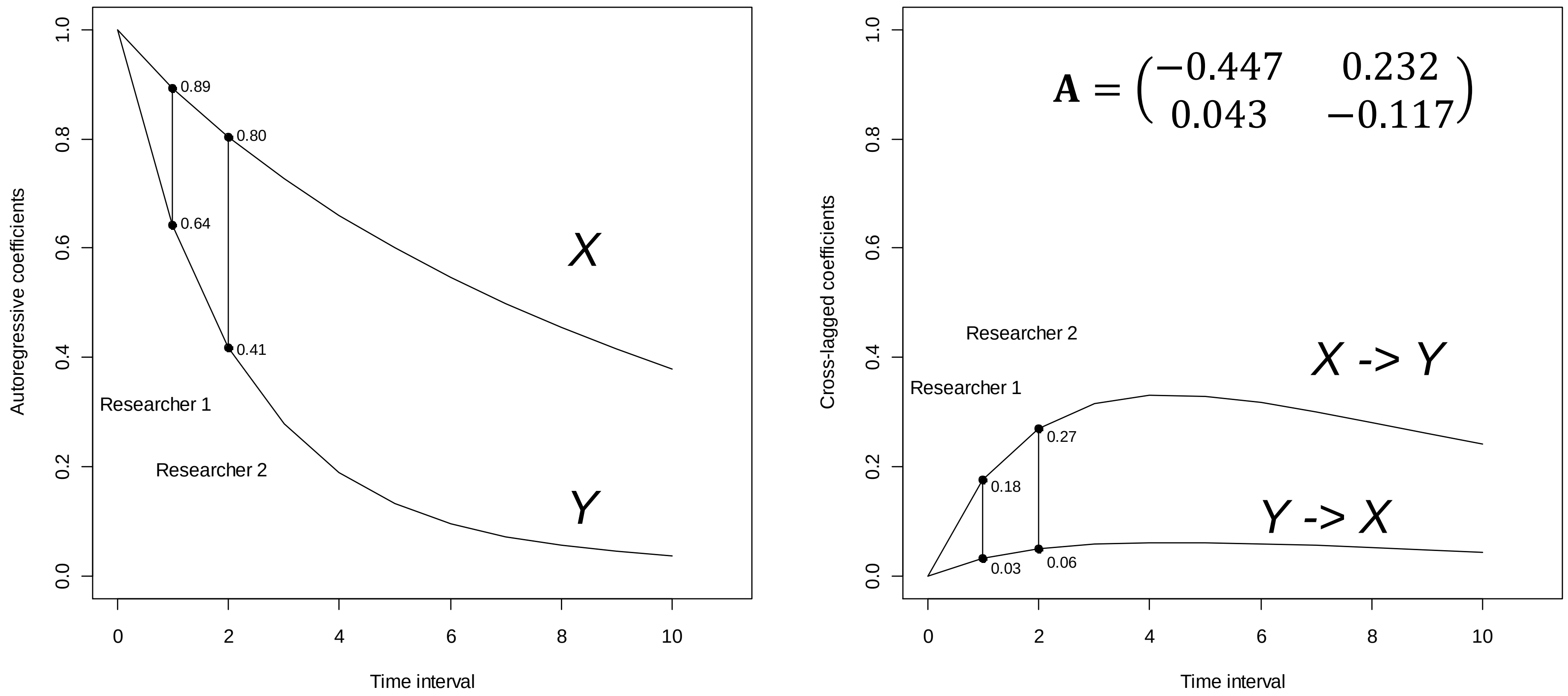
```
free parameters:
    name matrix row col      Estimate   Std.Error
1  phi11      S   1   1   0.632860723 0.017155319
2  phi21      S   2   1   0.244730438 0.011330932
3  phi22      S   2   2   0.457576808 0.012403227
4    F11  DRIFT   1   1  -0.447282043 0.019877226
5    F21  DRIFT   2   1   0.043292845 0.009631034
6    F12  DRIFT   1   2   0.232497994 0.018058916
7    F22  DRIFT   2   2  -0.117466337 0.008651670
8  cint1   CINT   1   1   0.536314454 0.046290824
9  cint2   CINT   1   2   0.220003765 0.022199724
10   q11      Q   1   1   0.473242113 0.015697220
11   q12      Q   2   1  -0.004610147 0.005495074
12   q22      Q   2   2   0.154509580 0.003846262
13    m1      M   1  F1   2.503428393 0.015249241
14    m2      M   1  F2   2.842722000 0.012965461

observed statistics:  13375
estimated parameters:  14
degrees of freedom:  13361
-2 log likelihood:  23415.93
```

Y
Y -> X
X -> Y
X

Drift matrix

2. A Super-Quick Introduction to CT Models

Plots: Autoregressive and cross-lagged parameters



$$\mathrm{e}^{\mathbf{A}\cdot\Delta t_i} = \mathrm{e}^{\mathbf{A}\cdot 1} = \begin{pmatrix} 0.643 & 0.176 \\ 0.033 & 0.893 \end{pmatrix}$$

$$\mathrm{e}^{\mathbf{A}\cdot\Delta t_i} = \mathrm{e}^{\mathbf{A}\cdot 2} = \begin{pmatrix} 0.419 & 0.271 \\ 0.050 & 0.804 \end{pmatrix}$$

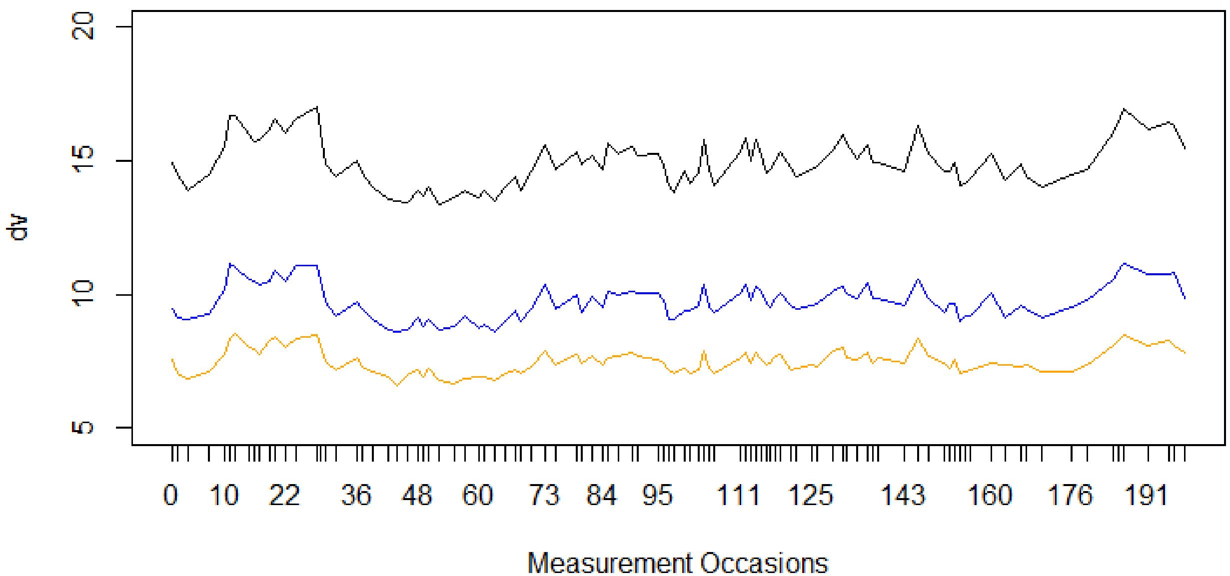
2. The Potential of CT Models

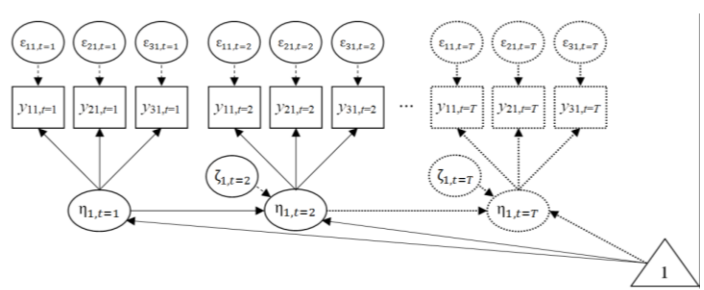
Continuous time models resolve the problem of unequal time intervals,

and….

The Potential of CT Models

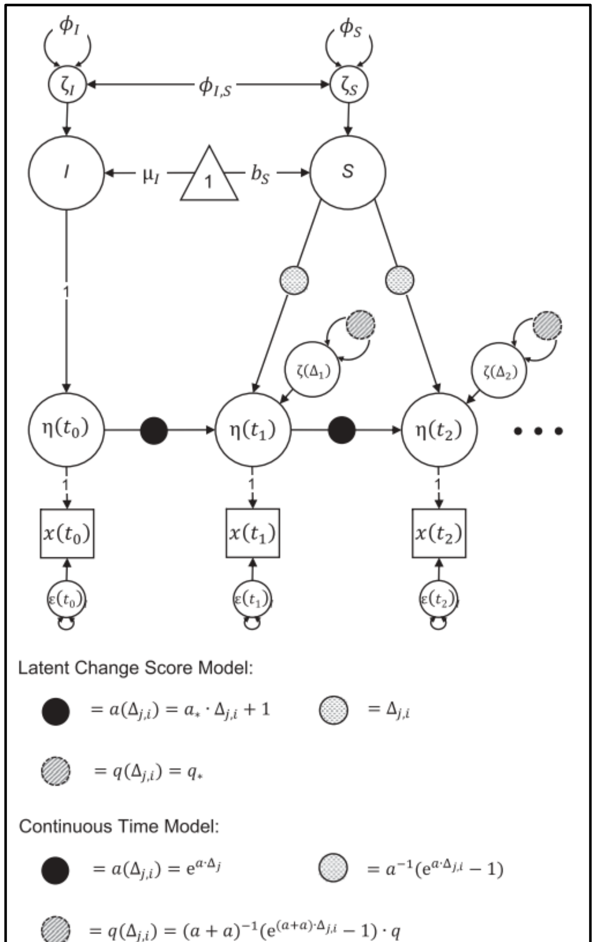
…permit the analysis of panel models, *N* = 1 time series (dynamic factor models), and the integration of BP and WP models

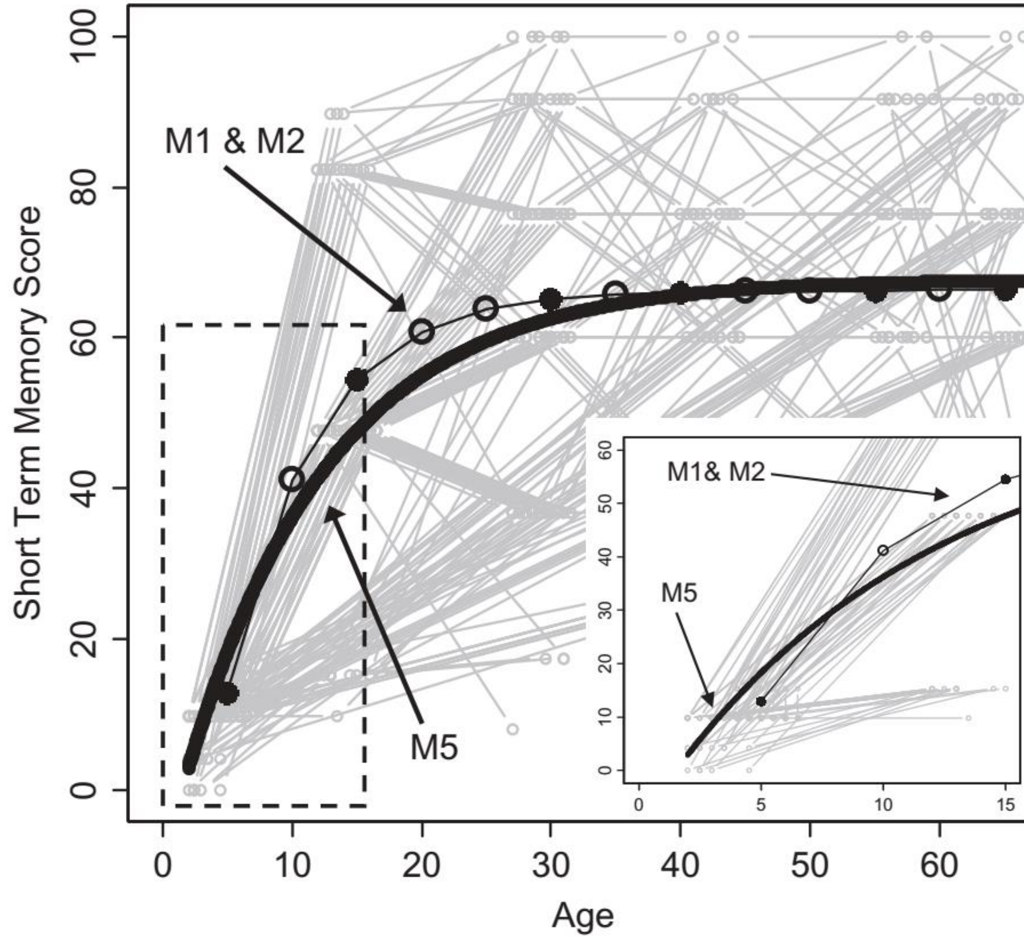




The Potential of CT Models

…comprise latent change scores models as a special case

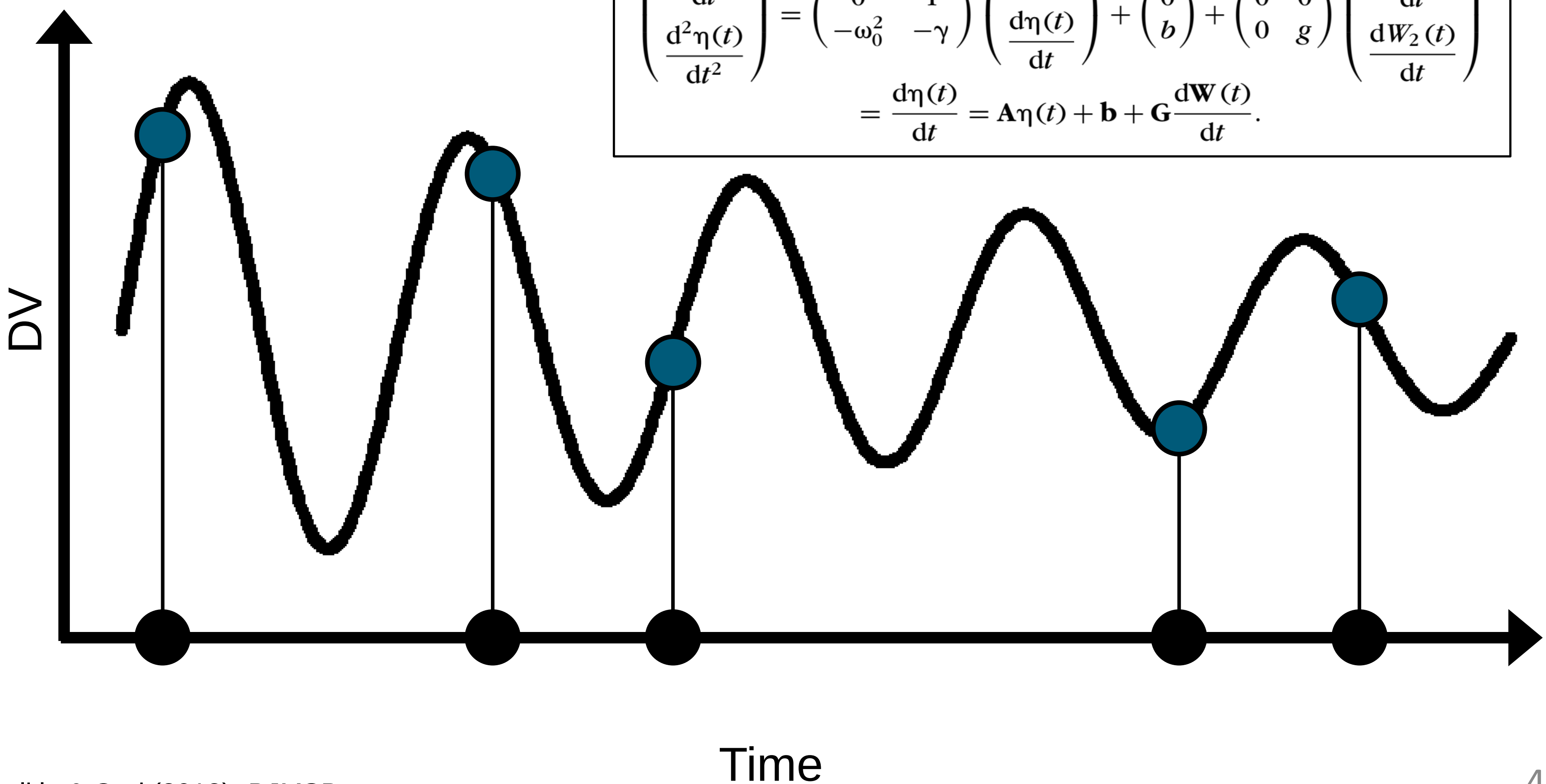




2. The Potential of CT Models

…permit the estimation of oscillating and/or higher order (coupled) processes

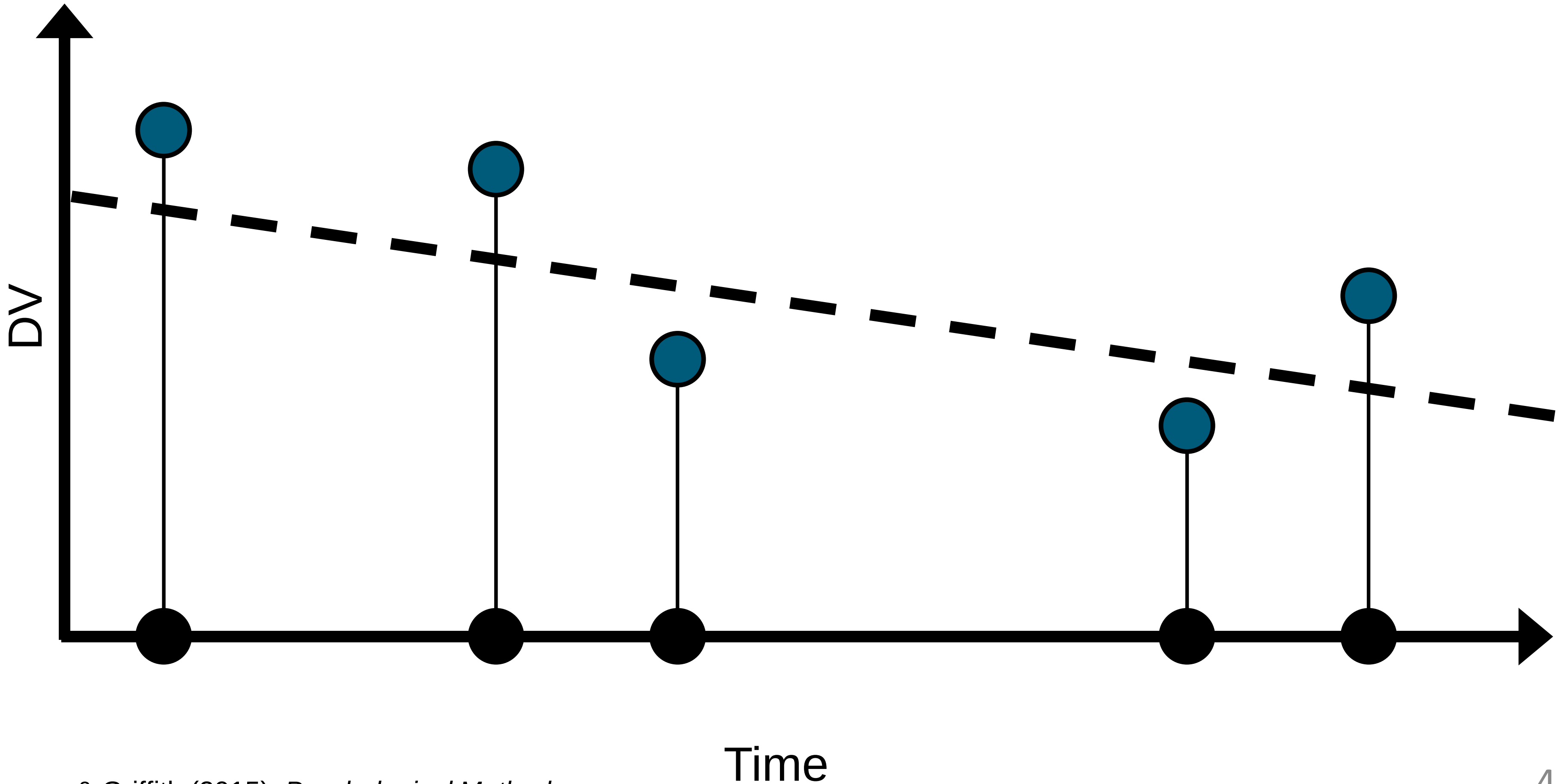
$$\begin{pmatrix}\frac{\mathrm{d}\eta(t)}{\mathrm{d}t}\\ \frac{\mathrm{d}^2\eta(t)}{\mathrm{d}t^2}\end{pmatrix} = \begin{pmatrix}0 & 1\\ -\omega_0^2 & -\gamma\end{pmatrix}\begin{pmatrix}\eta(t)\\ \frac{\mathrm{d}\eta(t)}{\mathrm{d}t}\end{pmatrix} + \begin{pmatrix}0\\ b\end{pmatrix} + \begin{pmatrix}0 & 0\\ 0 & g\end{pmatrix}\begin{pmatrix}\frac{\mathrm{d}W_1(t)}{\mathrm{d}t}\\ \frac{\mathrm{d}W_2(t)}{\mathrm{d}t}\end{pmatrix}$$
$$= \frac{\mathrm{d}\eta(t)}{\mathrm{d}t} = \mathbf{A}\eta(t) + \mathbf{b} + \mathbf{G}\frac{\mathrm{d}\mathbf{W}(t)}{\mathrm{d}t}.$$



Voelkle & Oud (2013). *BJMSP.*

The Potential of CT Models

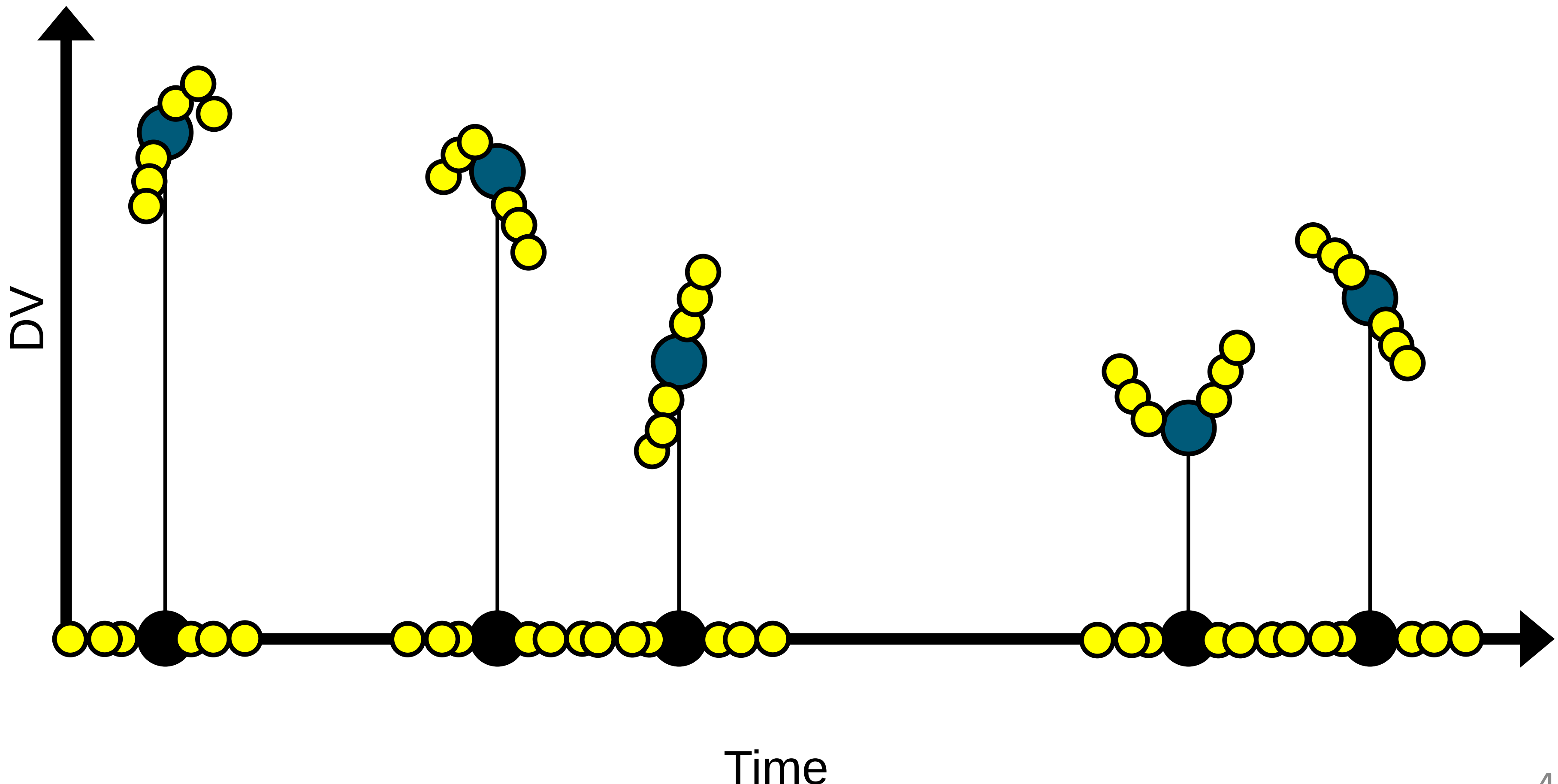
…may help in improving study designs by optimizing sampling and identifying "optimal lags" (Dormann, 2015, p. 597)



Dorman & Griffith (2015). *Psychological Methods.*

2. The Potential of CT Models

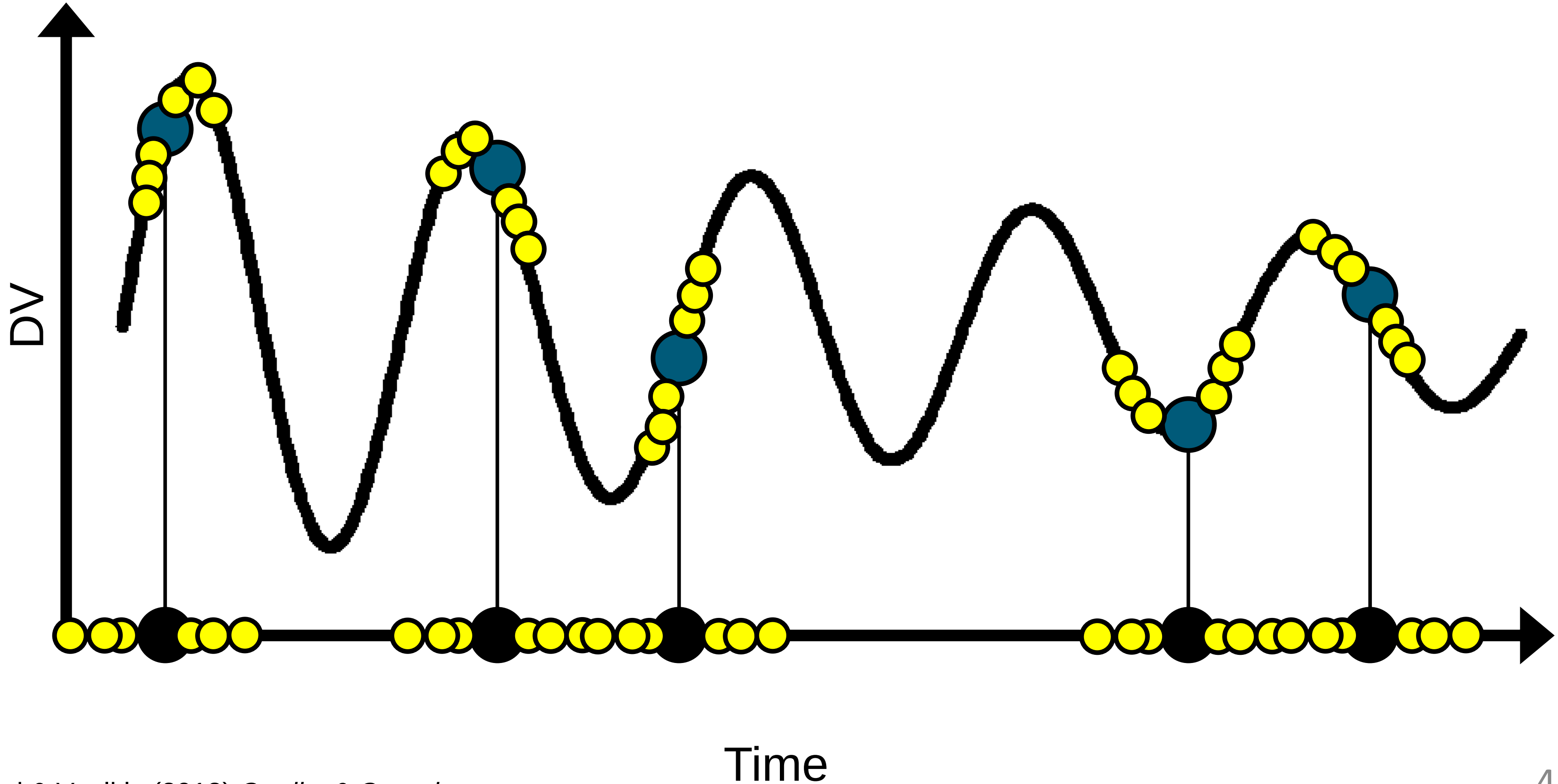
…may help in improving study designs by optimizing sampling and identifying “optimal lags”



Oud & Voelkle (2013) *Quality & Quantity*

The Potential of CT Models

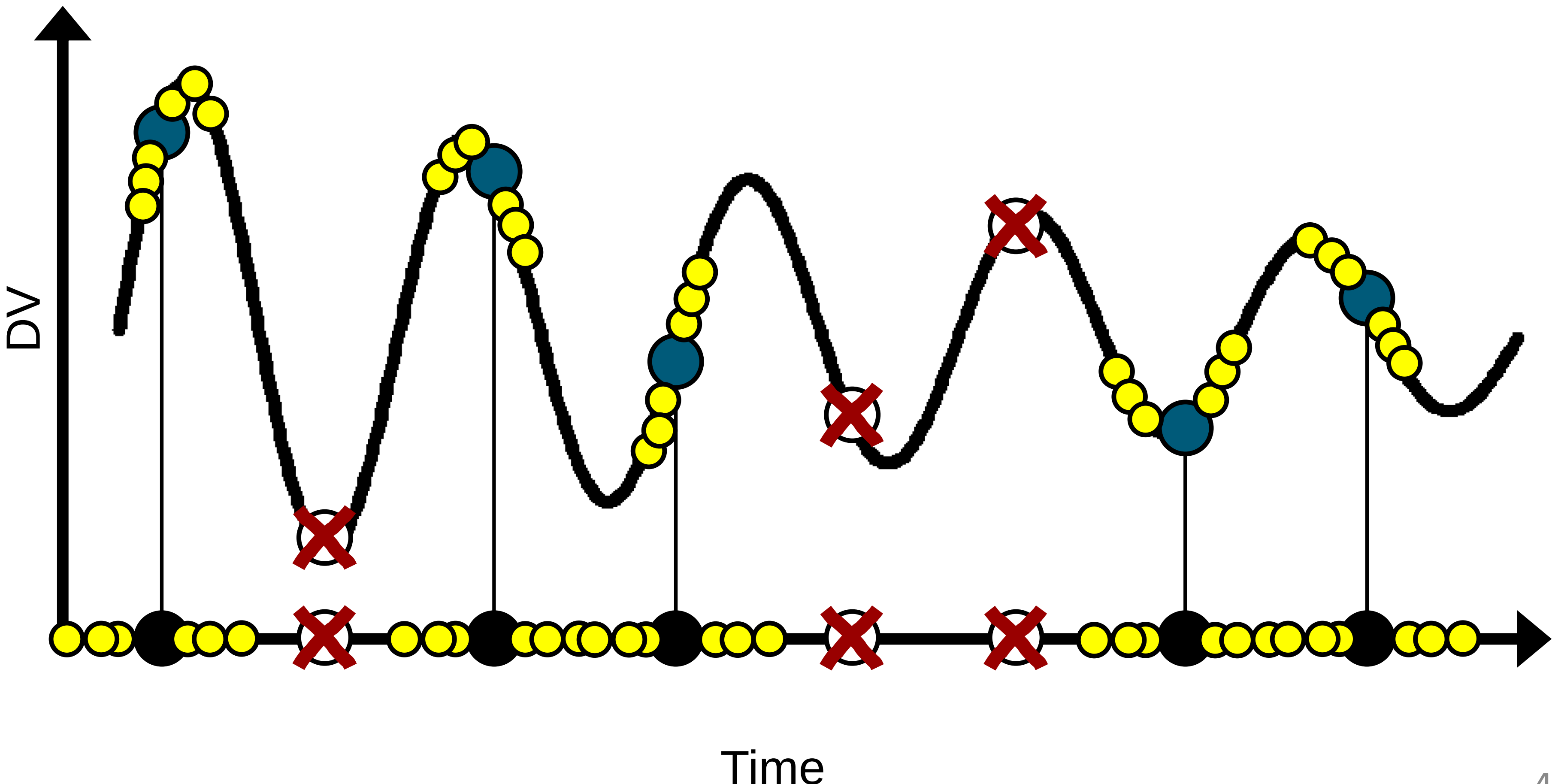
…may help in improving study designs by optimizing sampling and identifying “optimal lags”



Oud & Voelkle (2013) *Quality & Quantity*

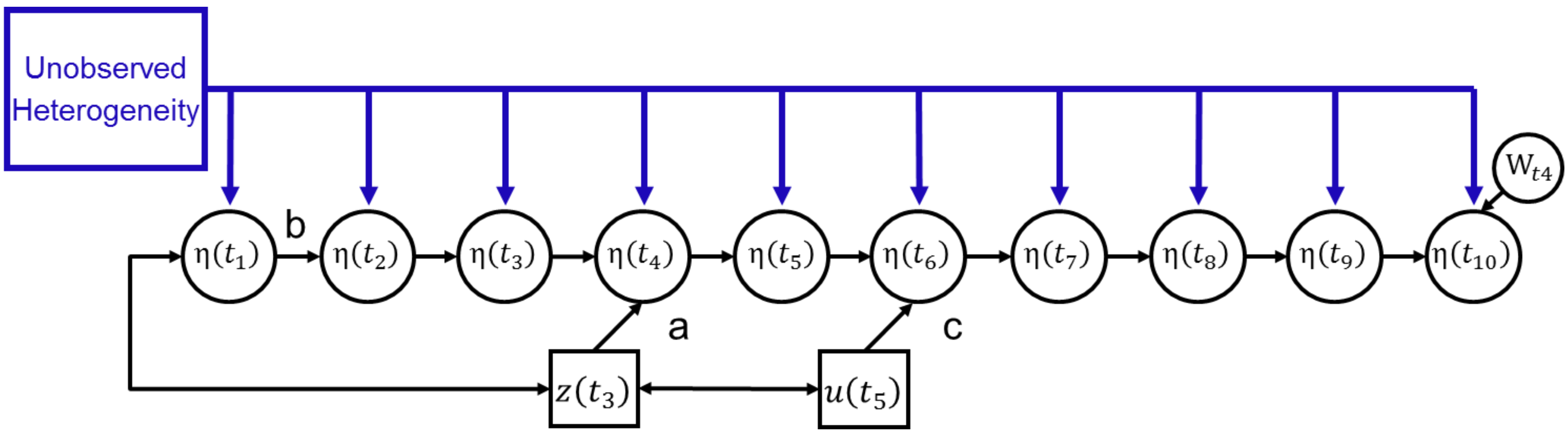
The Potential of CT Models

…offers new perspectives on missing values (which “do not exist”) in continuous time



The Potential of CT Models

…permits various extensions, including time-varying and time-invariant predictors and random effects (“traits)

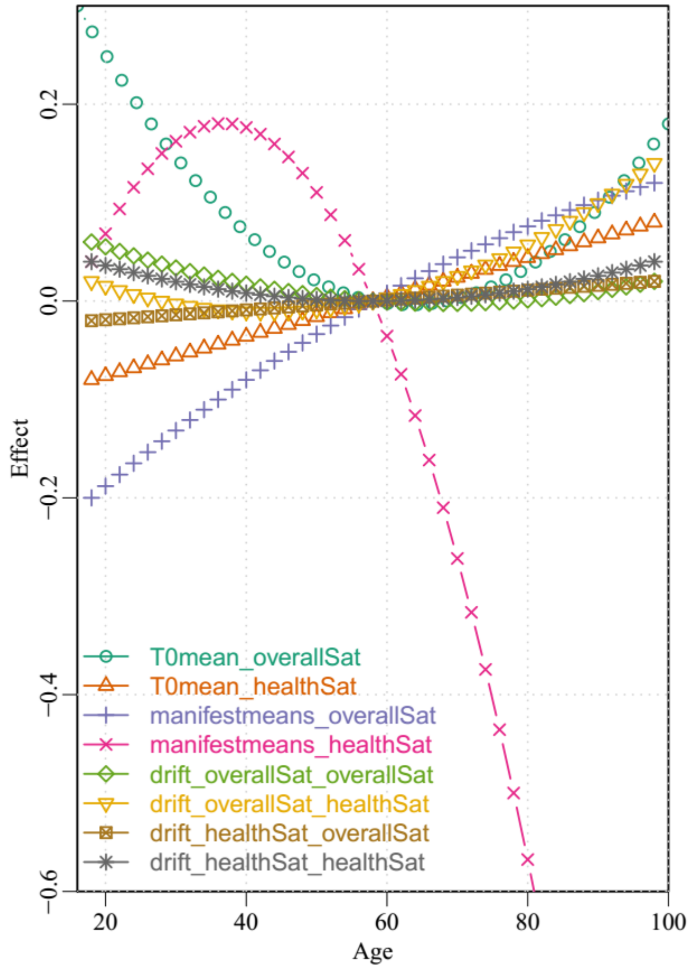


$$\mathrm{d}\boldsymbol{\eta}(t) = (\mathbf{A}\boldsymbol{\eta}(t) + \mathbf{b} + \mathbf{M}\mathbf{x}(t))\mathrm{d}t + \mathbf{G}\mathrm{d}\mathbf{W}(t)$$

Hamaker (2015). *Psychological Methods;* Voelkle (2015). *Science.*

The Potential of CT Models

…is currently being extended to a fully hierarchical Bayesian approach by means of rstan

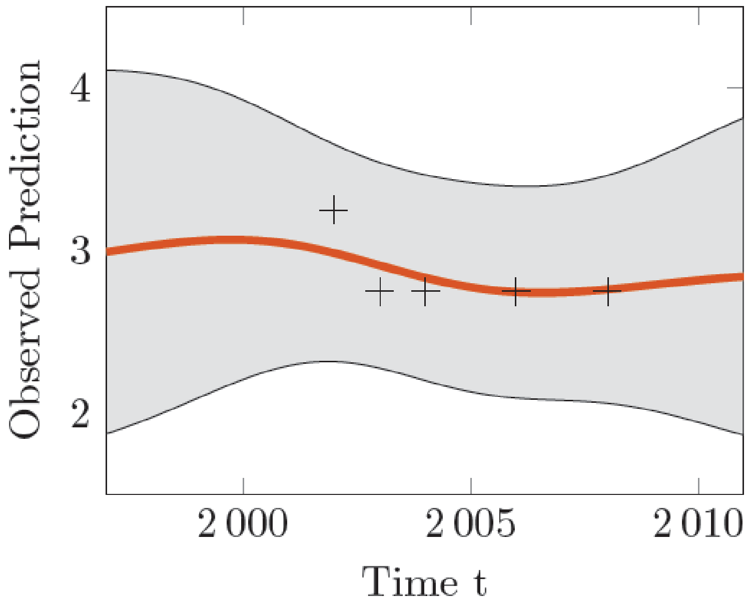


Driver & Voelkle (in prep.)

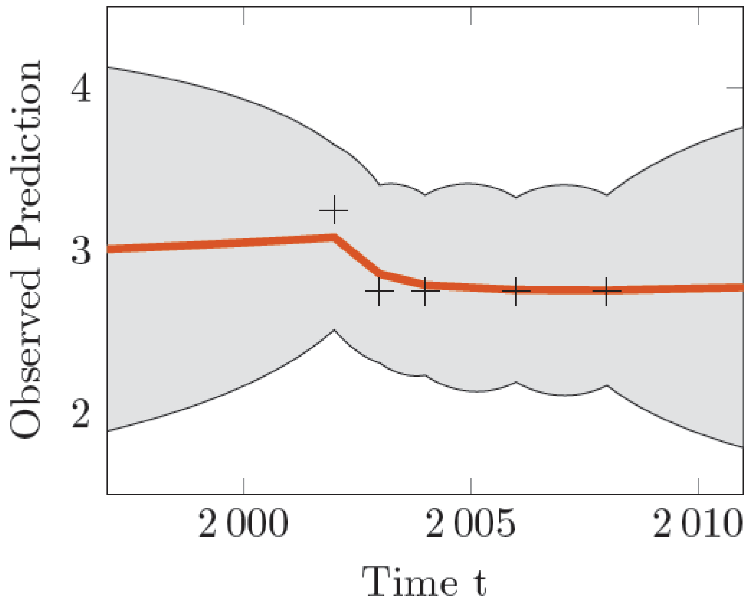
2. The Potential of CT Models

…is related to Gaussian Process Panel (GPPM) models, which provides additional flexibility, e.g. in the choice of kernel function and person specific predictions

Smoothness Model



AR(1) Model



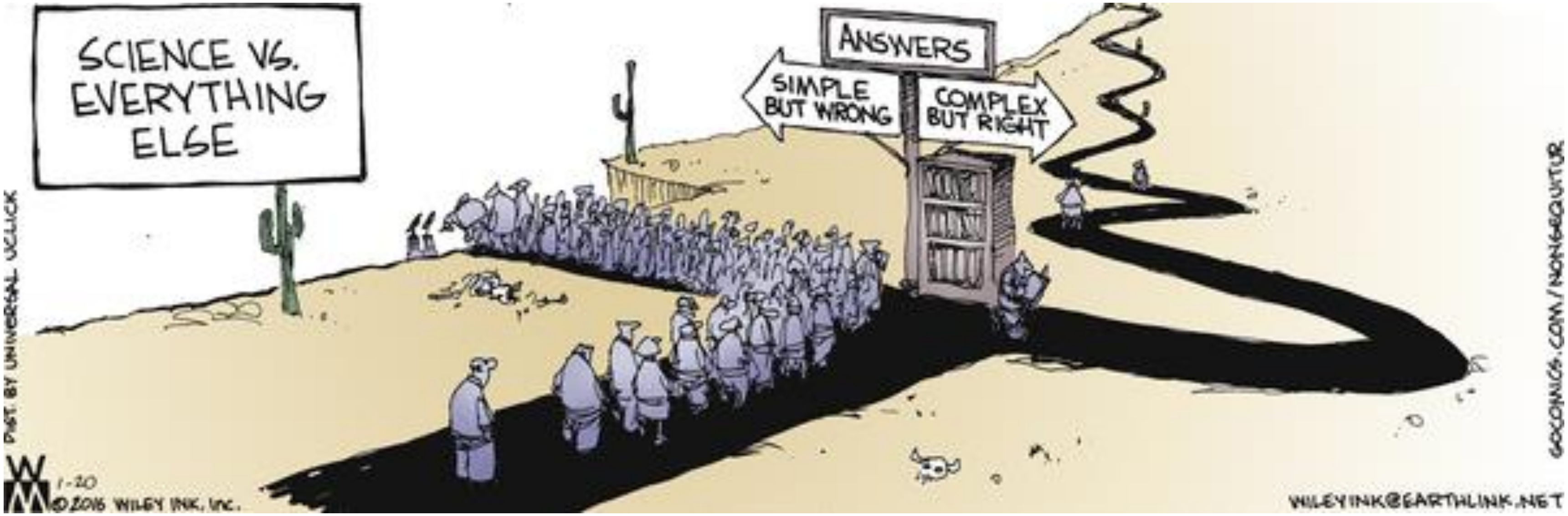
Karch (submitted)

Another Dimension, Many Complexities?

3. Another Dimension, Many Complexities?

- Yes…as we get more familiar with the unknown third dimension, the loose ends become obvious.

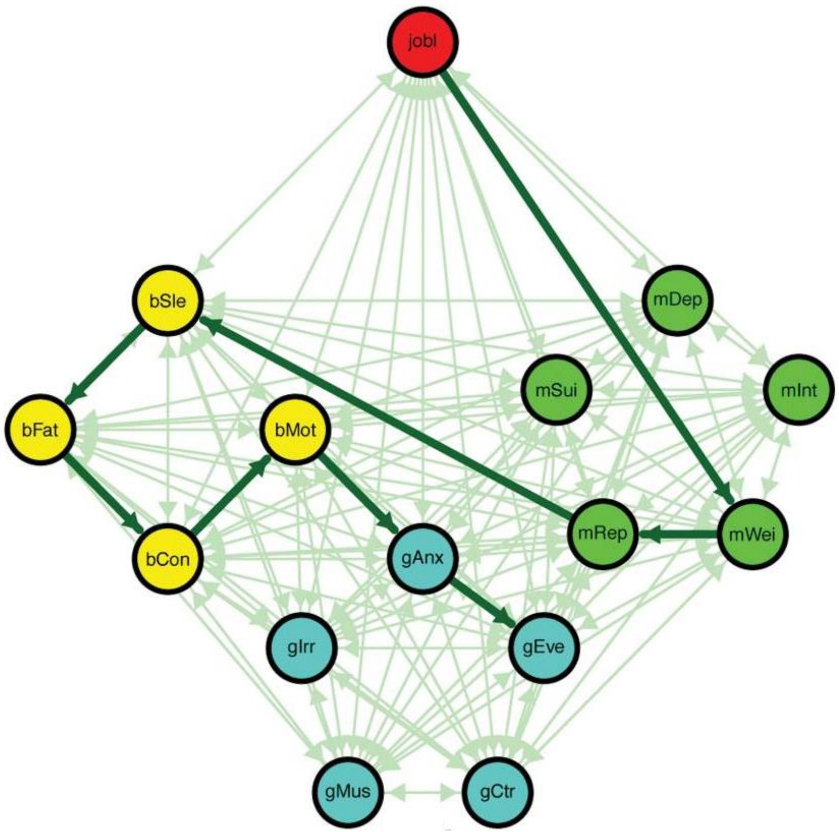
- We may distinguish between **statistical** and **conceptual** problems *and opportunities*.



Another Dimension, Many Complexities?

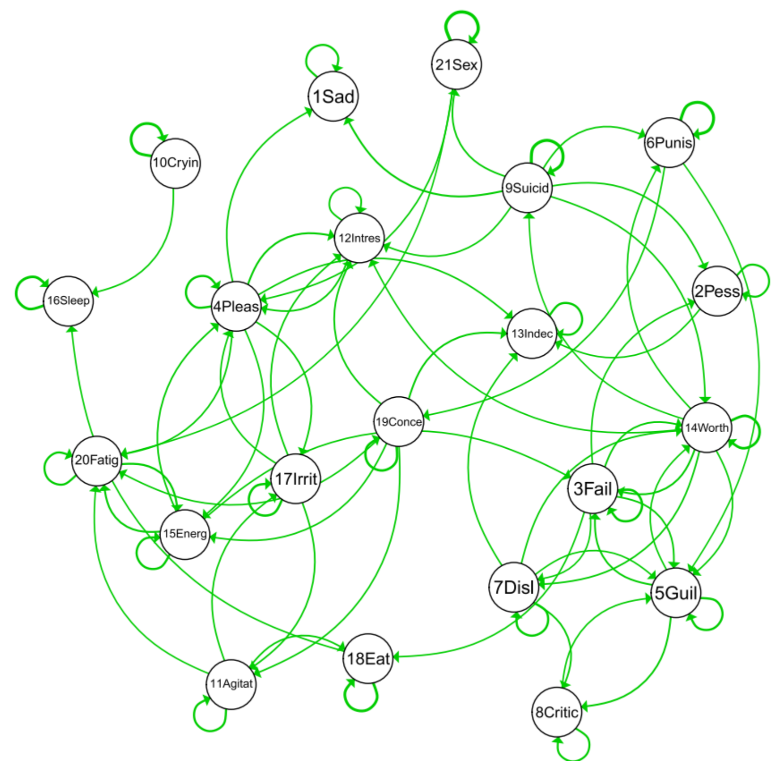
1. Statistical problems and opportunities:

A) Computational limitations with respect to the number of individuals, time points, and variables/processes.



Borsboom et al. (2011)

BDI-II Network (21 nodes, N = 182, $T \approx 14$)

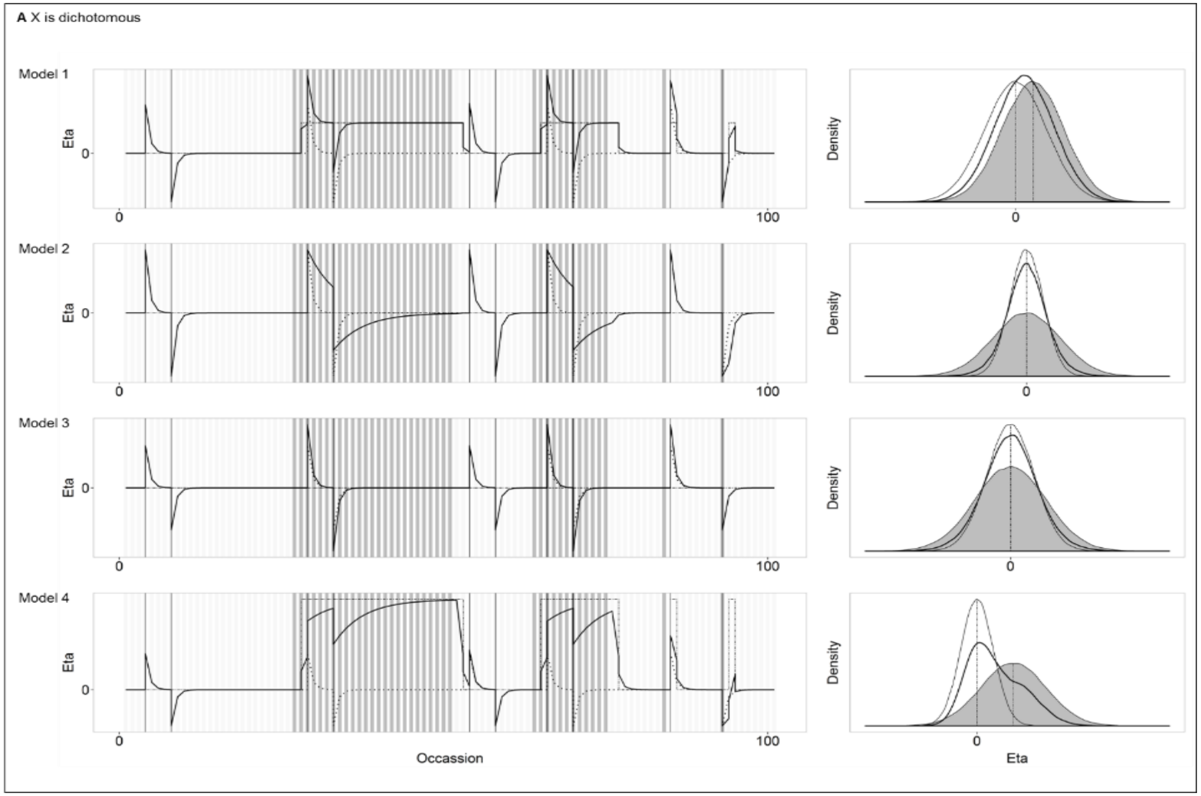


Bringmann et al. (2015)

Another Dimension, Many Complexities?

1. Statistical problems and opportunities:

B) Better approaches to control or observed and unobserved heterogeneity across individuals and time

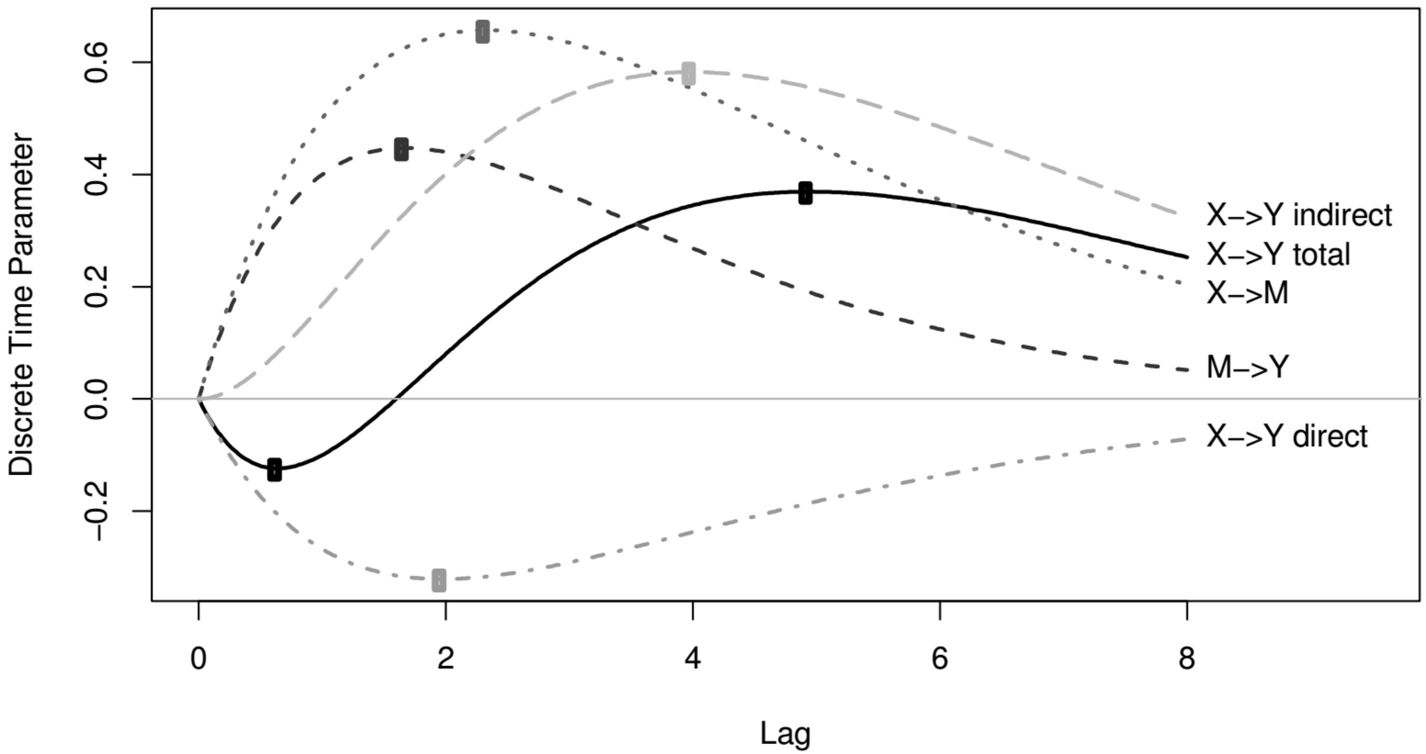


Adolf (under revision)

Another Dimension, Many Complexities?

2. Conceptual problems and opportunities:

A) We need to reconsider traditional approaches to mediation analysis from a continuous time perspective



Deboeck & Preacher (2016). *Structural Equation Modeling*.

Another Dimension, Many Complexities?

2. Conceptual problems and opportunities:

B) Need to better connect continuous time approaches to established frameworks of causal inference (e.g., DAGs)

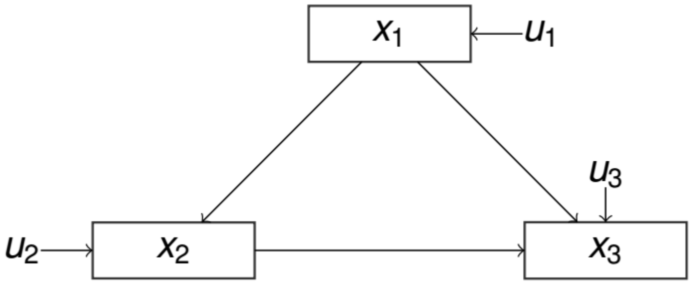
$$\frac{\partial \mathrm{E}(X_3 \mid do(x_2'))}{\partial x_2'} = \frac{\partial}{\partial x_2'} \frac{\sigma_{X_2X_3}}{\sigma^2_{X_2}} x_2' = \frac{\partial}{\partial x_2'} c_{32}^{3|12} x_2' = \frac{\partial}{\partial x_2'} \beta_{32} x_2' = \beta_{32}$$

doing

vs.

$$\begin{aligned}\frac{\partial}{\partial x_2'} \mathrm{E}(X_3 \mid X_2 = x_2') &= \frac{\partial}{\partial x_2'} c_{32}^{3|2} x_2' = c_{32}^{3|2} \\ &= \frac{\sigma_{X_2X_3}}{\sigma^2_{X_2}} \\ &= \frac{\beta_{21}(\beta_{21}\beta_{32} + \beta_{31})\sigma^2_{U_1} + \beta_{32}\sigma^2_{U_2}}{\beta^2_{21}\sigma^2_{U_1} + \sigma^2_{U_2}} \\ &= \beta_{32} + \frac{\beta_{21}\beta_{31}\sigma^2_{U_1}}{\beta^2_{21}\sigma^2_{U_1} + \sigma^2_{U_2}}\end{aligned}$$

seeing

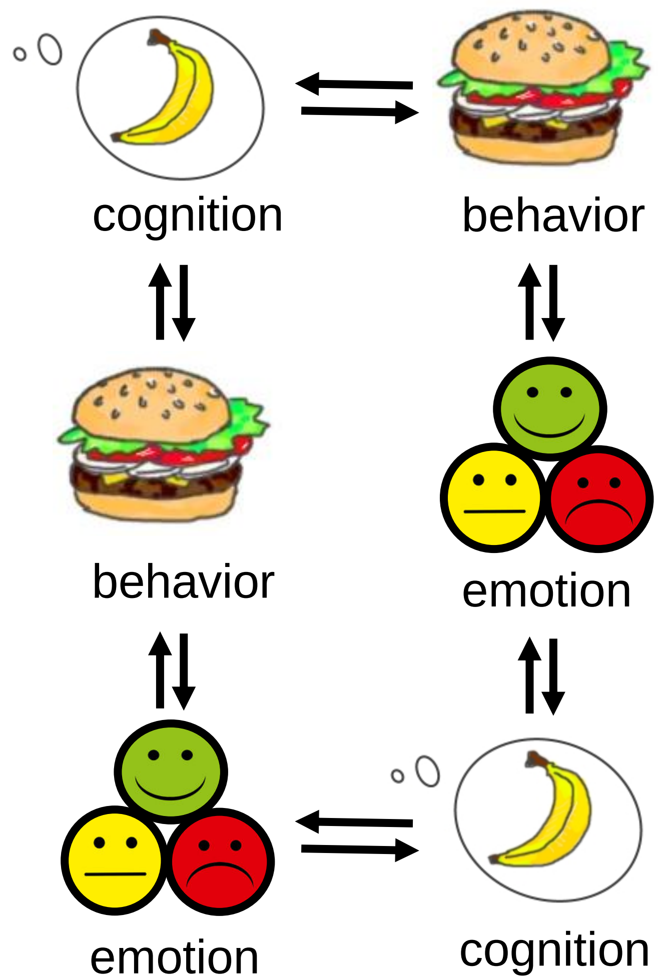


Pearl (2000); Gische (2016)

So…where to go from here? An Outlook

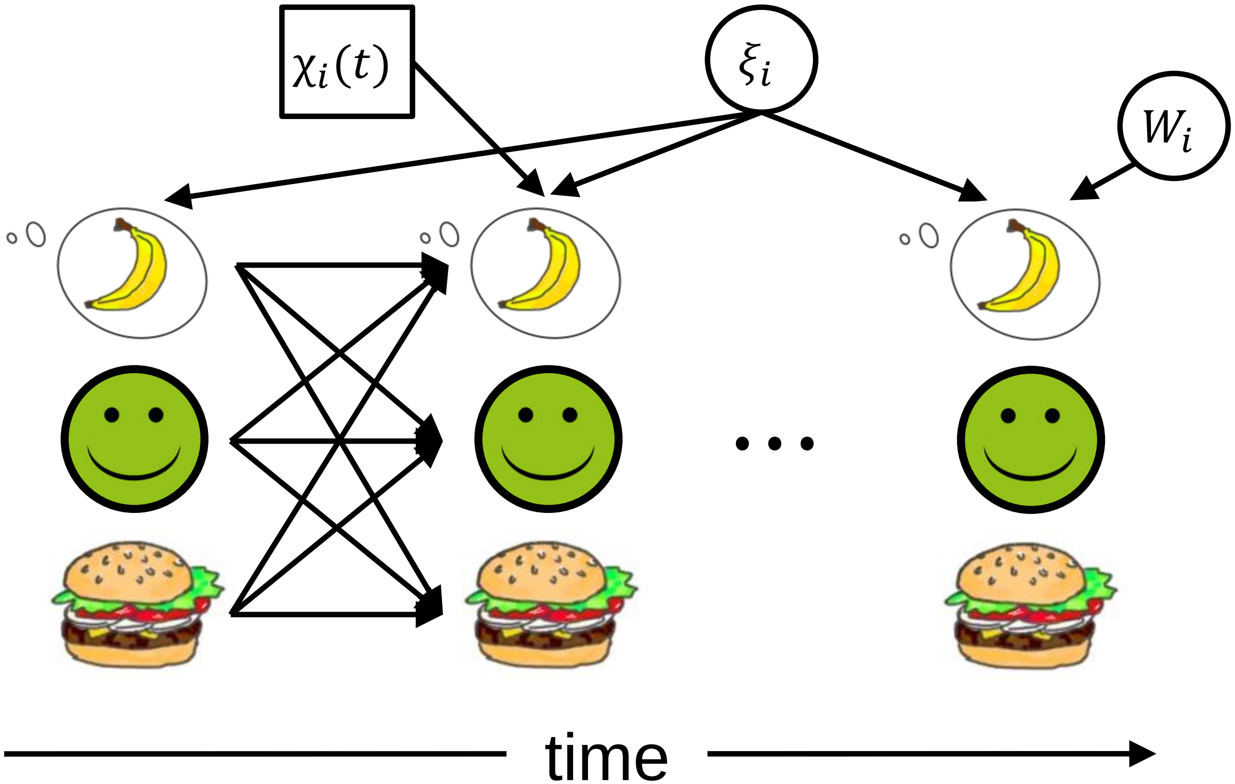
3. An Outlook

…on (the future of) studying the mechanisms of the human, mind, brain, and behavior



An Outlook

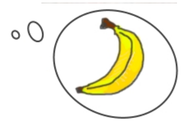
1. Cast theories in terms of dynamic models:



An Outlook

1. Cast theories in terms of dynamic models:

$$\mathrm{d}\boldsymbol{\eta}(t) = (\mathbf{A}\boldsymbol{\eta}(t) + \mathbf{b} + \mathbf{M}\mathbf{x}(t))\mathrm{d}t + \mathbf{G}\mathrm{d}\mathbf{W}(t)$$

$$\mathbf{A}(\Delta t = 1) = \begin{bmatrix} +0.6 & \pm 0.0 & +0.4 \\ -0.2 & +0.7 & +0.4 \\ -0.3 & -0.2 & +0.5 \end{bmatrix}$$



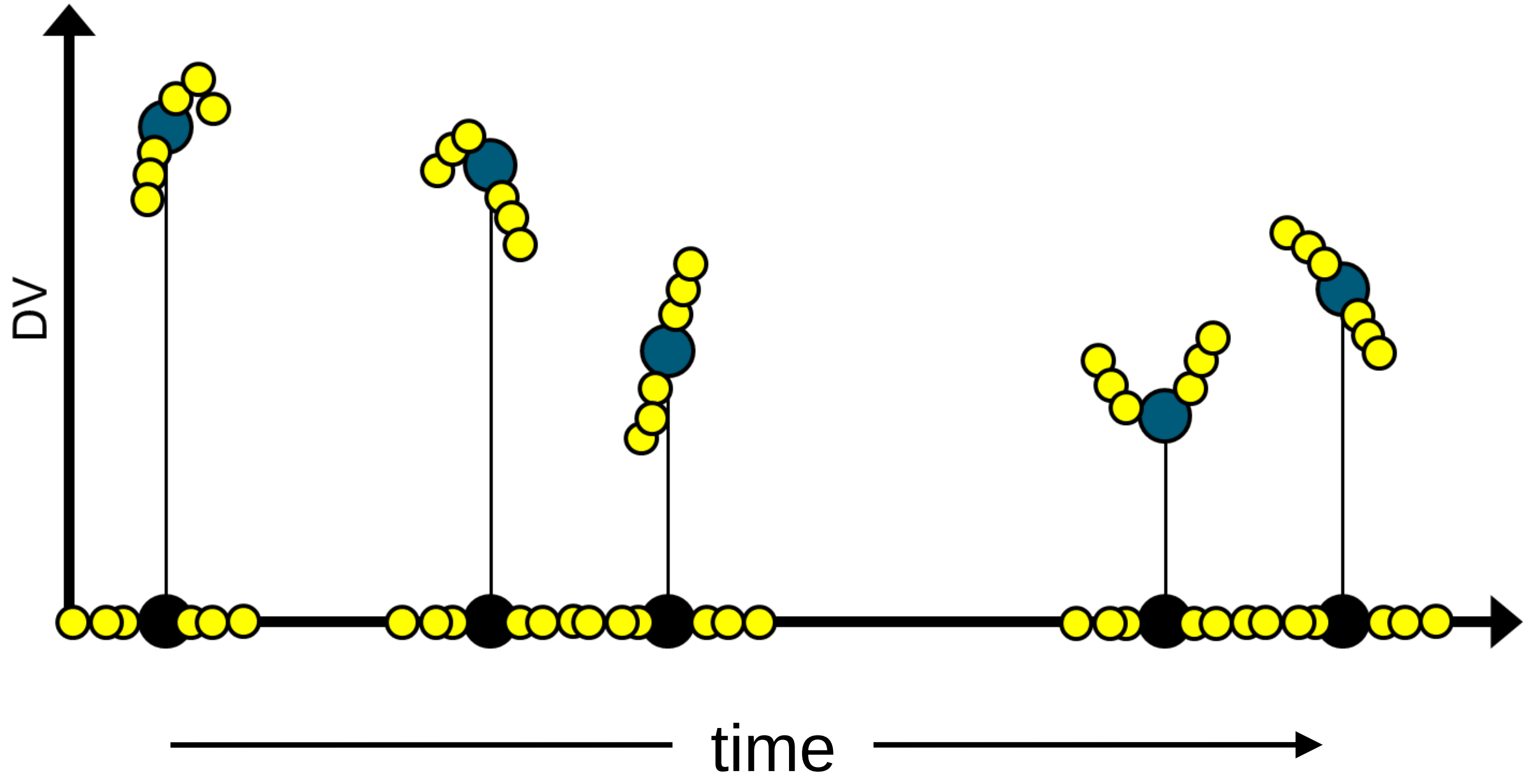
 = “thinking healthy” (cognition)

 = “being happy” (affective experience)

 = “eating unhealthy” (behavior)

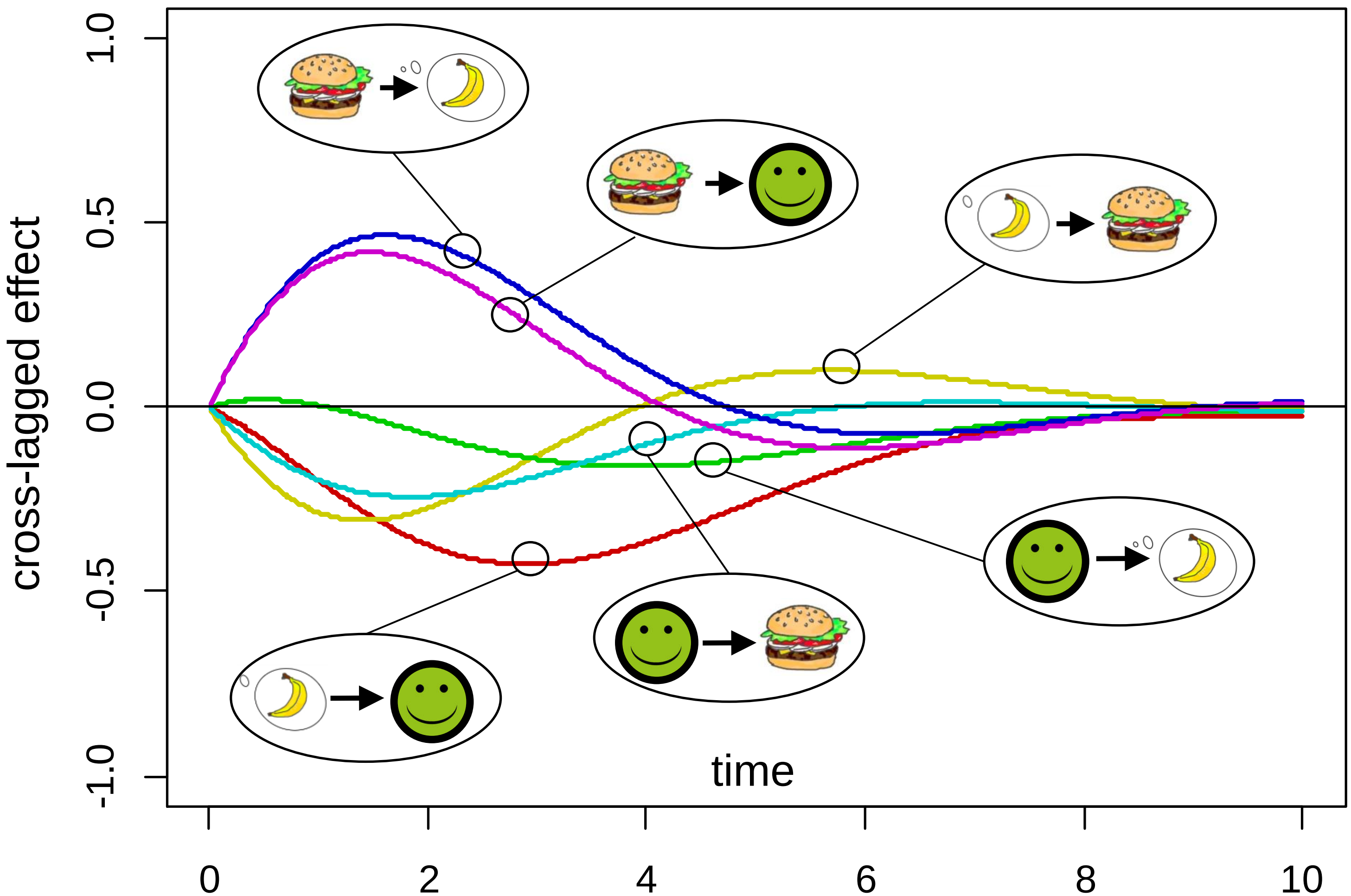
An Outlook

2. Optimize the (sampling) design to yield maximum information about the presumed dynamic mechanisms:



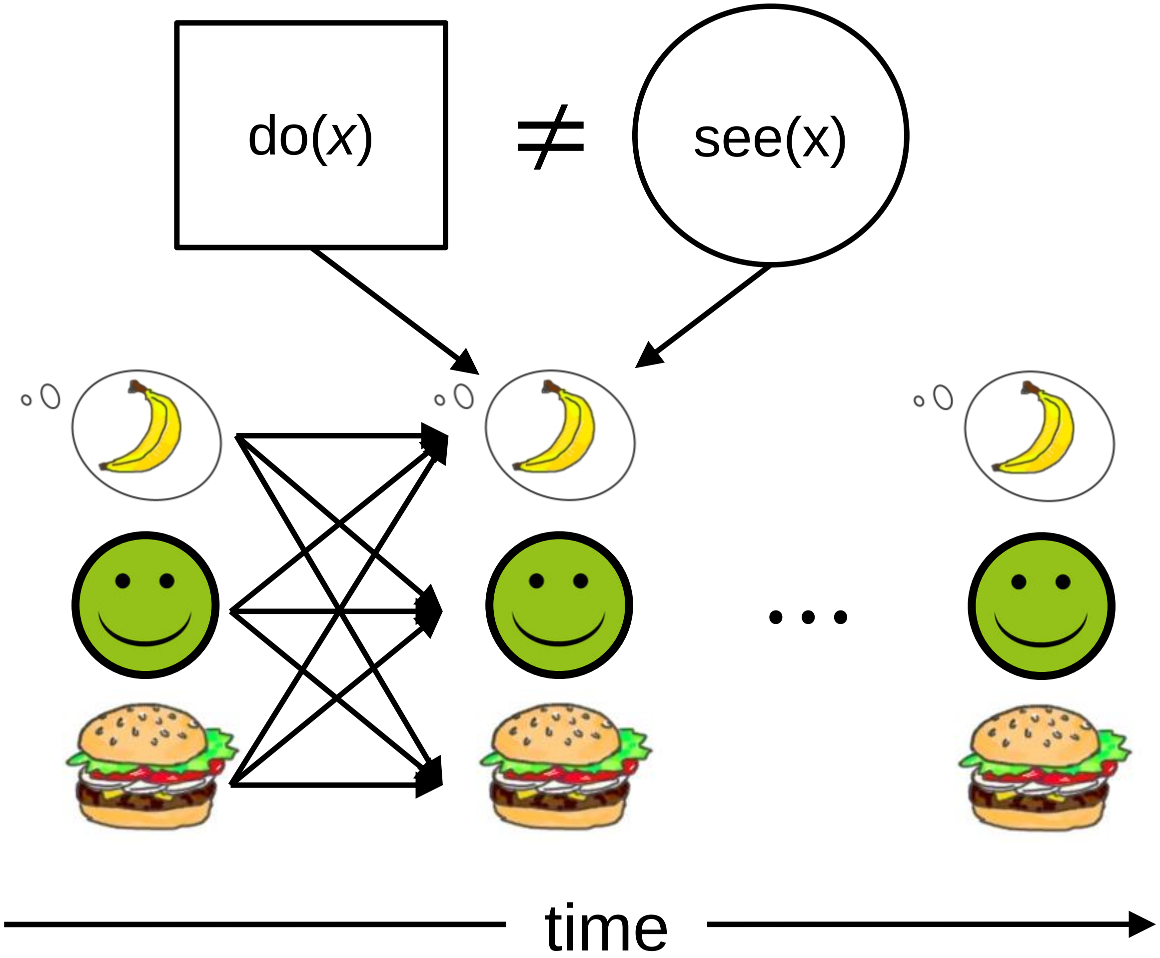
An Outlook

3. Estimate (and understand!) the underlying continuous time dynamics:



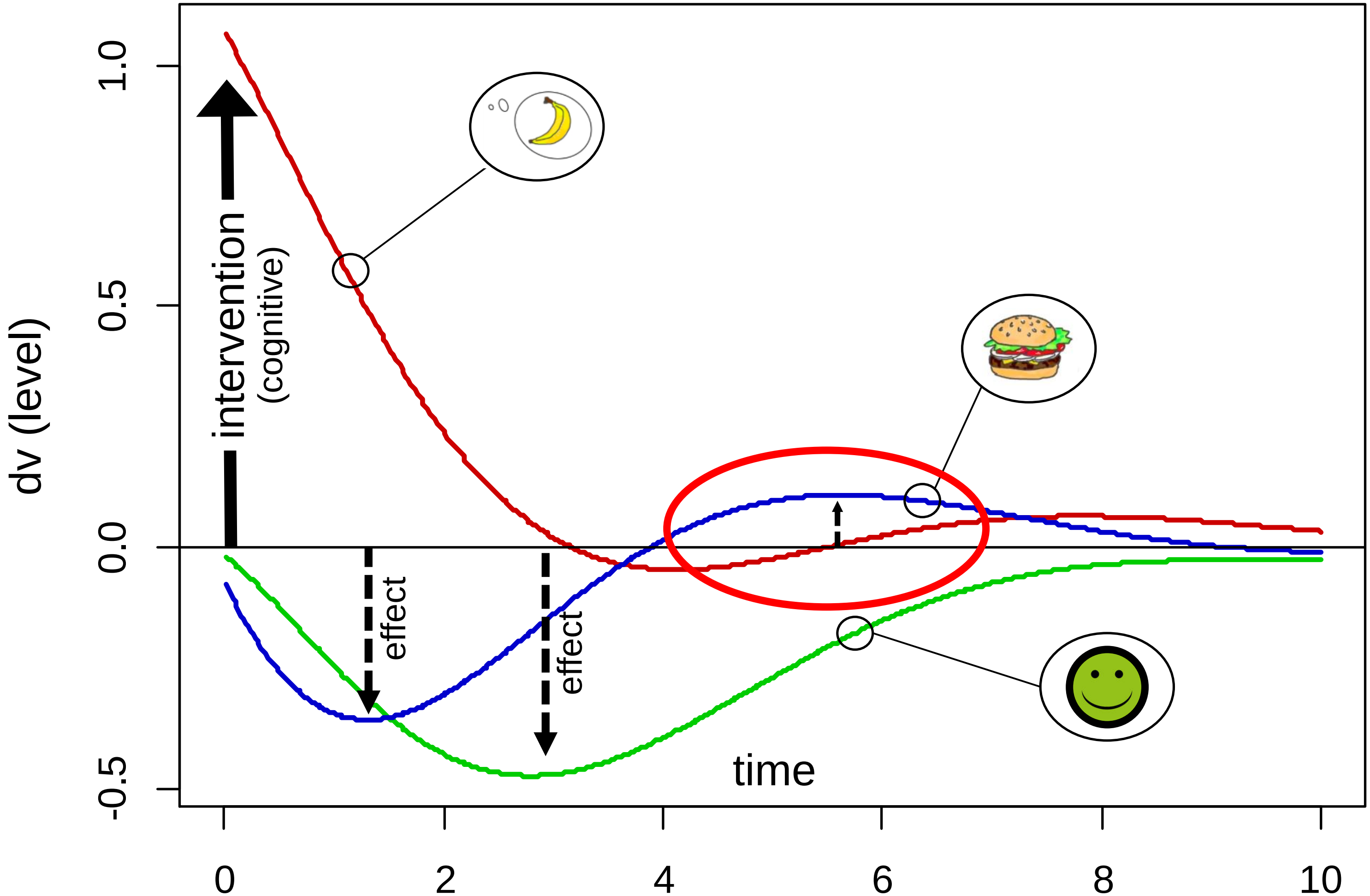
An Outlook

4. Study the causal nature of the system:



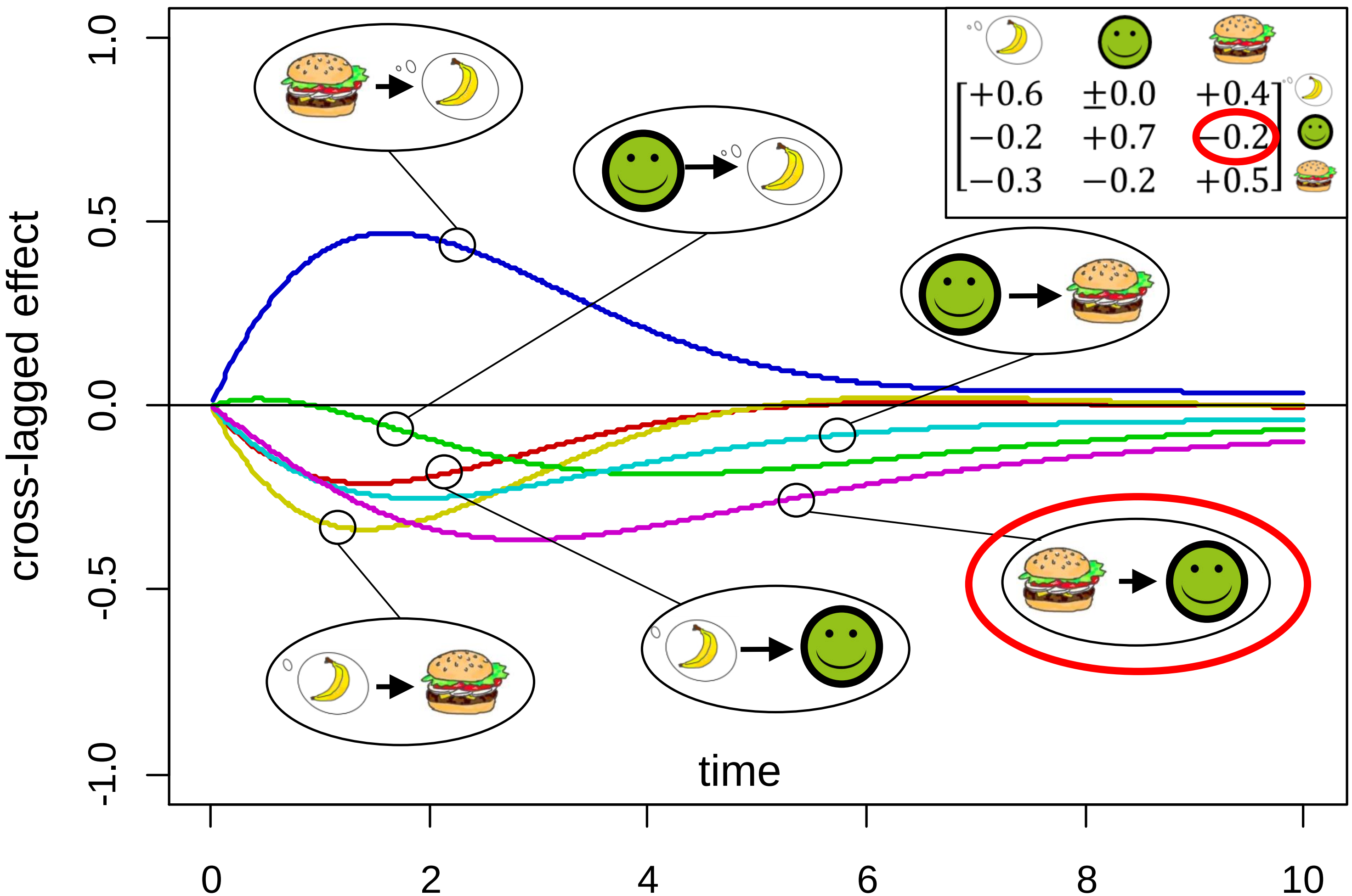
An Outlook

5. Develop targeted interventions based on the entire system:



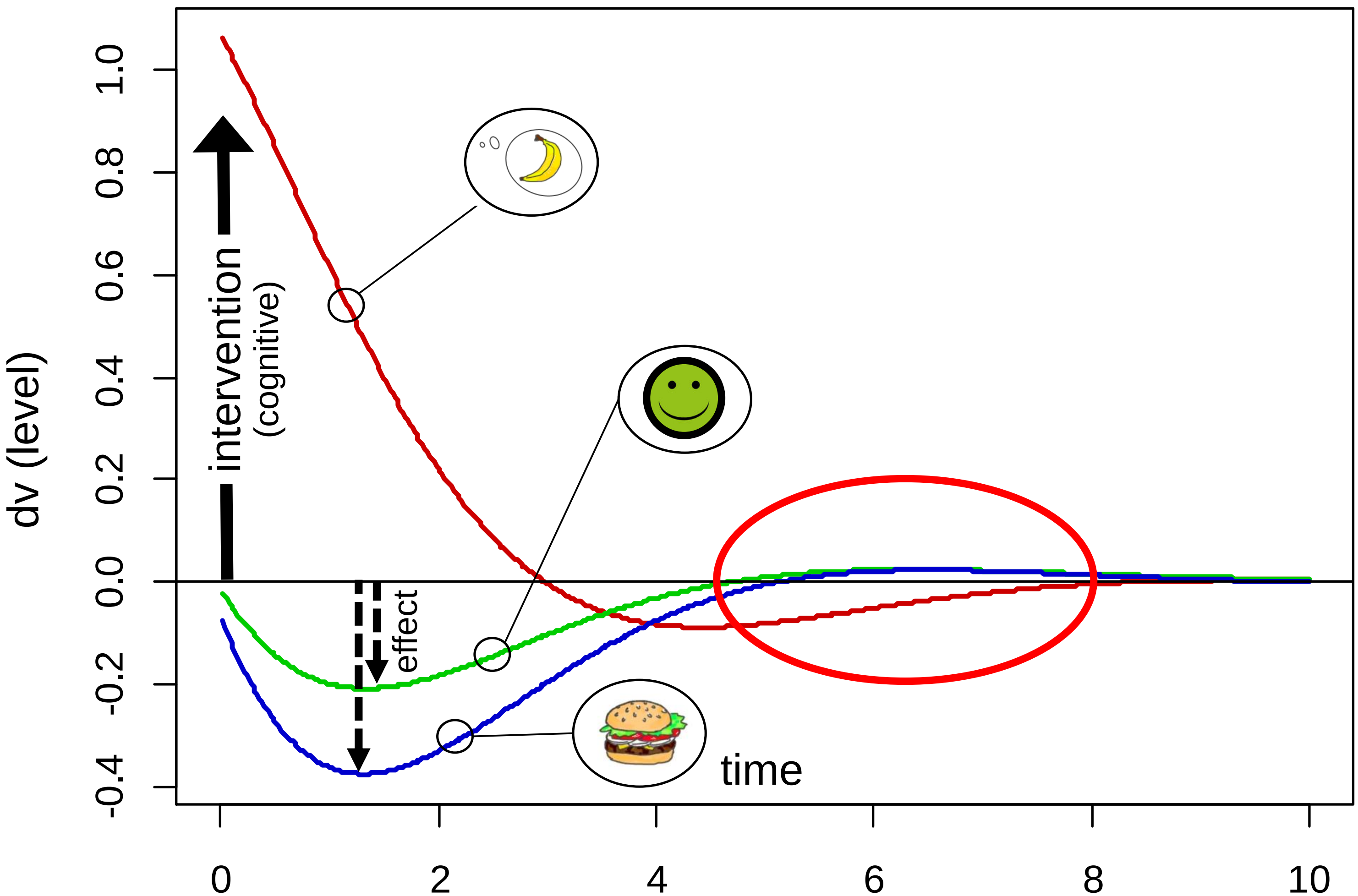
An Outlook

6. Develop targeted interventions to change the system:



An Outlook

7. Anticipate the effect of targeted interventions based on an altered system:



Summary

Part I. Another dimension, another scientific paradigm?

maybe…

Part II. Another dimension or another variable?

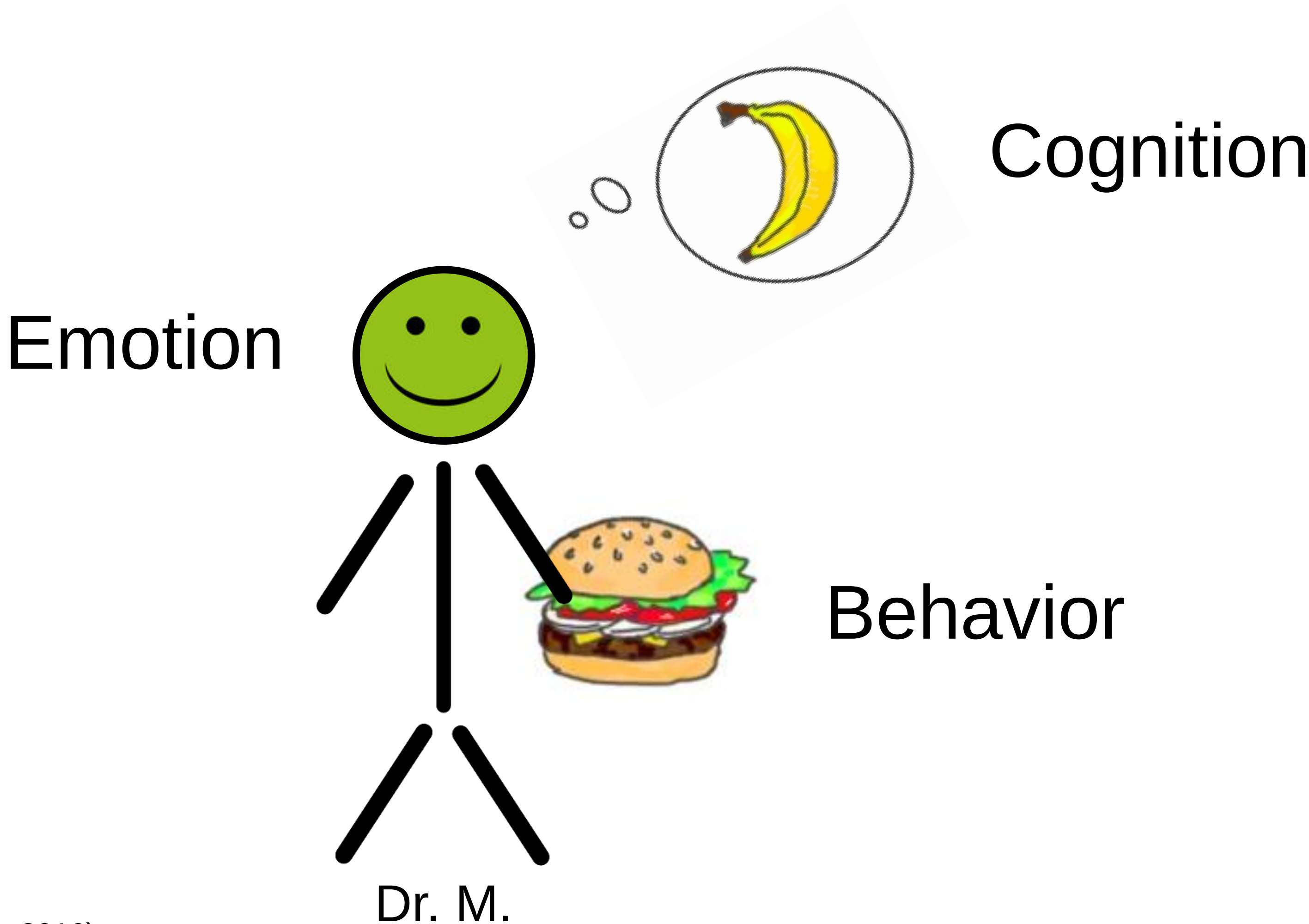
it depends…

Part III. Another dimension, many complexities?

yes!

The Goal

…is to understand the mechanisms of the human mind, brain, and behavior.



Thank you very much for your attention!

manuel.voelkle@hu-berlin.de