Modeling Dynamic Processes with Panel Data: An Application of Continuous Time Models to Prevention Research

Pascal R. Deboeck[1], David A. Cole[2], Kristopher J. Preacher[2], Rex Forehand[3], and Bruce E. Compas[2]

Modern Modeling Methods 2023
University of Connecticut
June 27, 2023

[1]University of Utah, [2]Vanderbilt University, [3]University of Vermont

Introduction

- Continuous Time Models and Prevention/Intervention Research[2]

[2]Deboeck, P. R., Cole, D. A., Preacher, K. J., Forehand, R. & Compas, B. E. (2021). Modeling Dynamic Processes with Panel Data: An Application of Continuous Time Models to Prevention Research. International Journal of Behavioral Development, 45(1), 28–39.

Introduction

- Continuous Time Models and Prevention/Intervention Research[2]
- Open Systems: Dynamic/Process Errors change your model

[2] Deboeck, P. R., Cole, D. A., Preacher, K. J., Forehand, R. & Compas, B. E. (2021). Modeling Dynamic Processes with Panel Data: An Application of Continuous Time Models to Prevention Research. International Journal of Behavioral Development, 45(1), 28–39.

Introduction

- Continuous Time Models and Prevention/Intervention Research[2]
- Open Systems: Dynamic/Process Errors change your model
- Dynamical Systems: Mean differences are not enough

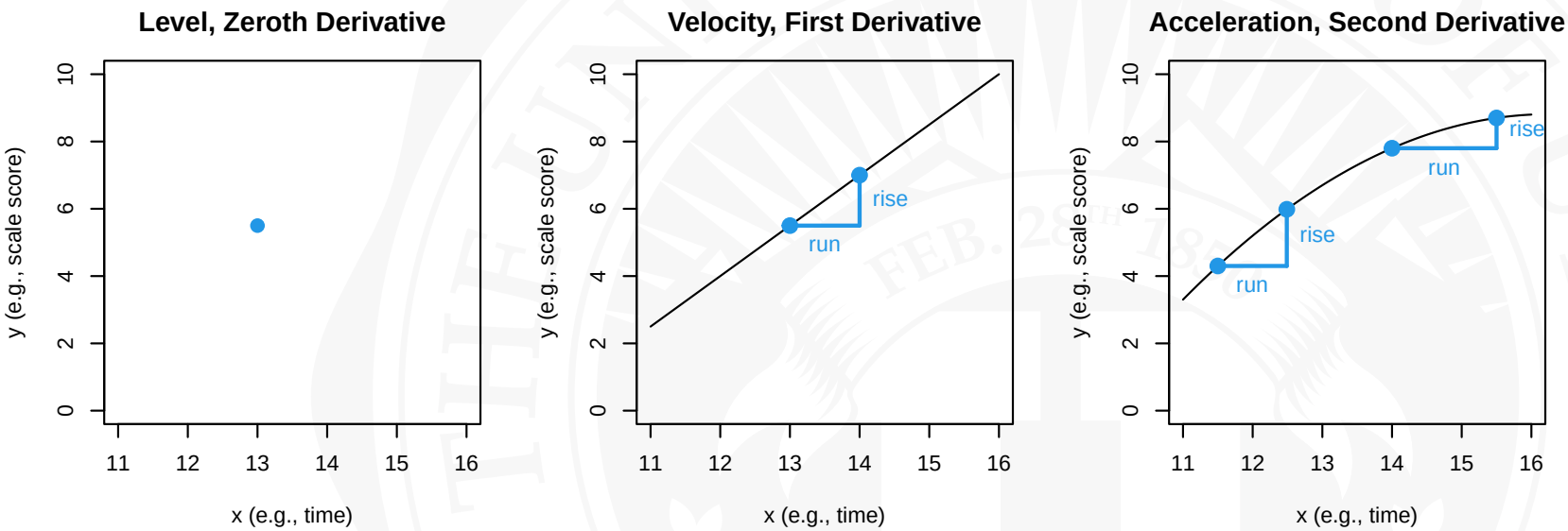
[2] Deboeck, P. R., Cole, D. A., Preacher, K. J., Forehand, R. & Compas, B. E. (2021). Modeling Dynamic Processes with Panel Data: An Application of Continuous Time Models to Prevention Research. International Journal of Behavioral Development, 45(1), 28–39.

Introduction

- Continuous Time Models and Prevention/Intervention Research[2]
- Open Systems: Dynamic/Process Errors change your model
- Dynamical Systems: Mean differences are not enough
- Substantive Example: What are the hallmark(s) of a successful intervention?

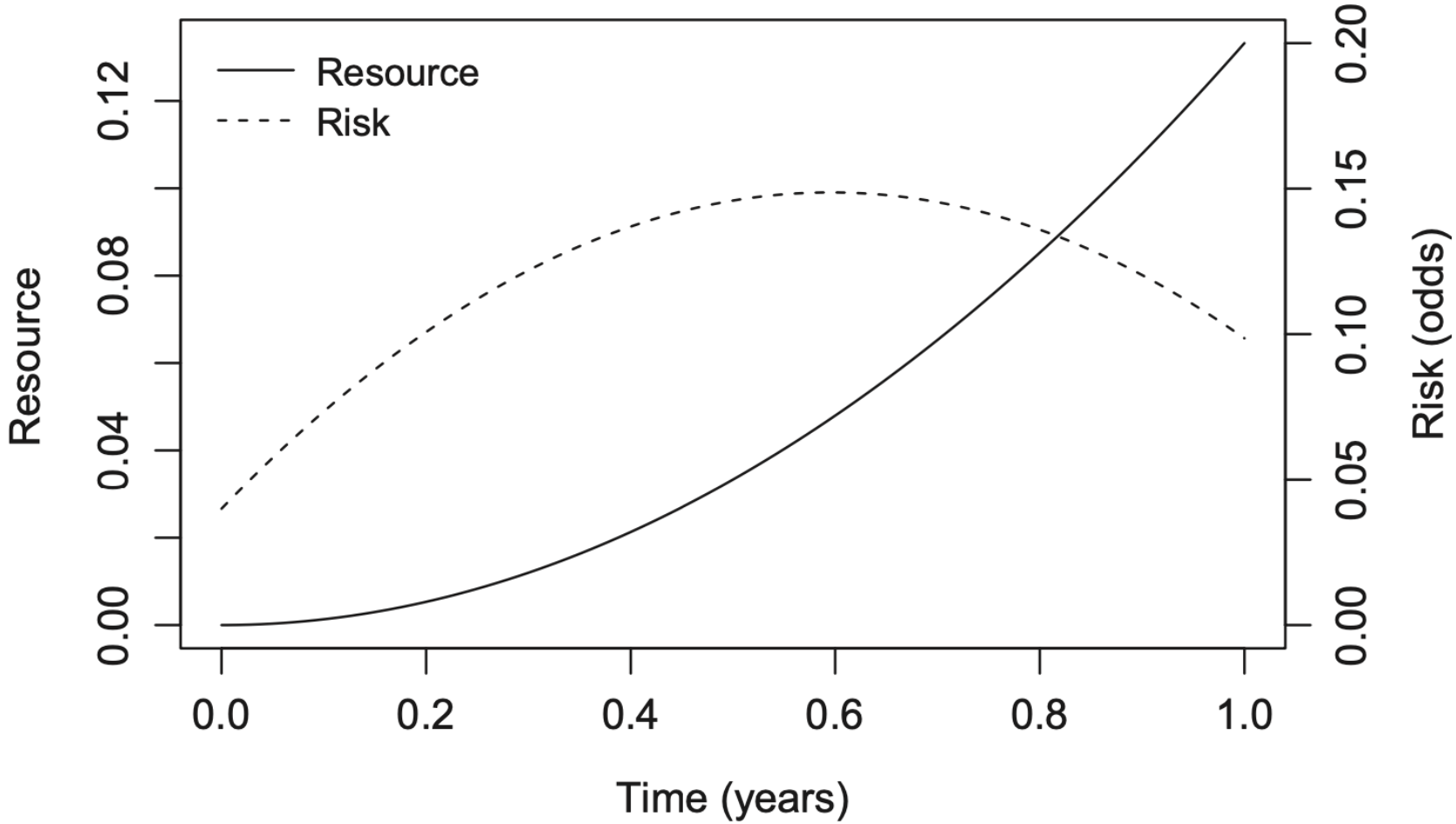
[2] Deboeck, P. R., Cole, D. A., Preacher, K. J., Forehand, R. & Compas, B. E. (2021). Modeling Dynamic Processes with Panel Data: An Application of Continuous Time Models to Prevention Research. International Journal of Behavioral Development, 45(1), 28–39.

Derivatives



- Relations between derivatives, Differential equations

Differential Equations Modeling



Open Systems

- Closed Systems, Open Systems

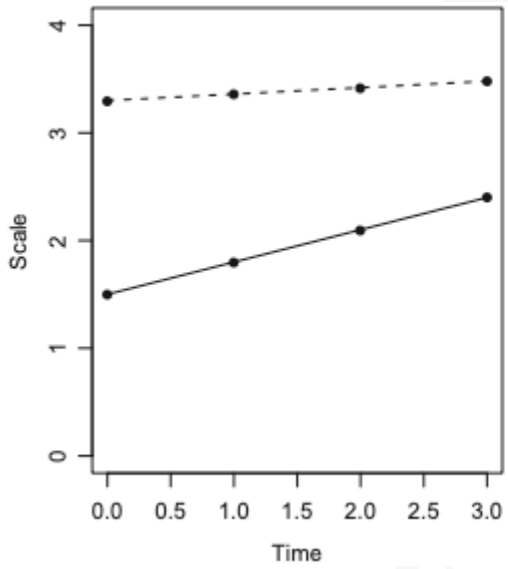
Open Systems

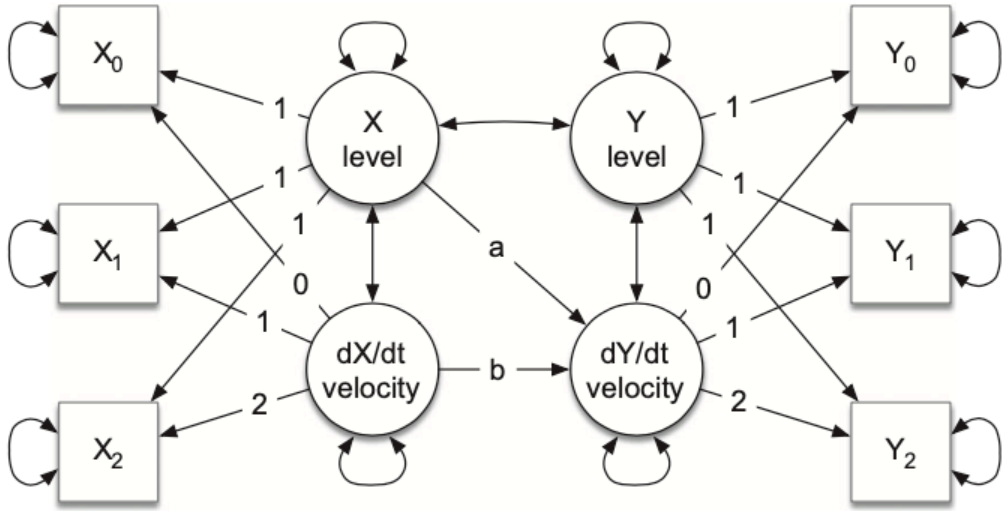
- Closed Systems, Open Systems
- Dynamic/Process Errors

Open Systems

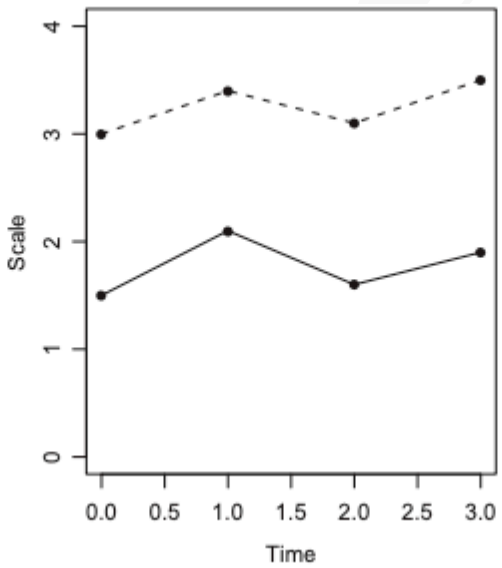
- Closed Systems, Open Systems
- Dynamic/Process Errors
- Continuum of models

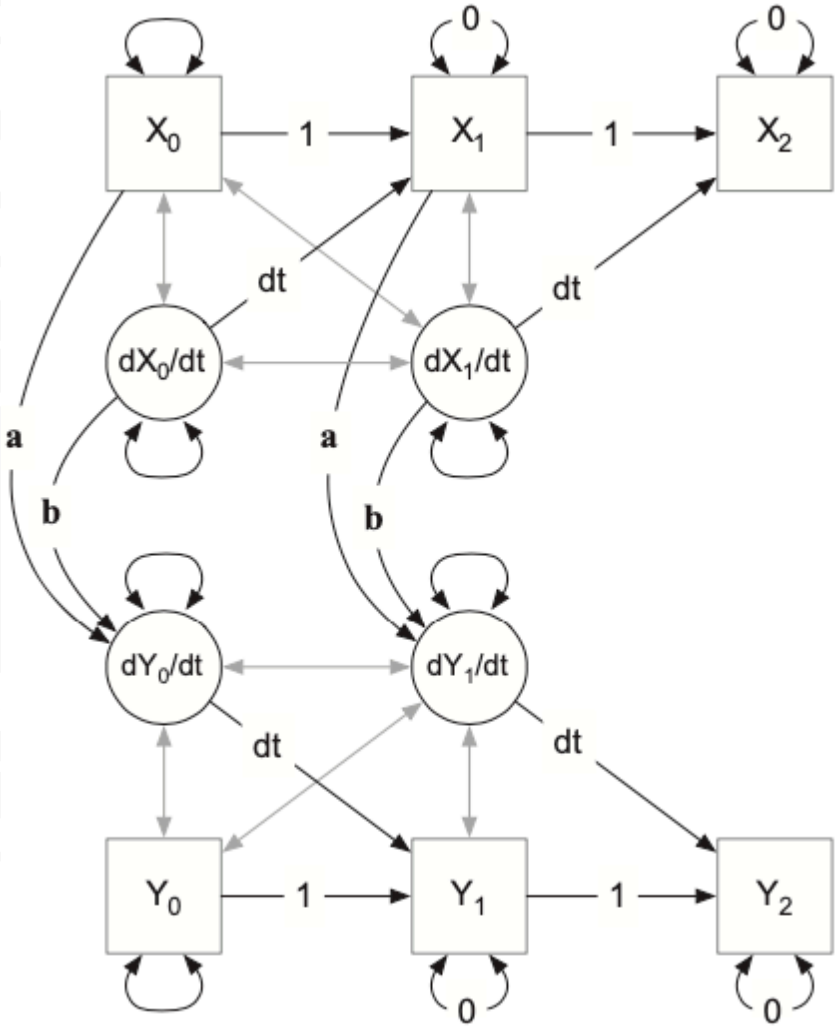
Small Dynamic Errors



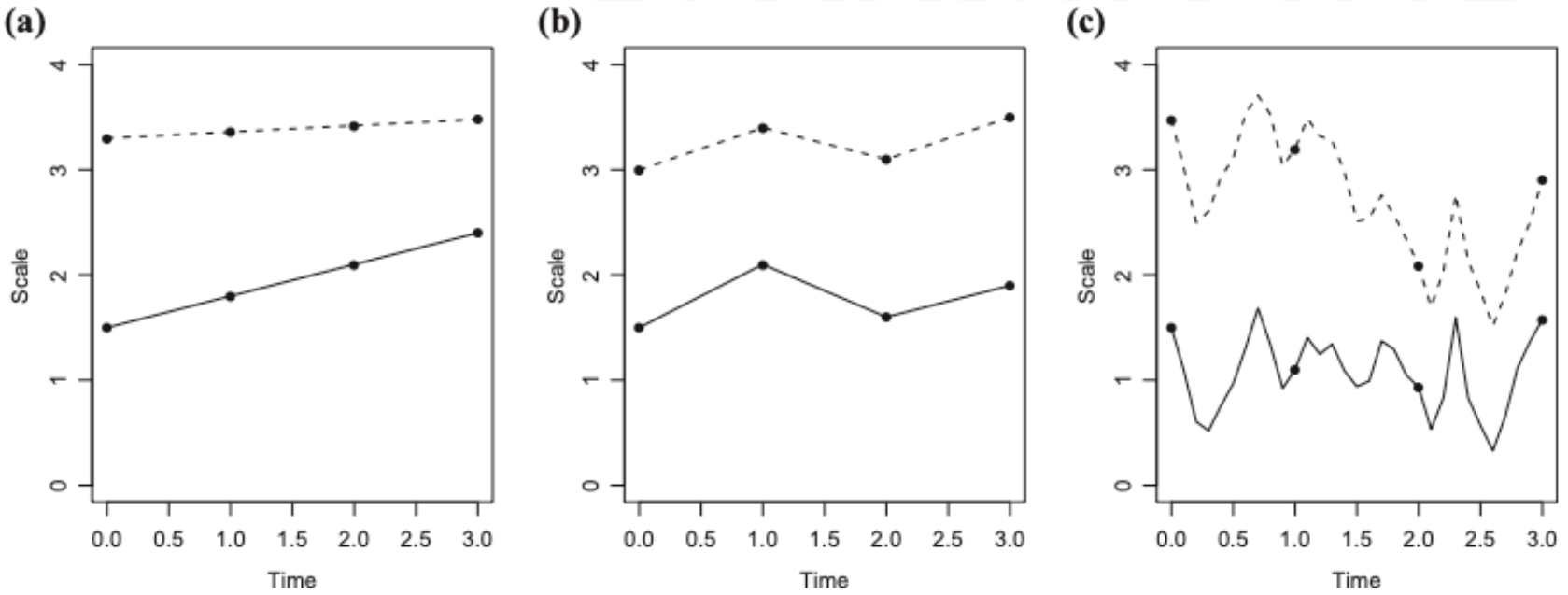


Moderate Dynamic Errors

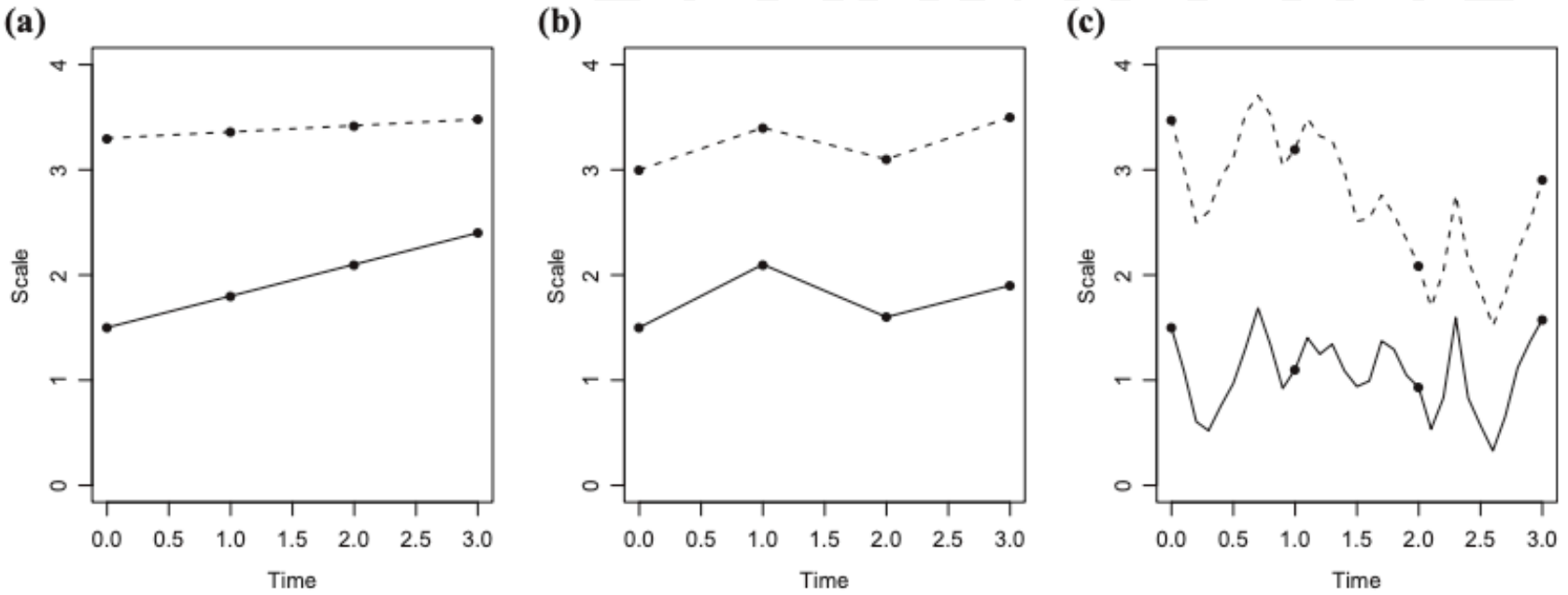




Frequent Dynamic Errors

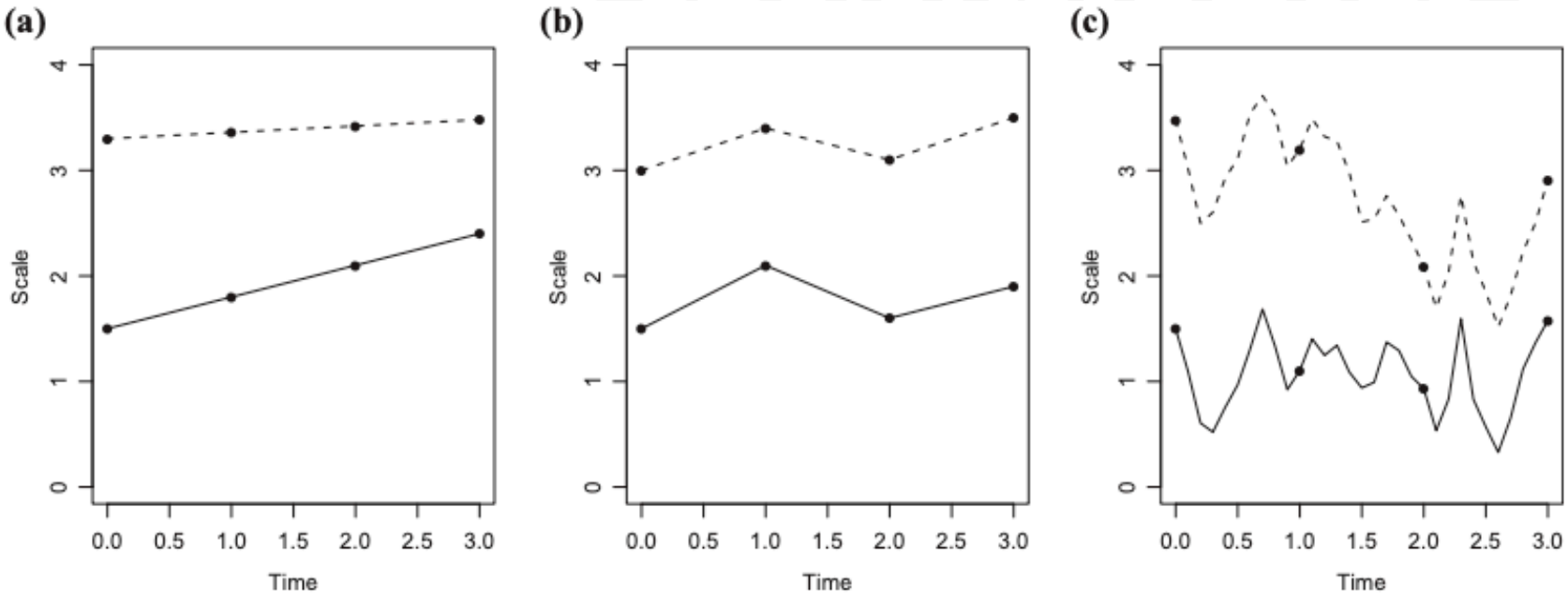


Frequent Dynamic Errors



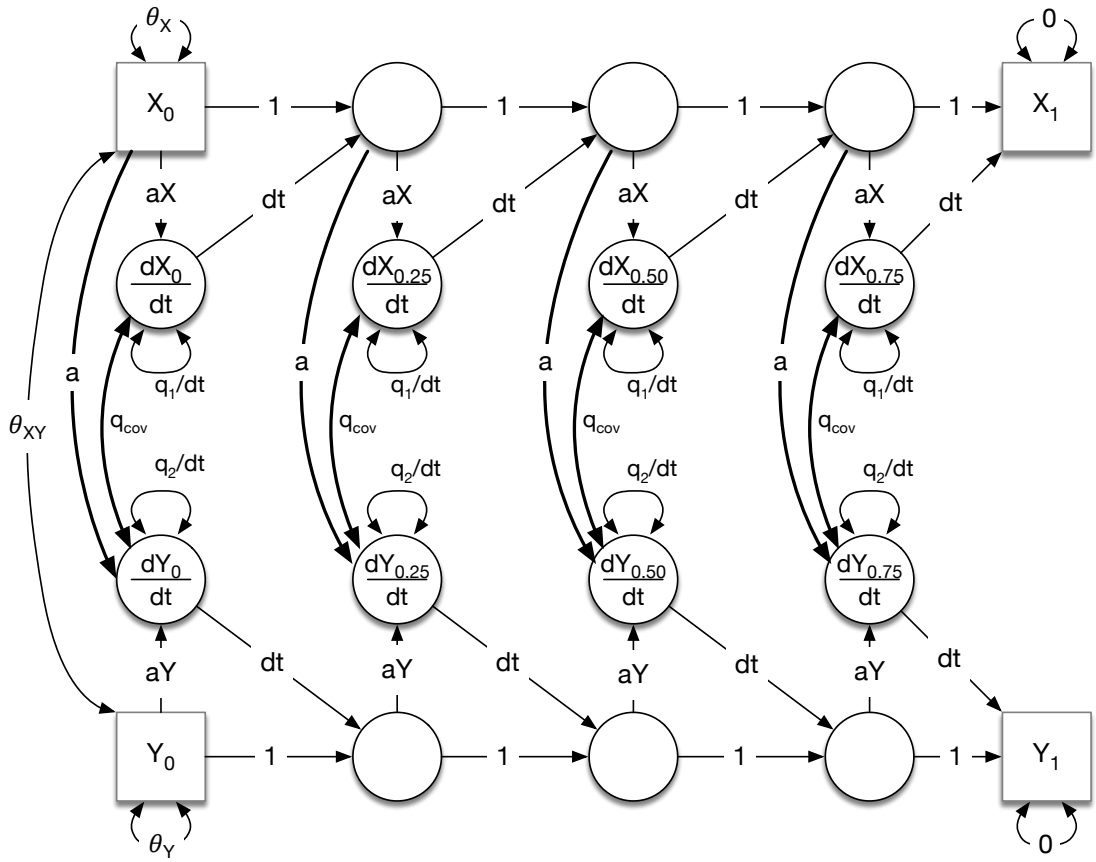
- Changes are frequent relative to sampling rate

Frequent Dynamic Errors

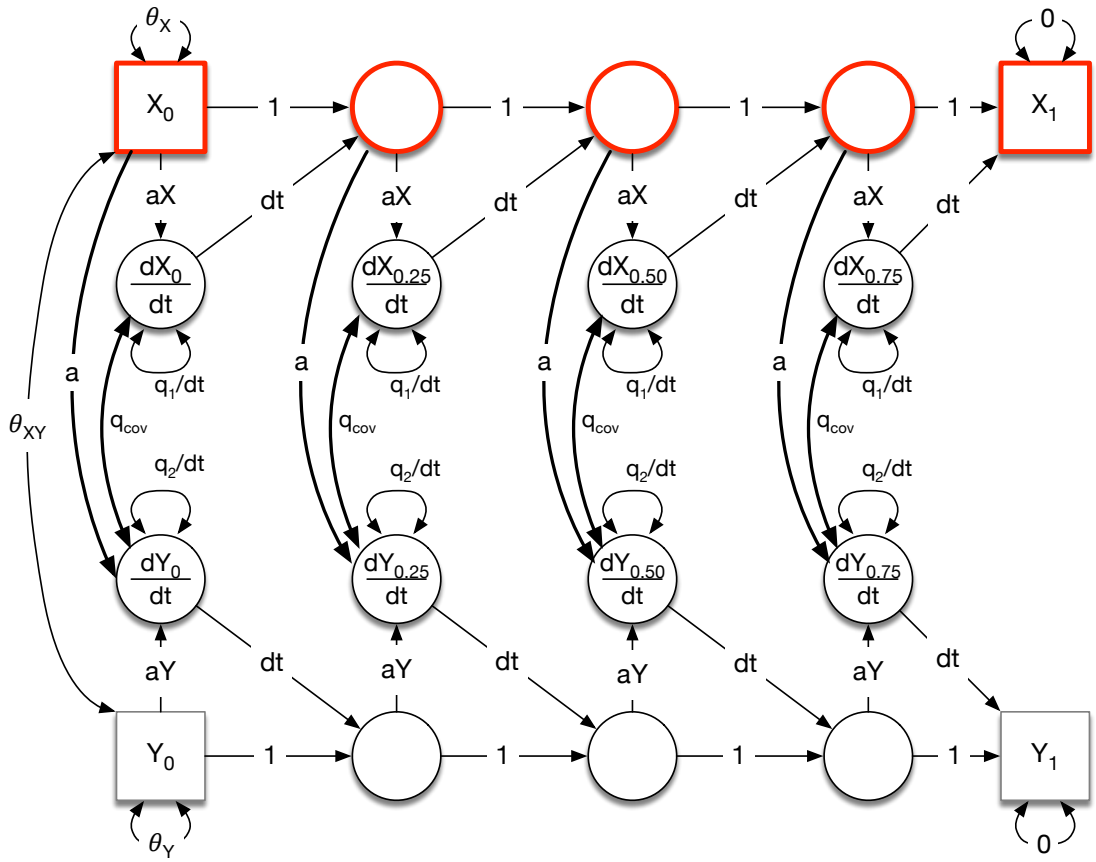


- Changes are frequent relative to sampling rate
- Ongoing interaction between constructs
- Stochastic Differential Equations

Stochastic Differential Equations

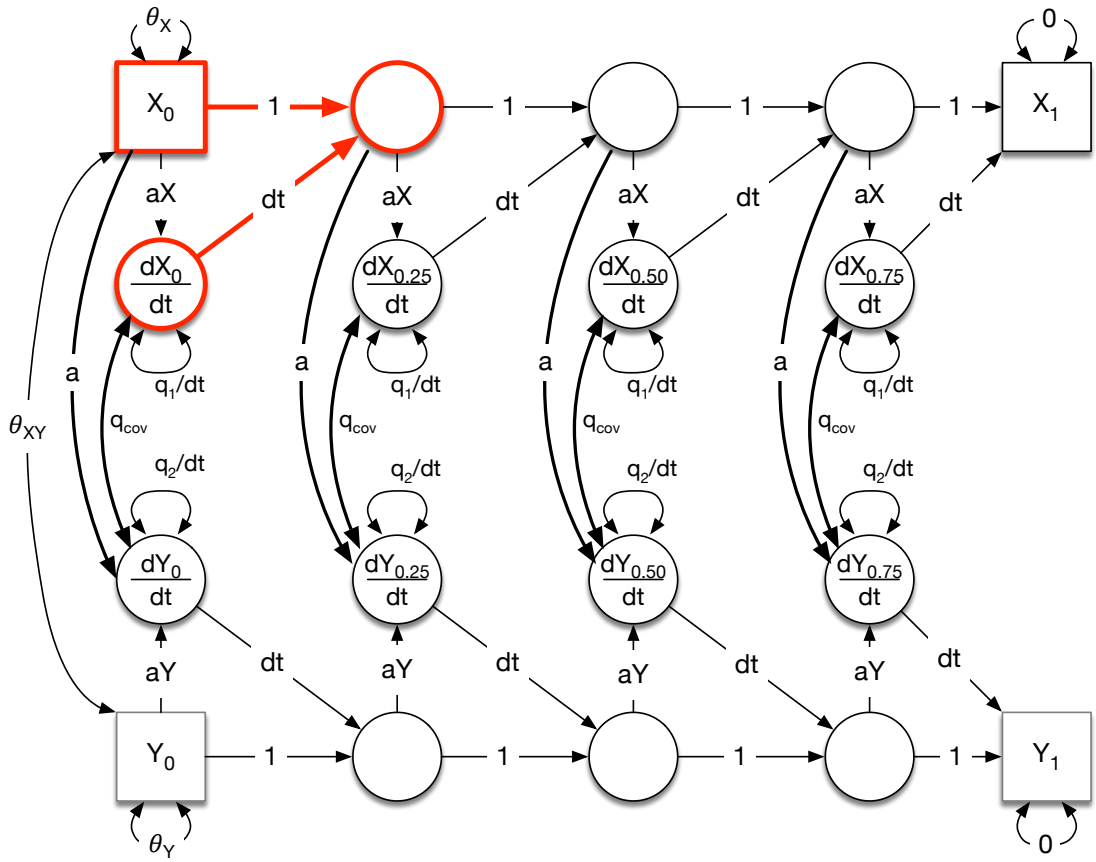


Stochastic Differential Equations



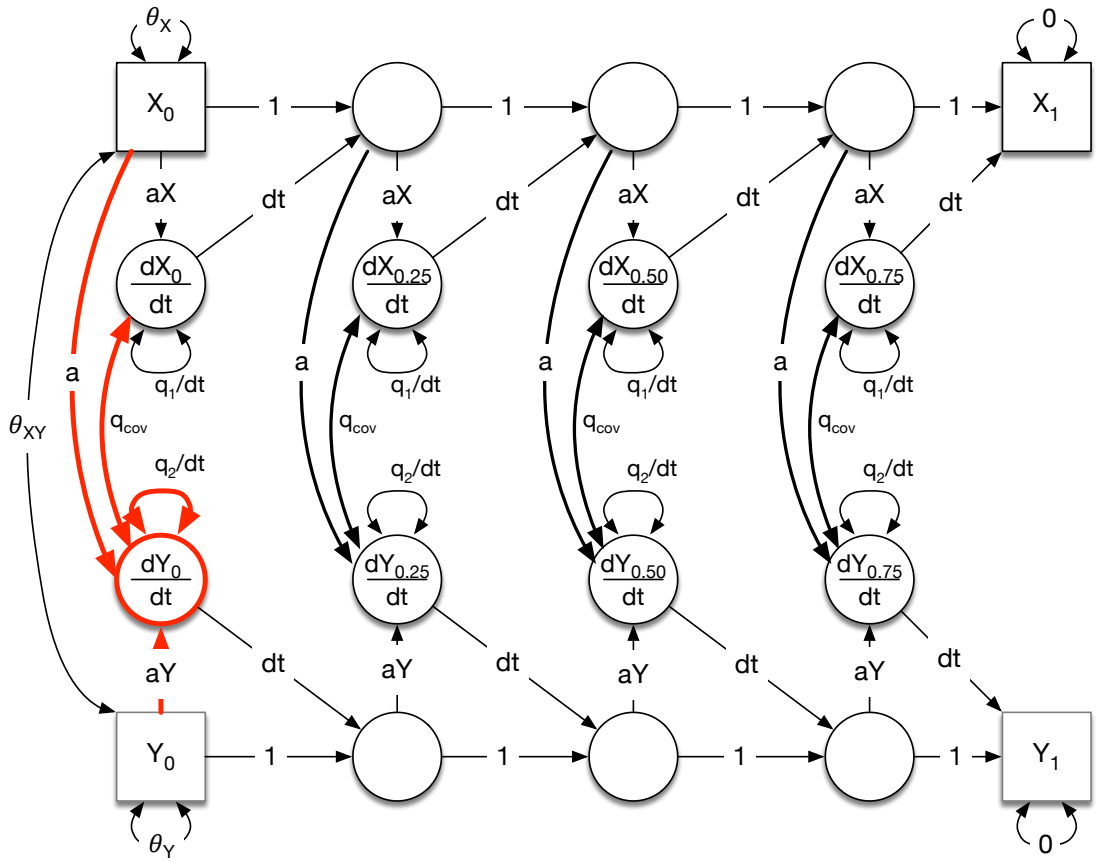
- Constructs exist between observed values

Stochastic Differential Equations



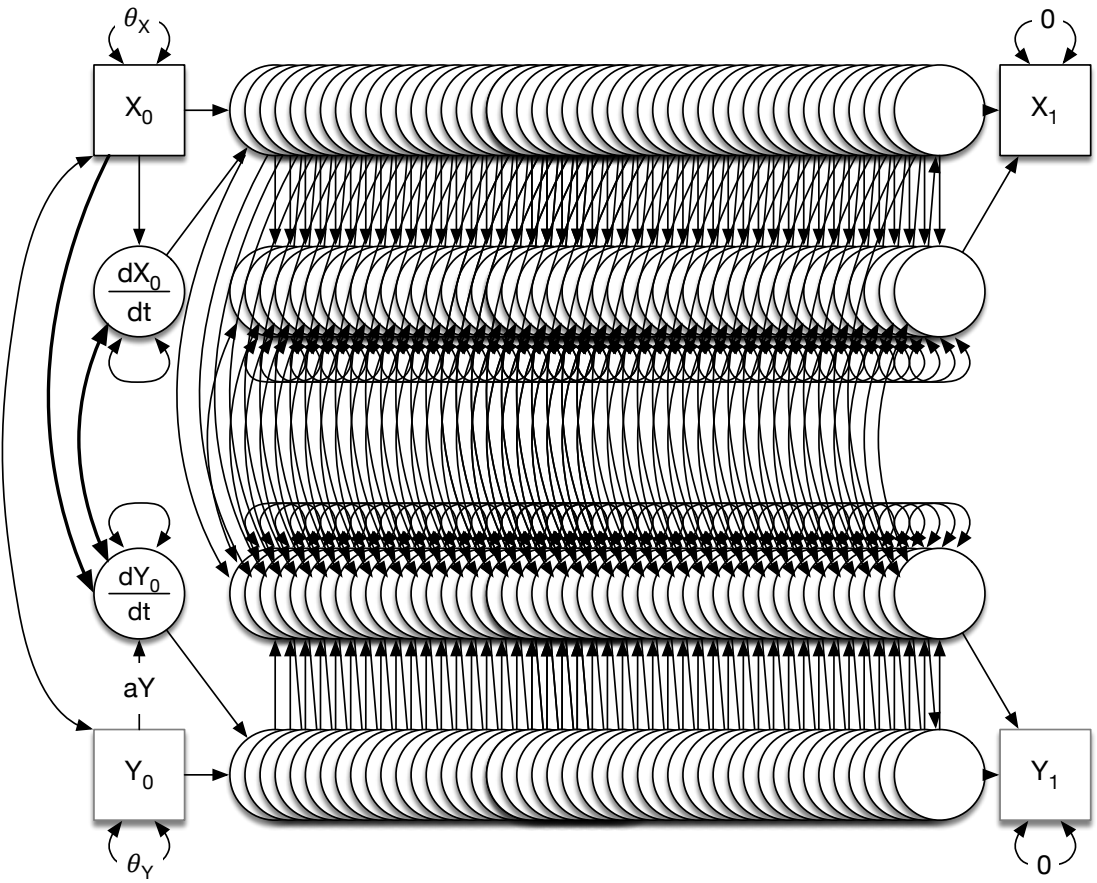
- Constructs exist between observed values
- Value is equal to the prior value plus change

Stochastic Differential Equations



- Constructs exist between observed values
- Value is equal to the prior value plus change
- Change is defined (stochastic perturbations, correlated change, differential equation modeling)

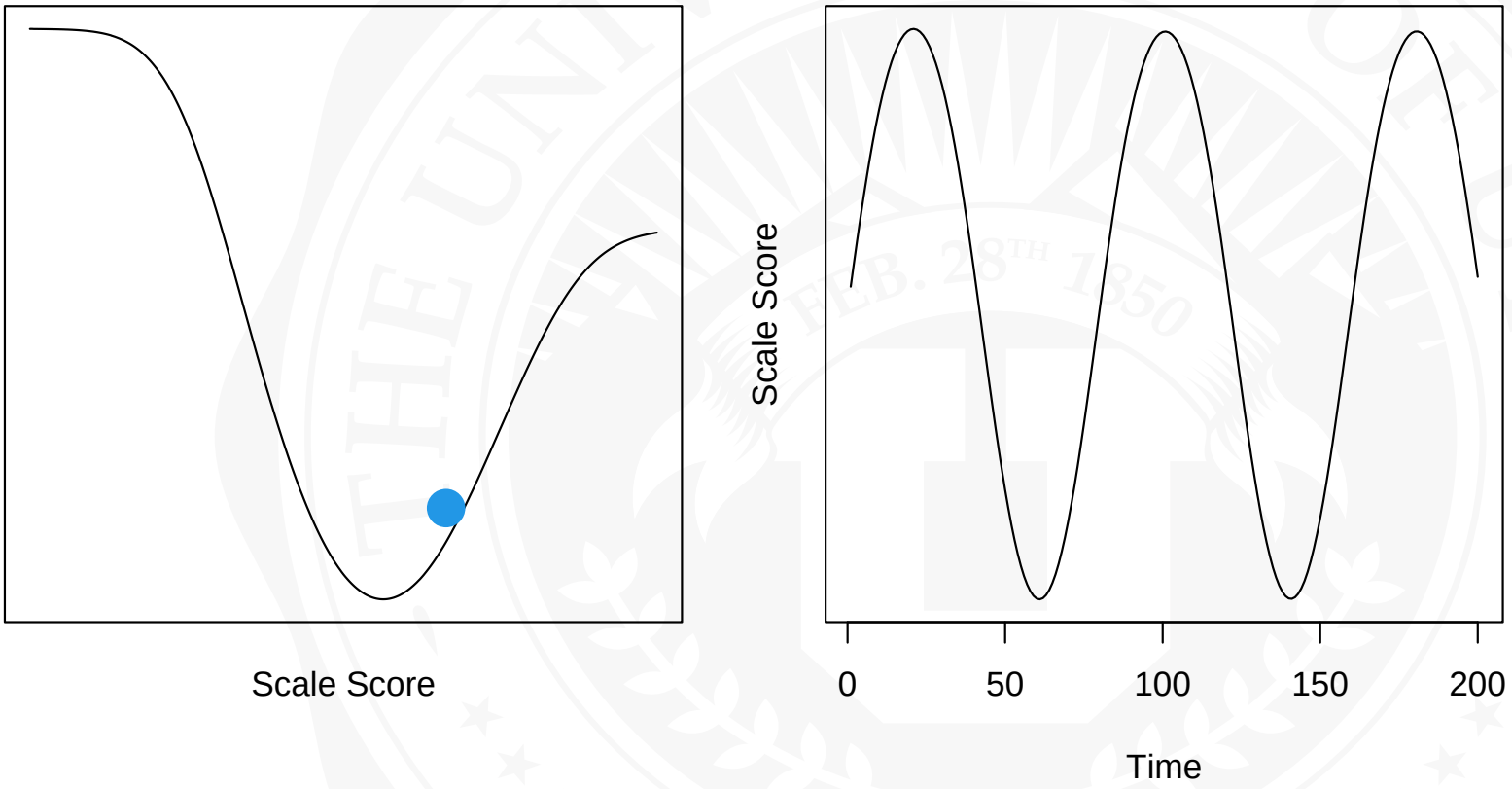
Stochastic Differential Equations



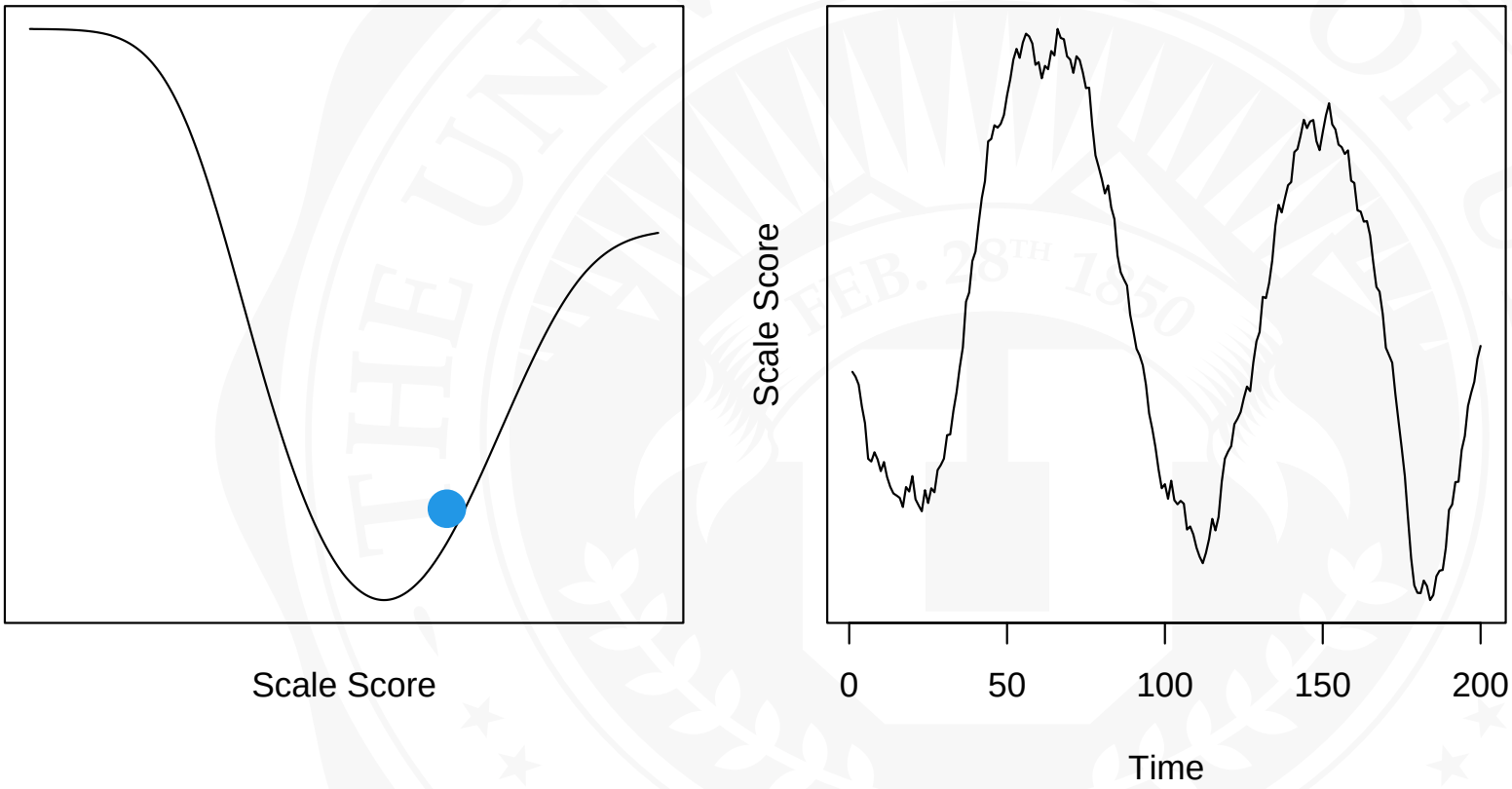
- Constructs exist between observed values
- Value is equal to the prior value plus change
- Change is defined (stochastic perturbations, correlated change, differential equation modeling)
- Number of intermediate latent occasions goes to infinity[a]

[a] InSDE; Deboeck & Boulton, 2016

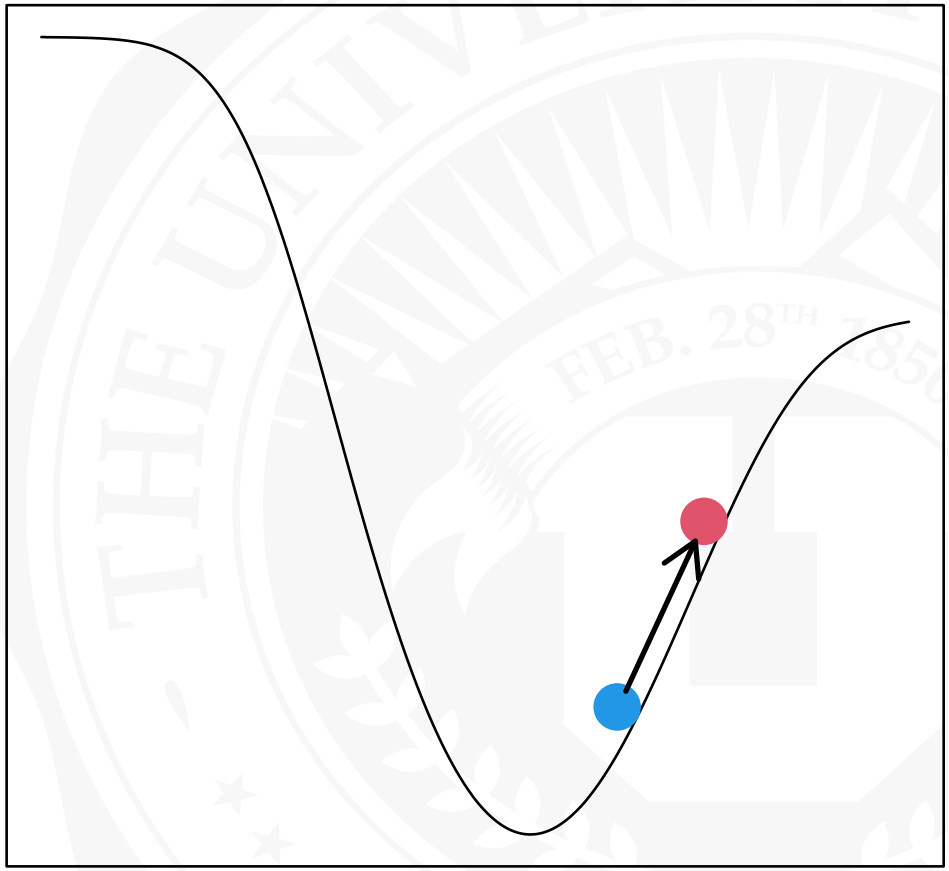
Attractor Dynamics



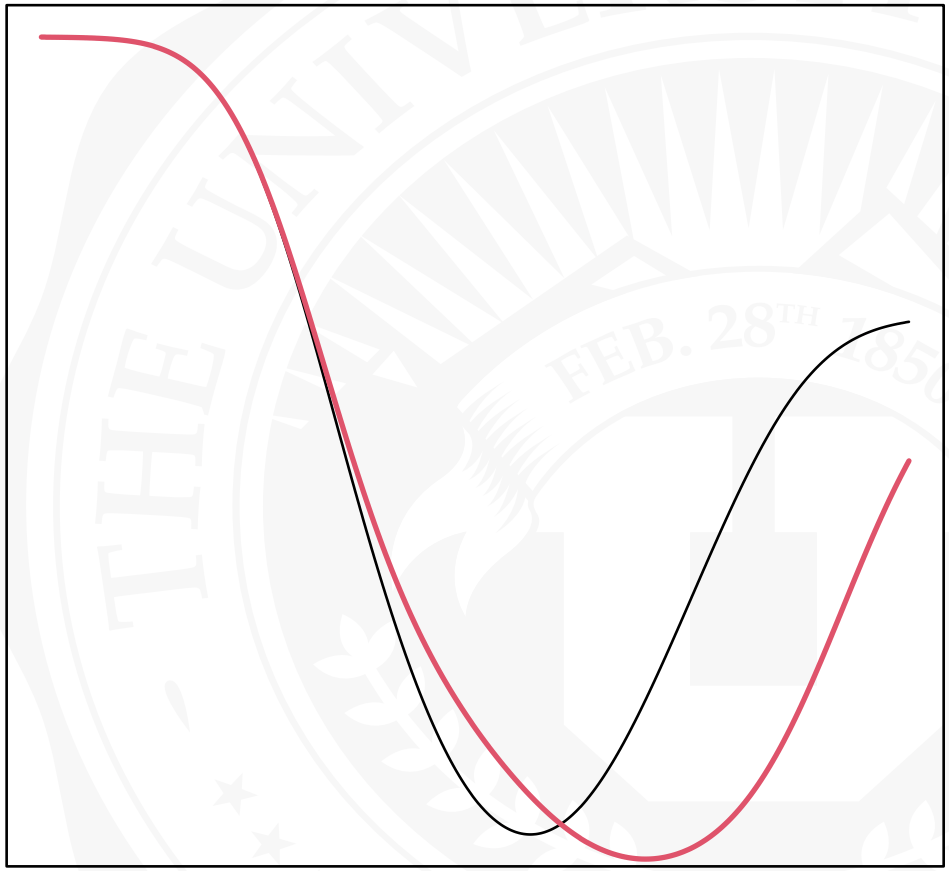
Attractor Dynamics



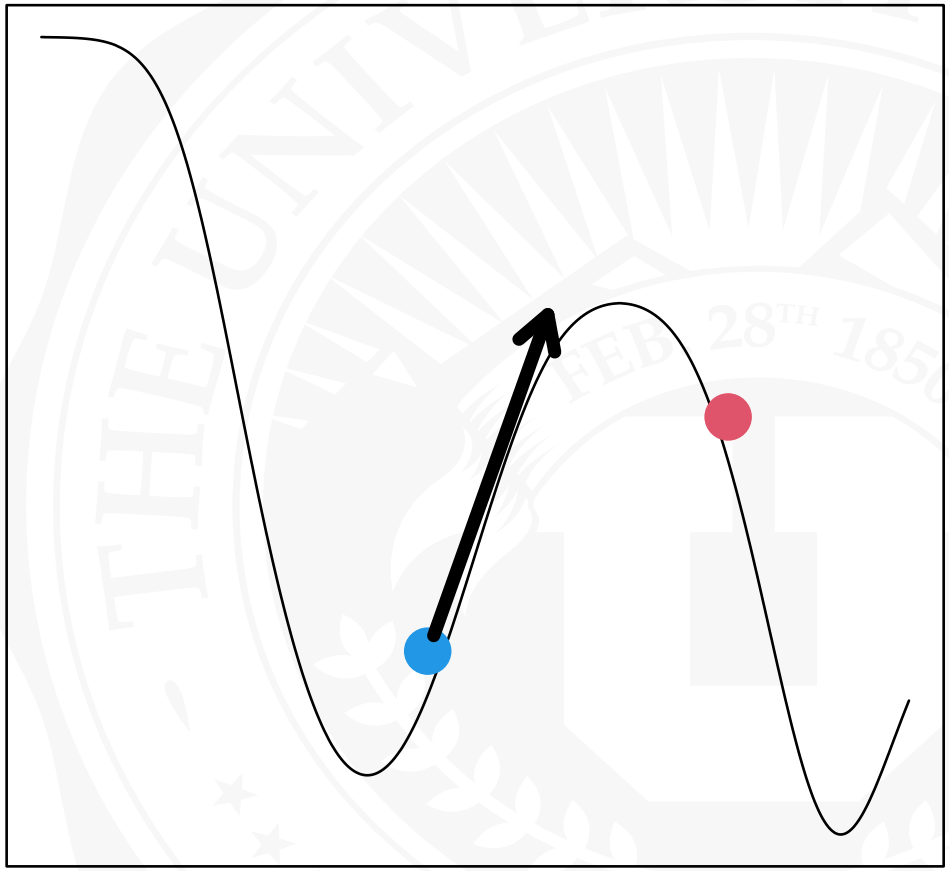
Producing A Change in Mean Score



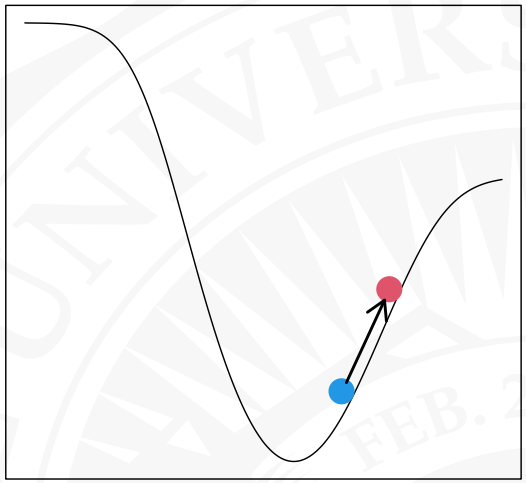
Producing A Change in Mean Score

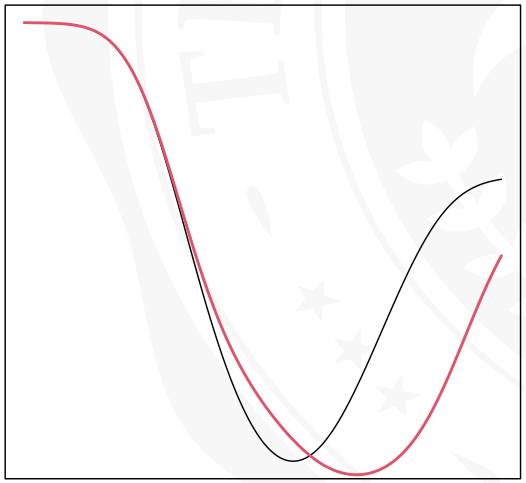


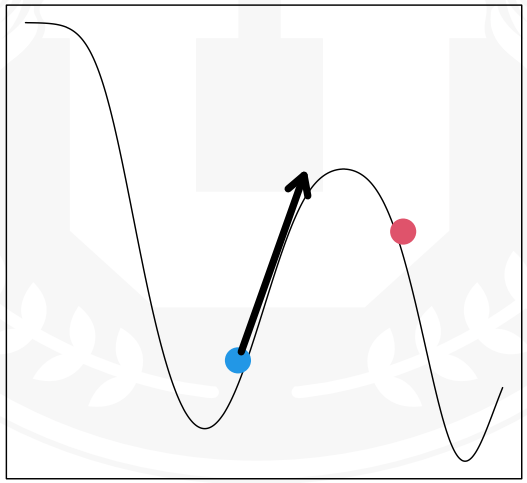
Producing A Change in Mean Score



What is the effect of an intervention?







Reading Intervention

- Frequent Dynamic Errors (SDEs)
- Changing/Different Attractors (Differential Equations)

[3] Compas, B. E. et al., 2009, 2010, 2011, 2015

Reading Intervention

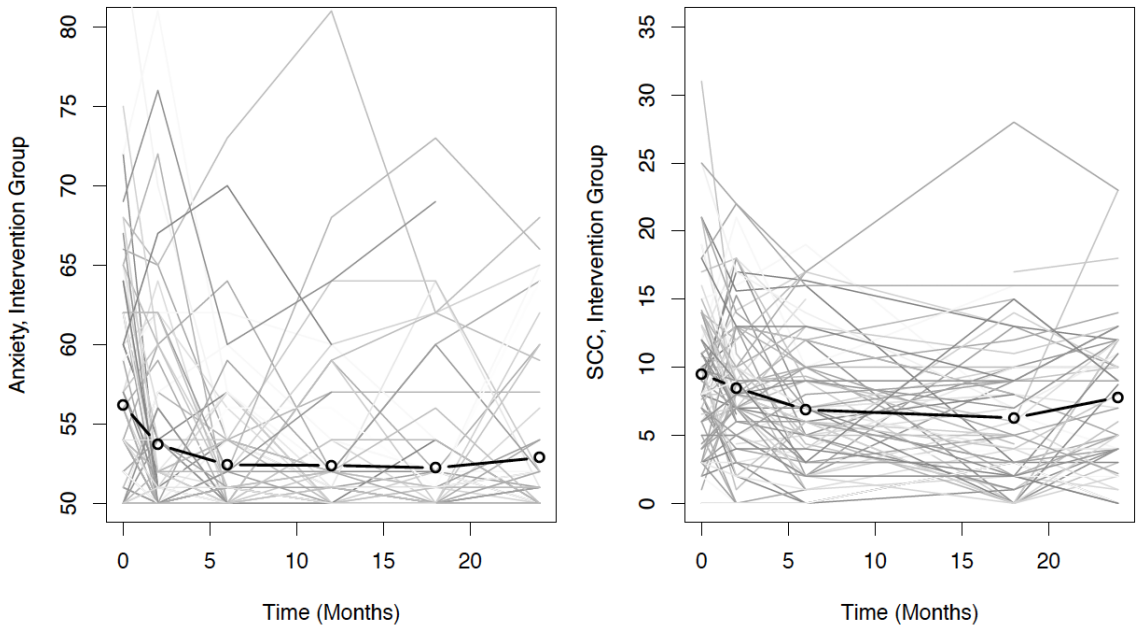
- Frequent Dynamic Errors (SDEs)
- Changing/Different Attractors (Differential Equations)

- Efficacy of a cognitive-behavioral preventive intervention for children of parents with a history of depression[3]
- Active intervention consisted of a 12-session program (8 weekly sessions, 4 month booster) teaching children skills to cope with stress related to their parents' depression
- $n = 122$ active intervention, $n = 120$ control group

[3] Compas, B. E. et al., 2009, 2010, 2011, 2015

Reading Intervention

- Data were collected at 6 times: baseline (before the intervention) and 2, 6, 12, 18 and 24 months after baseline.
- Children's reports of secondary control coping (SCC)[4], and anxiety/depression[5]



[4] Compas, Connor, Osowiecki, & Welch, 1997; Compas, Connor, Saltzman, Thomsen, & Wadsworth, 1999

[5] Achenbach, 1991

Random Intercept, Months 6 to 24

Random Intercept, Months 6 to 24

- Initially, a random-intercept model was fit separately for anxiety/depression (four observations, $n = 192$) and SCC (three observations, $n = 187$)

Random Intercept, Months 6 to 24

- Initially, a random-intercept model was fit separately for anxiety/depression (four observations, $n = 192$) and SCC (three observations, $n = 187$)
- The random intercept-only models fit the data relatively well and seem to be a reasonable approximation of the trajectories between 6 and 24 months ($CFI_{ANX} = .978, RMSEA_{ANX} = .062; CFI_{SCC} = .962, RMSEA_{SCC} = .079$)

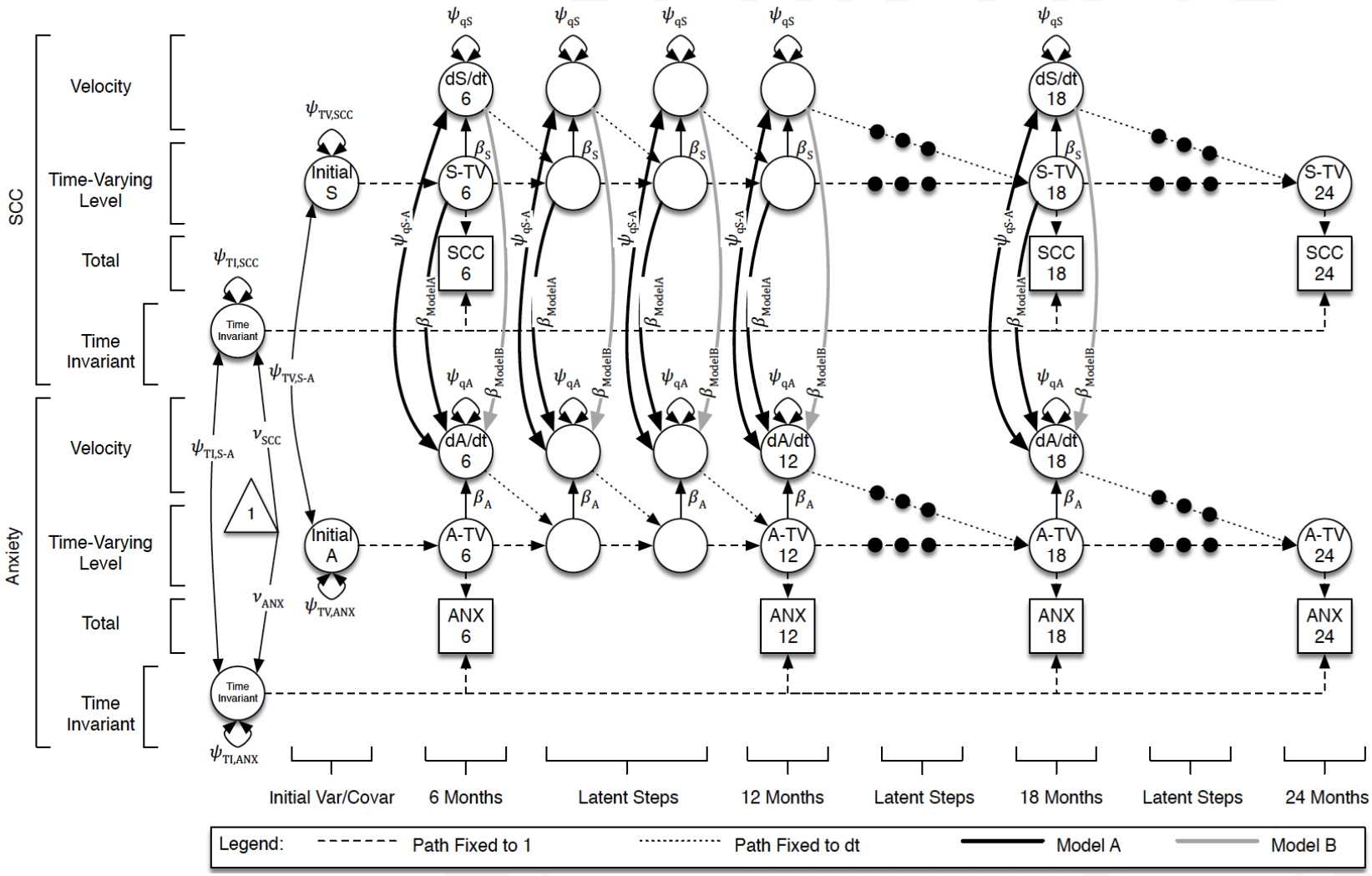
Random Intercept, Months 6 to 24

- Initially, a random-intercept model was fit separately for anxiety/depression (four observations, $n = 192$) and SCC (three observations, $n = 187$)
- The random intercept-only models fit the data relatively well and seem to be a reasonable approximation of the trajectories between 6 and 24 months ($CFI_{ANX} = .978, RMSEA_{ANX} = .062; CFI_{SCC} = .962, RMSEA_{SCC} = .079$)
- The random intercepts capture the steady-state, time-invariant differences between individuals
- Does not describe how individuals vary around their individual intercepts

Random Intercept, Months 6 to 24

- Initially, a random-intercept model was fit separately for anxiety/depression (four observations, $n = 192$) and SCC (three observations, $n = 187$)
- The random intercept-only models fit the data relatively well and seem to be a reasonable approximation of the trajectories between 6 and 24 months ($CFI_{ANX} = .978, RMSEA_{ANX} = .062; CFI_{SCC} = .962, RMSEA_{SCC} = .079$)
- The random intercepts capture the steady-state, time-invariant differences between individuals
- Does not describe how individuals vary around their individual intercepts
- Random mean model, SDE, two-group SEM

Substantive Models



Results

- AIC/BIC did not show a clear preference for one model over the other
- Random mean anxiety/depression lower in intervention group, and less variance (both models)

Results

Parameter	Model A (level–velocity) Readings	Group Diff	S.E. Diff	*p* Value
Random effects (time-invariant)				
Mean anxiety/depression (ν_{ANX})	55.50	−2.82	0.78	.000
Mean SCC (ν_{SCC})	7.84	−0.89	0.71	.208
Variance anxiety/depression ($\psi_{TI,ANX}$)	33.08	−22.29	7.60	.003
Variance SCC ($\psi_{TI,SCC}$)	20.30	−10.85	6.58	.099
Covariance anxiety, SCC ($\psi_{TI,S\text{-}A}$)	14.96	−8.86	5.11	.083
TV initial covariance				
Variance anxiety/depression ($\psi_{TV,ANX}$)	15.39	−5.50	5.59	.326
Variance SCC ($\psi_{TV,SCC}$)	−0.09	1.89	3.95	.632
Covariance anxiety/depression, SCC ($\psi_{TV,S\text{-}A}$)	12.54	4.59	6.54	.483
Derivative relations				
Anxiety/depression level–velocity (β_A)	−1.43	0.60	0.63	.342
SCC level–velocity (β_S)	−1.69	1.03	0.89	.244
SCC level to anxiety/depression velocity (β_{ModelA})	−0.82	1.17	0.90	.195
SCC velocity to anxiety/depression velocity (β_{ModelB})	—	—	—	—
Stochastic perturbations				
Variance anxiety/depression (ψ_{qA})	78.02	−53.55	3.22	.021
Variance SCC (ψ_{qS})	39.59	−10.36	7.34	.550
Covariance anxiety/depression, SCC ($\psi_{qS\text{-}A}$)	36.12	−31.39	5.35	.041

Results

Parameter	Model B (velocity–velocity) Readings	Group Diff	S.E. Diff	*p* Value
Random effects (time-invariant)				
Mean anxiety/depression (ν_{ANX})	55.49	−2.83	0.79	.000
Mean SCC (ν_{SCC})	7.80	−0.79	0.71	.267
Variance anxiety/depression ($\psi_{TI,ANX}$)	33.32	−22.88	8.15	.005
Variance SCC ($\psi_{TI,SCC}$)	20.94	−8.29	6.56	.206
Covariance anxiety, SCC ($\psi_{TI,S\text{-}A}$)	14.93	−5.64	4.83	.243
TV initial covariance				
Variance anxiety/depression ($\psi_{TV,ANX}$)	25.30	−12.68	9.17	.166
Variance SCC ($\psi_{TV,SCC}$)	−11.50	9.09	6.26	.146
Covariance anxiety/depression, SCC ($\psi_{TV,S\text{-}A}$)	13.03	2.40	5.22	.646
Derivative relations				
Anxiety/depression level–velocity (β_A)	−1.55	0.84	0.69	.225
SCC level–velocity (β_S)	−9.30	8.27	19.45	.671
SCC level to anxiety/depression velocity (β_{ModelA})	—	—	—	—
SCC velocity to anxiety/depression velocity (β_{ModelB})	0.90	−0.72	0.28	.010
Stochastic perturbations				
Variance anxiety/depression (ψ_{qA})	45.29	−21.75	15.29	.155
Variance SCC (ψ_{qS})	182.52	−147.28	356.9	.680
Covariance anxiety/depression, SCC ($\psi_{qS\text{-}A}$)	—	—	—	—

Conclusions

- Open Systems: Dynamic/Process Errors change your model
  - Continuum of models (LGCM, LCS, SDE)
  - Frequent dynamic errors and ongoing interactions: SDEs

Conclusions

- Open Systems: Dynamic/Process Errors change your model
  - Continuum of models (LGCM, LCS, SDE)
  - Frequent dynamic errors and ongoing interactions: SDEs
- Dynamical Systems: Mean Differences are not enough
  - Attractor Dynamics, Changes in Means, Differential Equations

Conclusions

- Open Systems: Dynamic/Process Errors change your model
  - Continuum of models (LGCM, LCS, SDE)
  - Frequent dynamic errors and ongoing interactions: SDEs
- Dynamical Systems: Mean Differences are not enough
  - Attractor Dynamics, Changes in Means, Differential Equations
- Substantive Example: What are the hallmark(s) of a successful intervention?
  - Standard 2-group intervention, few post-intervention observations
  - Different underlying dynamic processes with limited data

Conclusions

- Open Systems: Dynamic/Process Errors change your model
  - Continuum of models (LGCM, LCS, SDE)
  - Frequent dynamic errors and ongoing interactions: SDEs
- Dynamical Systems: Mean Differences are not enough
  - Attractor Dynamics, Changes in Means, Differential Equations
- Substantive Example: What are the hallmark(s) of a successful intervention?
  - Standard 2-group intervention, few post-intervention observations
  - Different underlying dynamic processes with limited data
  - Intervention may have affected more than the mean and variance of individual means
  - Relations within constructs, stochastic perturbations, different coupled relations between variables

- Paper: Deboeck, P. R., Cole, D. A., Preacher, K. J., Forehand, R. & Compas, B. E. (2021). Modeling Dynamic Processes with Panel Data: An Application of Continuous Time Models to Prevention Research. International Journal of Behavioral Development, 45(1), 28–39.

- Derivatives Language: Deboeck, P. R., Nicholson, J. S., Kouros, C., Little, T. D., & Garber, J. (2015). Integrating developmental theory and methodology: Using derivatives to articulate change theories, models, and inferences. Applied Developmental Science, 19, 217–231.
- SDEs: Deboeck, P. R., & Boulton, A. J. (2016). Integration of stochastic differential equations using structural equation modeling: A method to facilitate model fitting and pedagogy. Structural Equation Modeling, 23, 888–903.