

Modeling Psychopathology: From Data Models to Formal Theories

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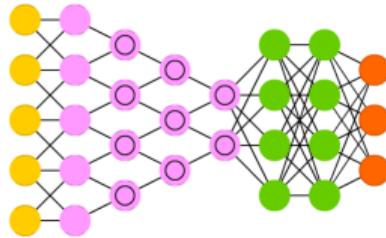
Psychology has a theory problem

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Statistics



Deep Convolutional Network (DCN)



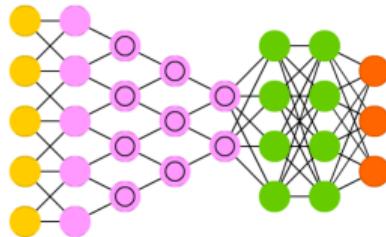
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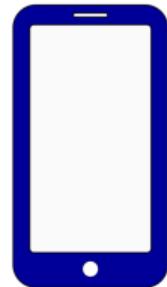


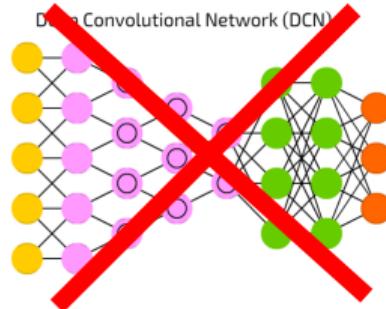
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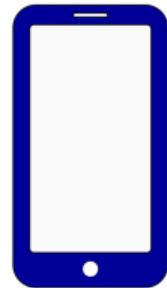
Statistics

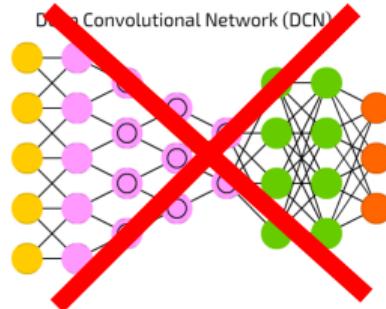




Psychology has a theory problem

Statistics

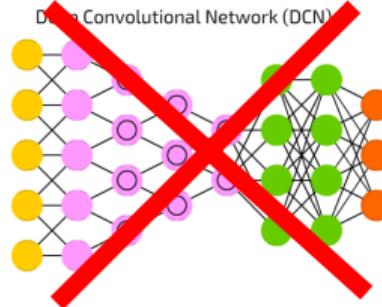




Psychology has a theory problem

Statistics





Psychology has a theory problem



Statistics



Theory  Statistics

“Theories in “soft” areas of psychology lack the cumulative character of scientific knowledge. They tend neither to be refuted nor corroborated, but instead merely fade away as people lose interest [...] the excessive reliance on significance testing is partly responsible, being a poor way of doing science [...]”

“[...] we must carefully distinguish substantive theory from statistical hypothesis. There is a tendency in the social sciences to conflate these in talking about our inferences.”

- Paul E. Meehl (1978)

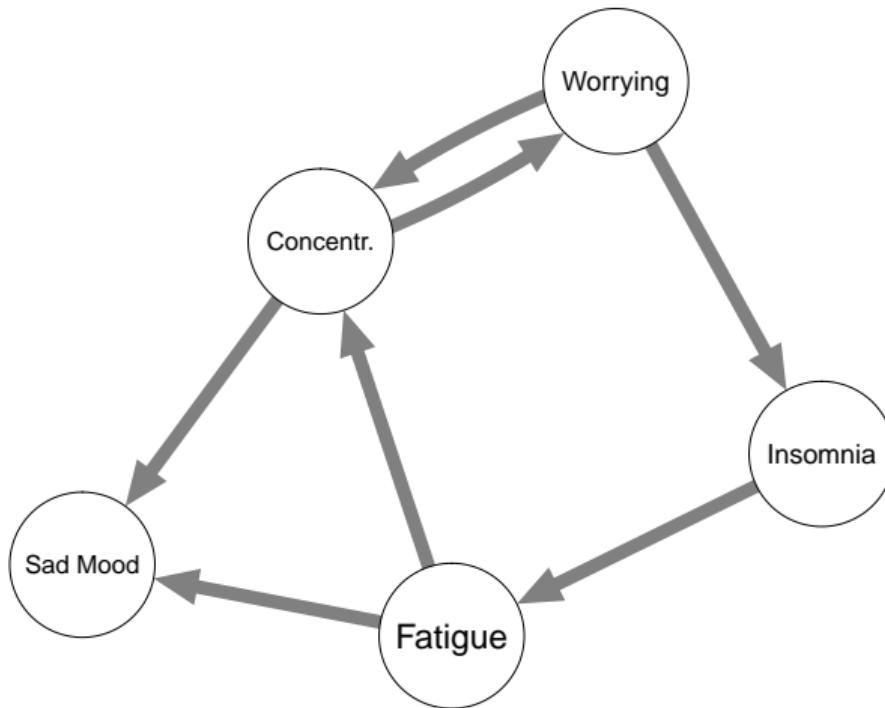
Formalizing theory as mathematical or computational models

- ▶ Forces us to be explicit and specific about our theoretical expectations
- ▶ Allows a common basis on which to build a cumulative body of theory
- ▶ Clarifies the role of statistical modeling in supporting theory development

I'm going to walk you through these ideas in the context of **clinical psychology**

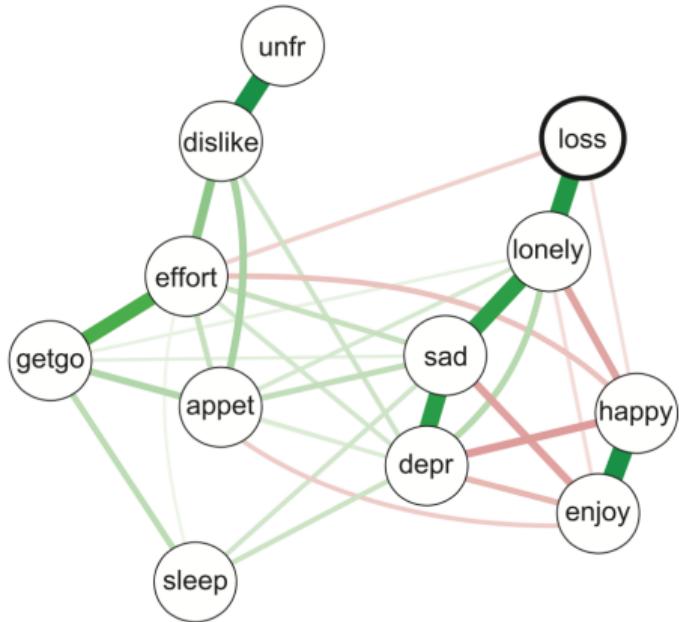
(Haslbeck*, Ryan*, Robinaugh*, et al., 2021; Oberauer & Lewandowsky 2019; Smaldino 2017; Borsboom et al. 2020; Guest & Martin 2020; van Rooij & Baggio 2020; Fried 2020)

Network Approach to Psychopathology



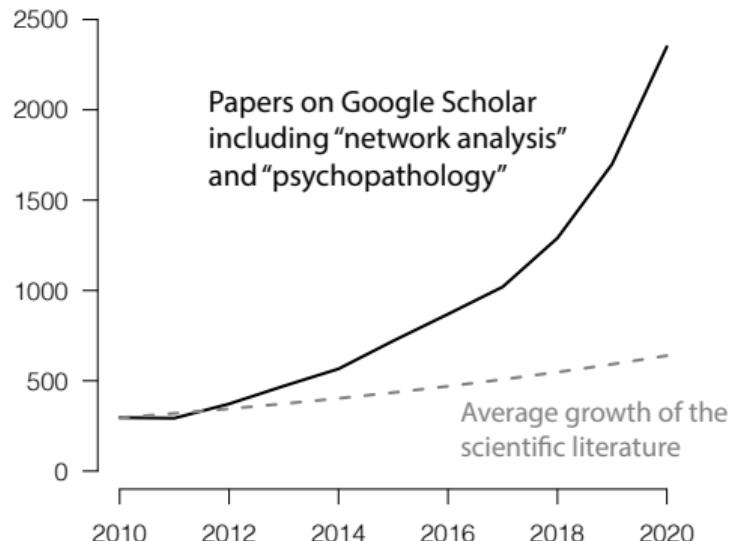
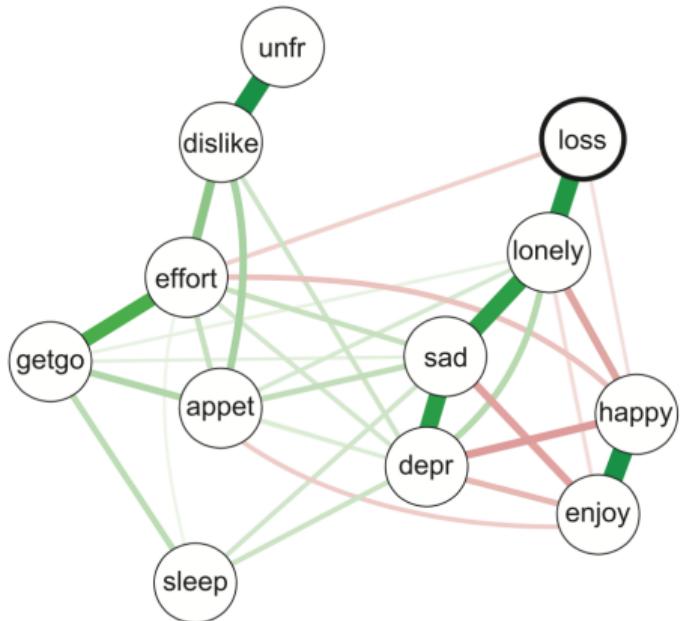
(Cramer et al, 2010; Borsboom et al. 2013; Schmittman et al, 2013; Borsboom, 2017)

Statistical Network Analysis



(Figure from Fried et al., 2015)

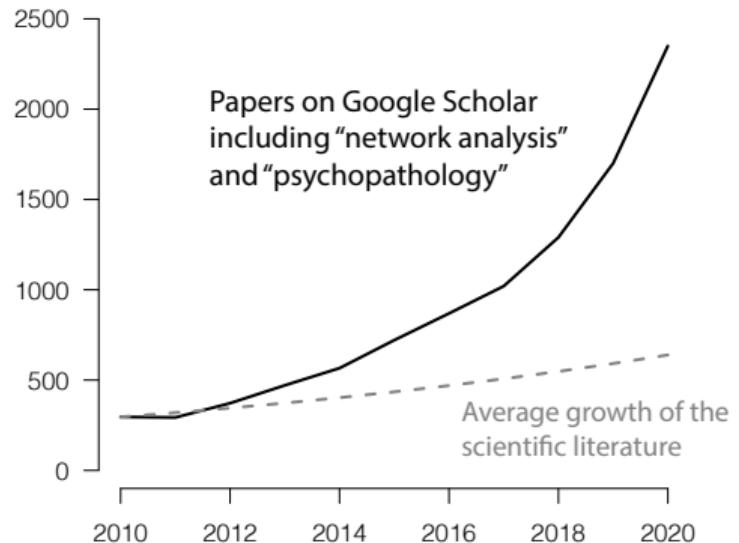
Statistical Network Analysis



(Figure from Fried et al., 2015)

Statistical Network Analysis

Theories?



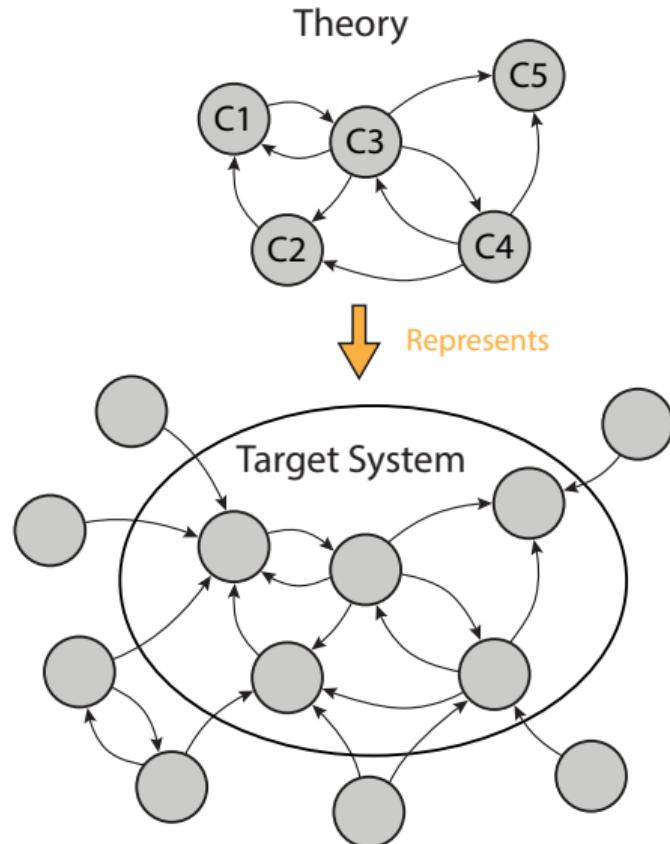
What are theories?

Theories explain *phenomena*: Stable features of the real world

Target System: The parts of the real world that give rise to the phenomena

Theories allow for *surrogate reasoning*

- ▶ Explanation, prediction and control



Verbal and Formal Theories

Verbal and Formal Theories

The rate of change in an object's temperature is proportional to the difference between its temperature and the temperature of the environment

$$\frac{dT}{dt} = -k(T - E)$$

Verbal Theory

If a stimulus “is perceived as a threat, a state of mild apprehension results. This state is accompanied by a wide range of bodily sensations. If these anxiety-produced sensations are interpreted in a catastrophic fashion, a further increase in apprehension occurs. This produces a further increase in body sensations and so on round in a vicious circle which culminates in a panic attack.”

- Clark, 1986, p. 462-463

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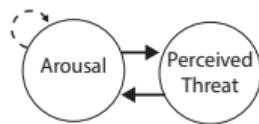
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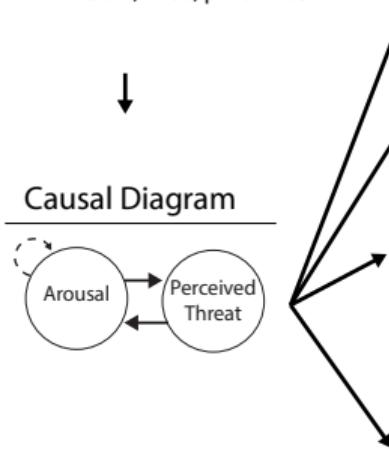
Causal Diagram



Verbal Theory

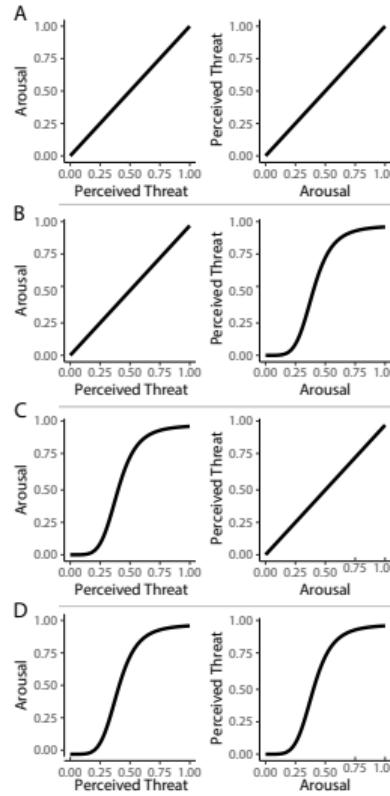
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Formal Theory

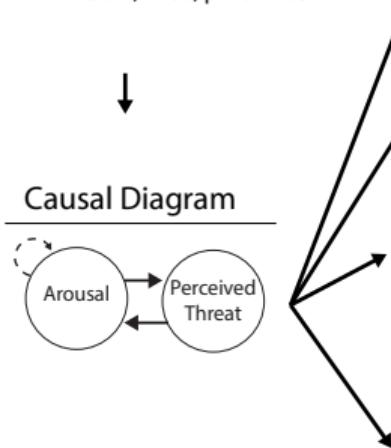
Effect of Perceived Threat on Arousal Effect of Arousal on Perceived Threat



Verbal Theory

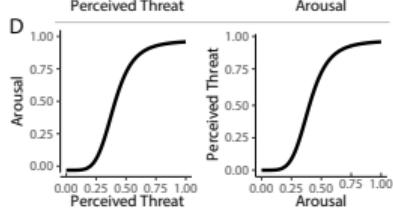
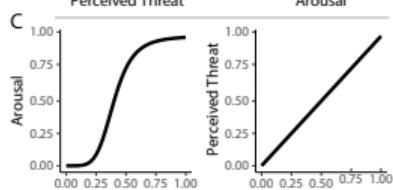
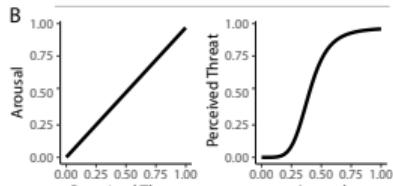
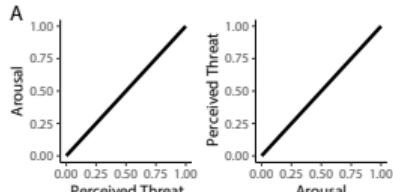
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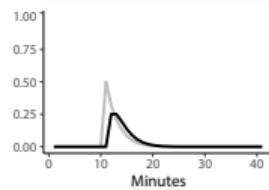
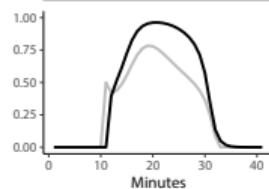
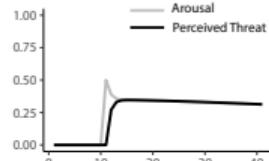
Formal Theory

Effect of Perceived Threat on Arousal Effect of Arousal on Perceived Threat

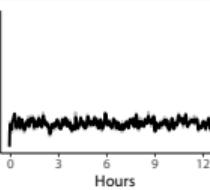
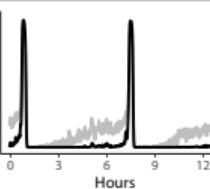
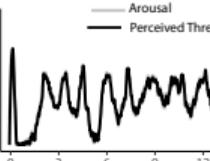


Theory-Implied Behavior

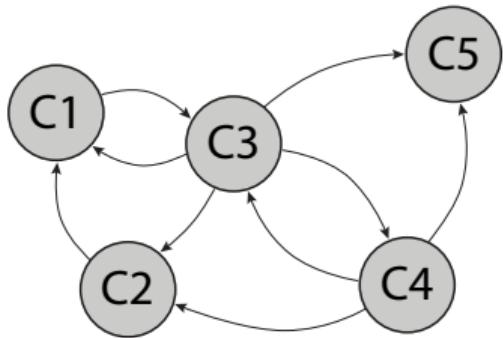
Condition 1: Simulated Perturbation to Arousal



Condition 2: Natural Variation in Arousal



Theory



We want theory, and ideally, theory formalized as a mathematical or computational model

- ▶ The more precise and specific the theory is, the better our surrogate reasoning
- ▶ Vague theories can neither be refuted nor corroborated
- ▶ Formal theories are explicit, specific
- ▶ Don't rely on idiosyncratic mental simulations of the researcher

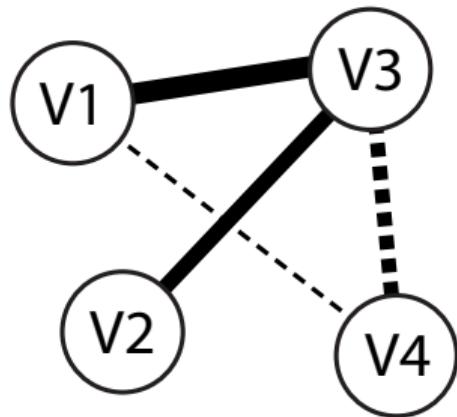
Outside of cognitive and mathematical psychology,
formalized theories are rare

- ▶ Notable exception: Robinaugh et al 2019

Data

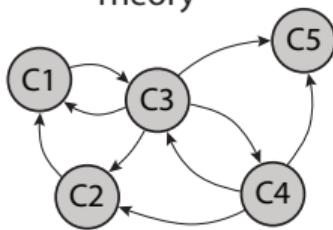
V1	V2	V3	V4
1.58	3.00	2.47	4.01
2.83	6.13	4.89	2.33
4.82	3.46	6.73	5.44
0.64	5.72	3.91	2.54
5.11	4.49	2.27	4.03

Data Model

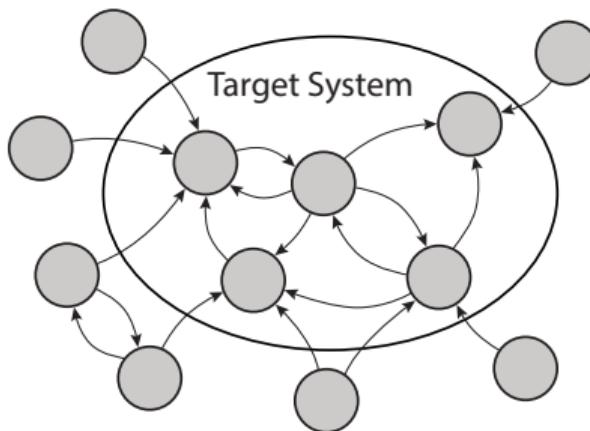
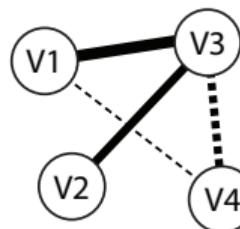


Target systems, Theories, Data and Data Models

Theory



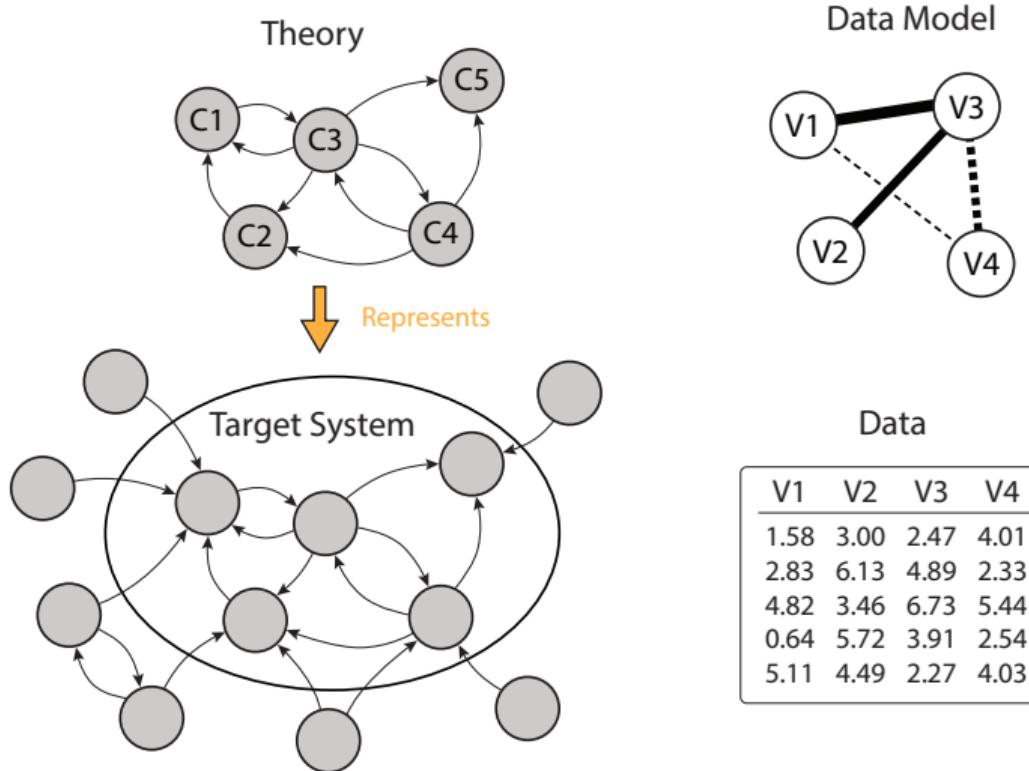
Data Model



Data

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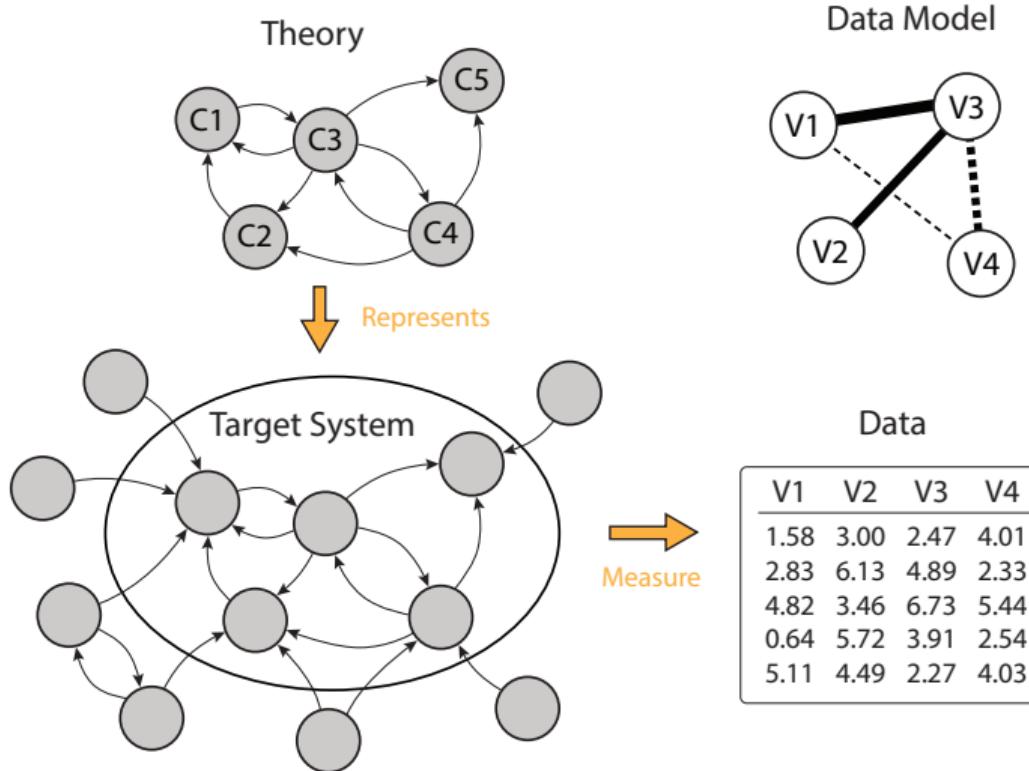
Target systems, Theories, Data and Data Models



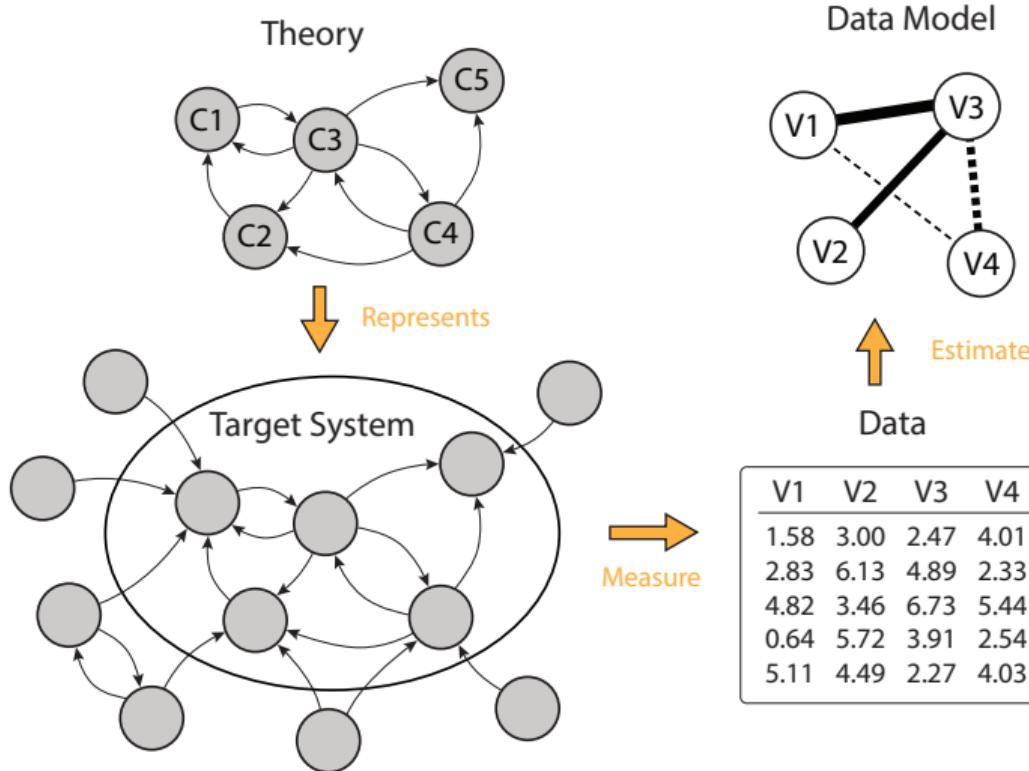
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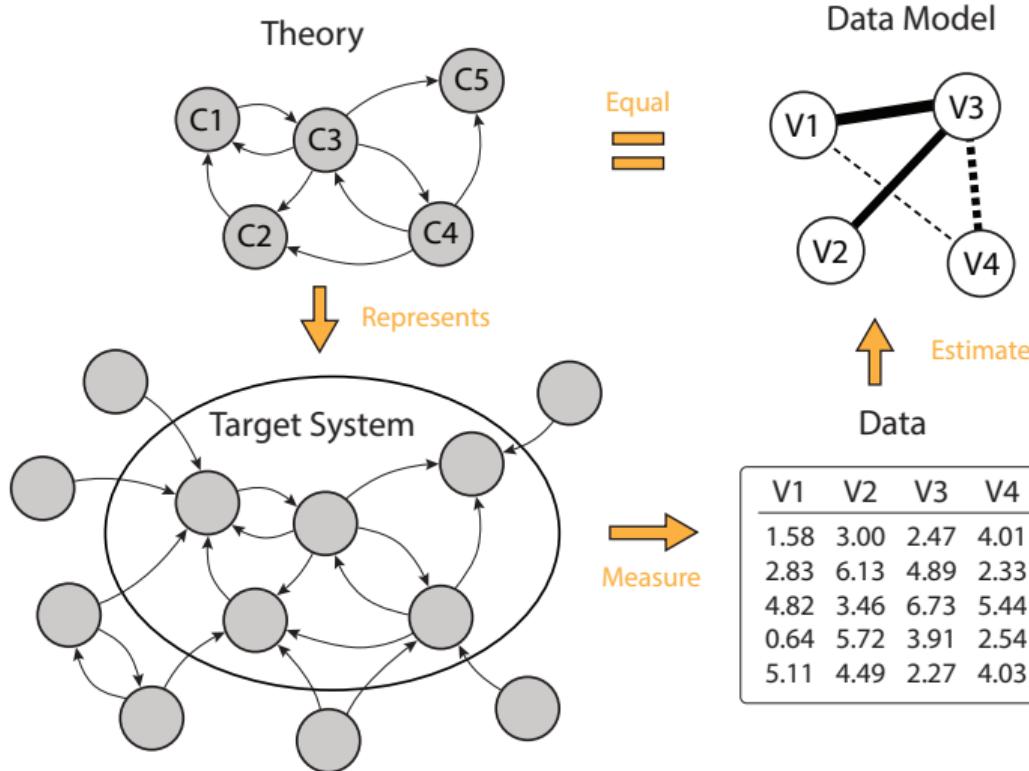
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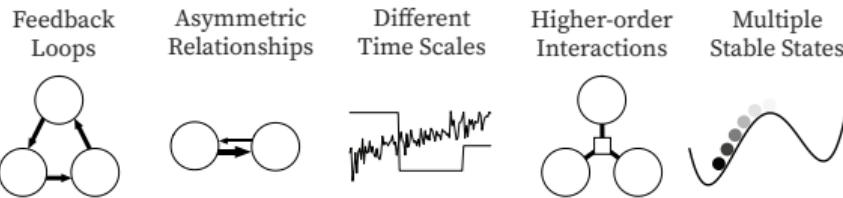


Target systems, Theories, Data and Data Models



Network Data Models as Theories?

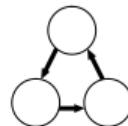
Network Data Models as Theories?



(Haslbeck*, Ryan*, Robinaugh*, et al., 2021)

Network Data Models as Theories?

Feedback Loops



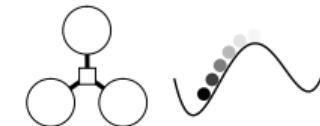
Asymmetric Relationships



Different Time Scales



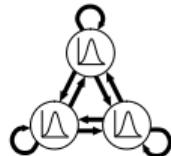
Higher-order Interactions



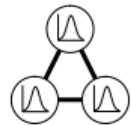
Multiple Stable States



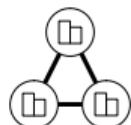
VAR Model



GGM

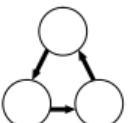
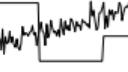
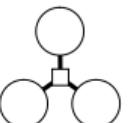
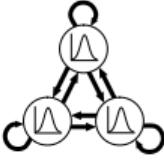
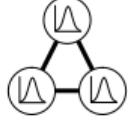
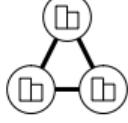


Ising Model



(Haslbeck*, Ryan*, Robinaugh*, et al., 2021)

Network Data Models as Theories?

	Feedback Loops	Asymmetric Relationships	Different Time Scales	Higher-order Interactions	Multiple Stable States
					
VAR Model		✓	✓	✗	✗
GGM		✓	✗	✗	✗
Ising Model		✓	✗	✗	✓

(Haslbeck*, Ryan*, Robinaugh*, et al., 2021)

[...] we must carefully distinguish substantive theory from statistical hypothesis. There is a tendency in the social sciences to conflate these in talking about our inferences."

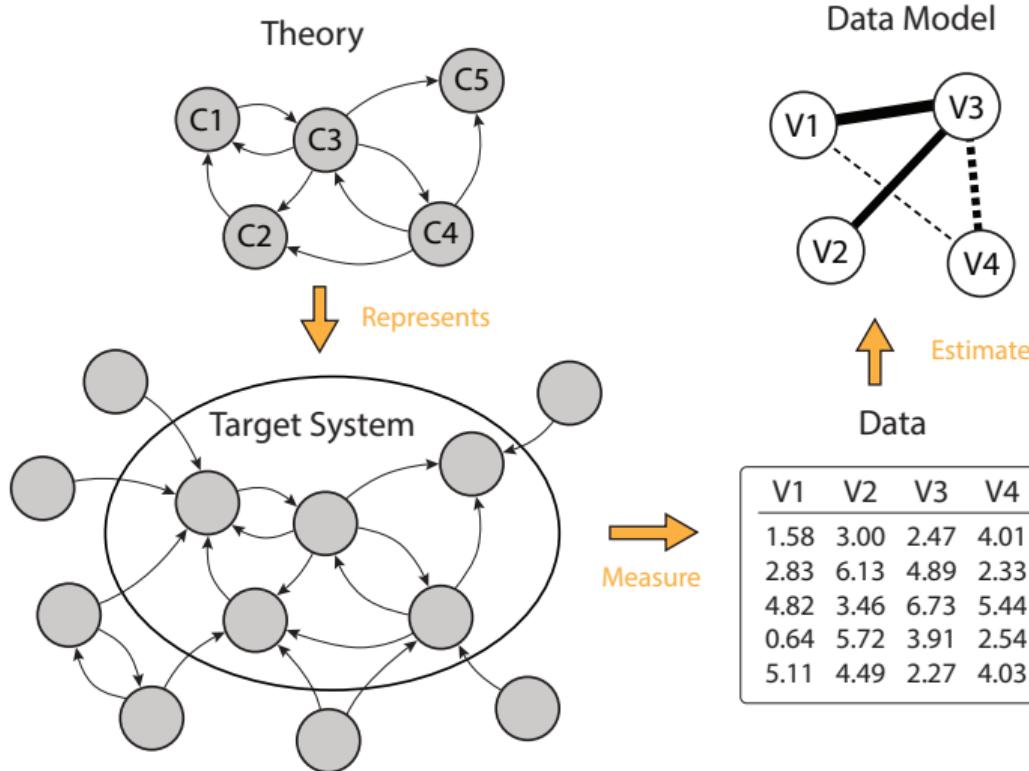
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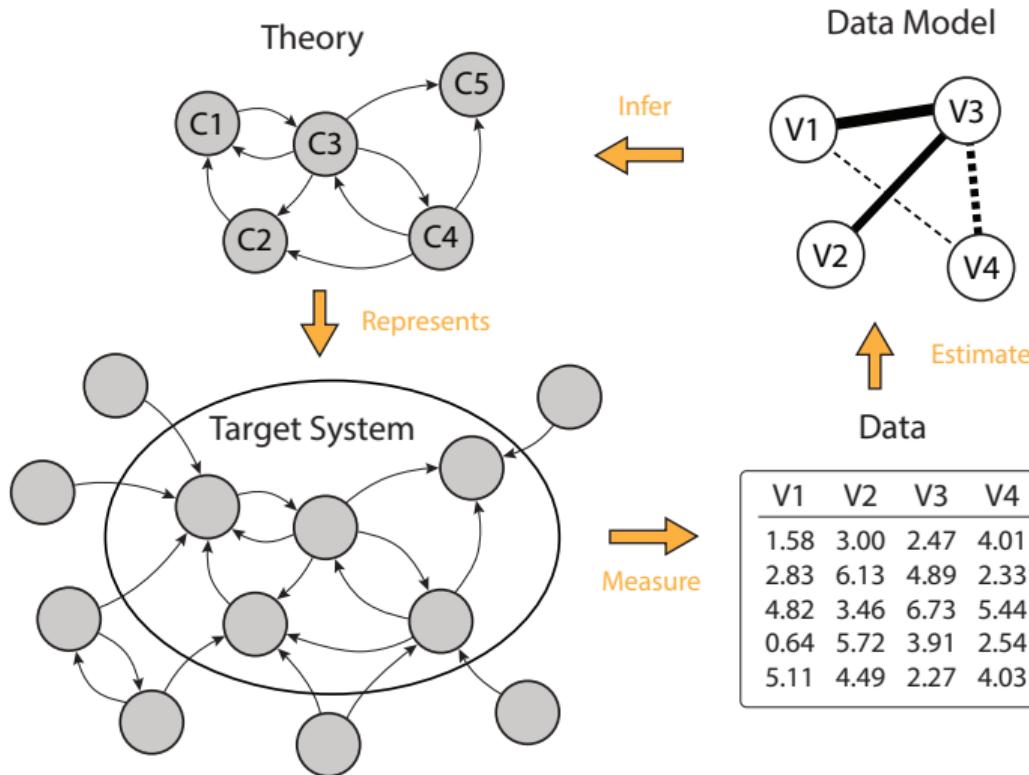
Paul E. Meehl (1978)

Data Models are not **Theories**

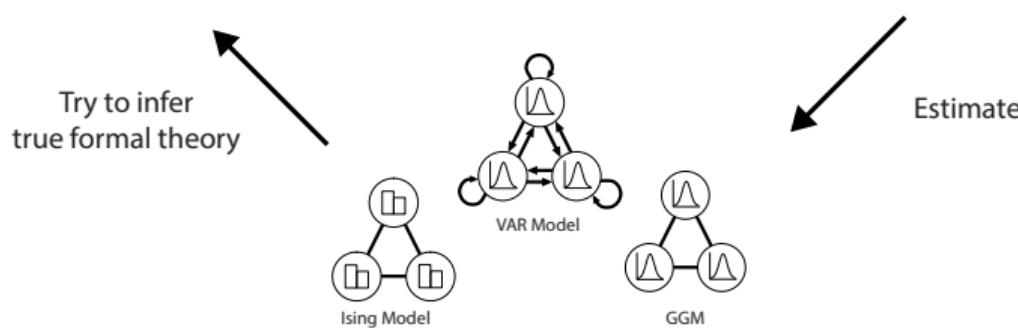
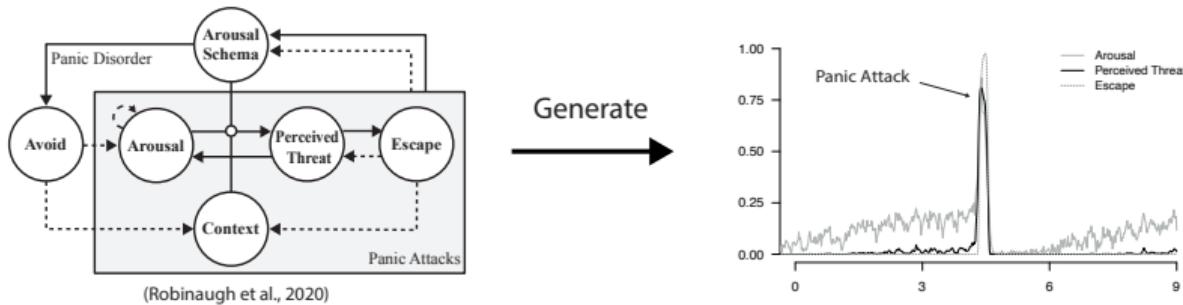
Target systems, Theories, Data and Data Models



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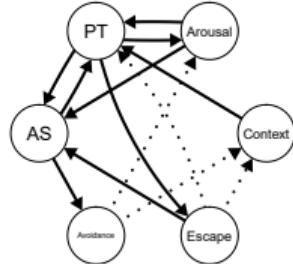
Infer Theories from Data Models?



(Robinaugh et al., 2020; Haslbeck*, Ryan*, Robinaugh*, et al., 2021)

Infer Theories from Data Models?

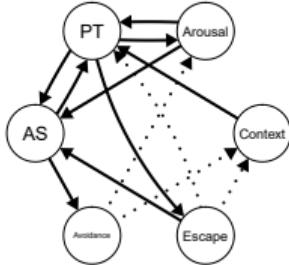
(a) True Causal Graph



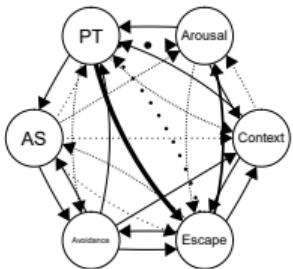
(Haslbeck*, Ryan*, Robinaugh*, et al., 2021; Ryan, Bringmann, Schuurman, 2020)

Infer Theories from Data Models?

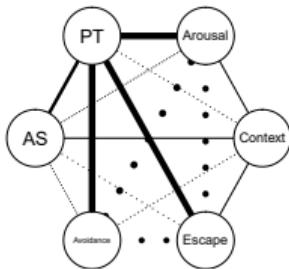
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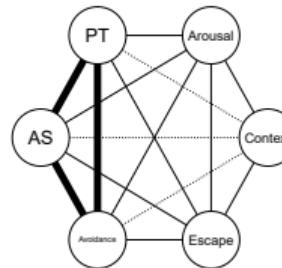
(b) VAR Model



(c) Gaussian Graphical Model

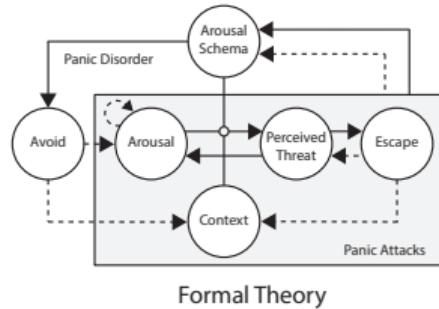


(d) Ising Model



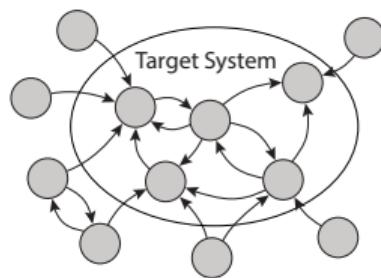
(Haslbeck*, Ryan*, Robinaugh*, et al., 2021; Ryan, Bringmann, Schuurman, 2020)

Alternative: Abductive Theory Construction

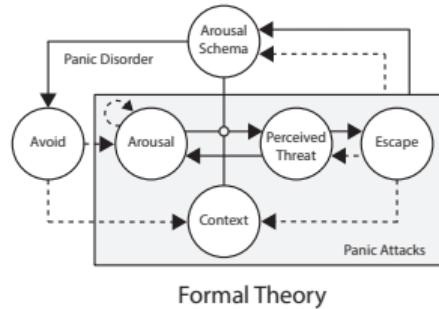


Formal Theory

↓
Represents

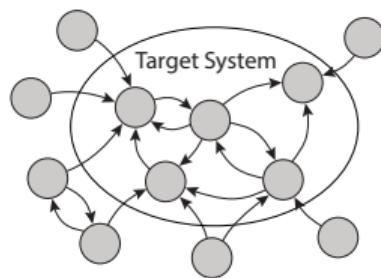


Alternative: Abductive Theory Construction



Formal Theory

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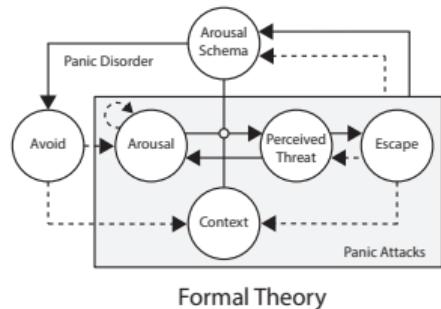


Measurement

Empirical
Data

Av	PA	PC
0	0	0
0	1	1
1	1	1
0	0	0
1	1	0

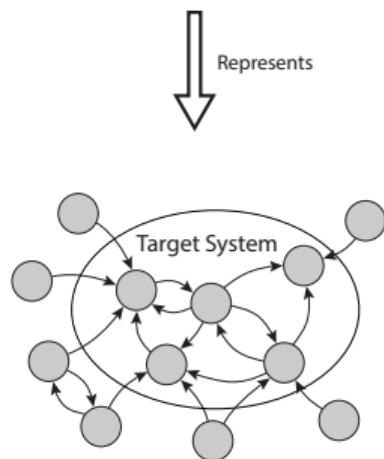
Alternative: Abductive Theory Construction



Emulated Measurement →

Simulated Data

Av	PA	PC
0	0	0
0	0	0
1	1	1
0	0	0
1	1	1

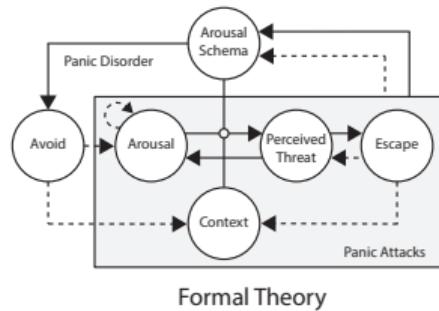


Measurement →

Empirical Data

Av	PA	PC
0	0	0
0	1	1
1	1	1
0	0	0
1	1	0

Alternative: Abductive Theory Construction

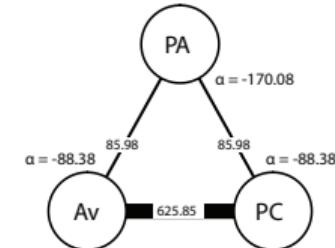


Emulated Measurement
→

Simulated Data

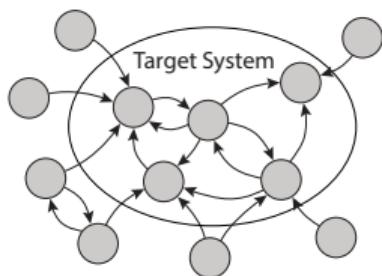
Av	PA	PC
0	0	0
0	0	0
1	1	1
0	0	0
1	1	1

Implied Data Model



Formal Theory

Represents
↓

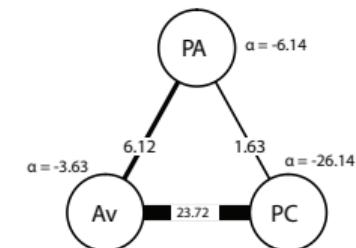


Measurement
→

Empirical Data

Av	PA	PC
0	0	0
0	1	1
1	1	1
0	0	0
1	1	0

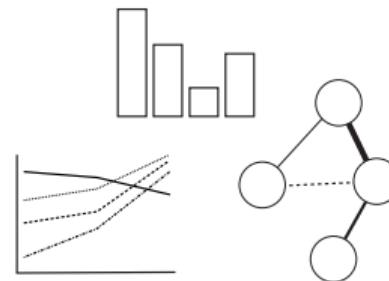
Empirical Data Model



How to generate an initial theory?

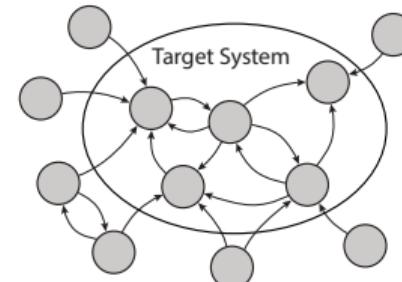
Step 1: Specify phenomenon to be explained

- ▶ Features of the real world
- ▶ Robust and replicable data models



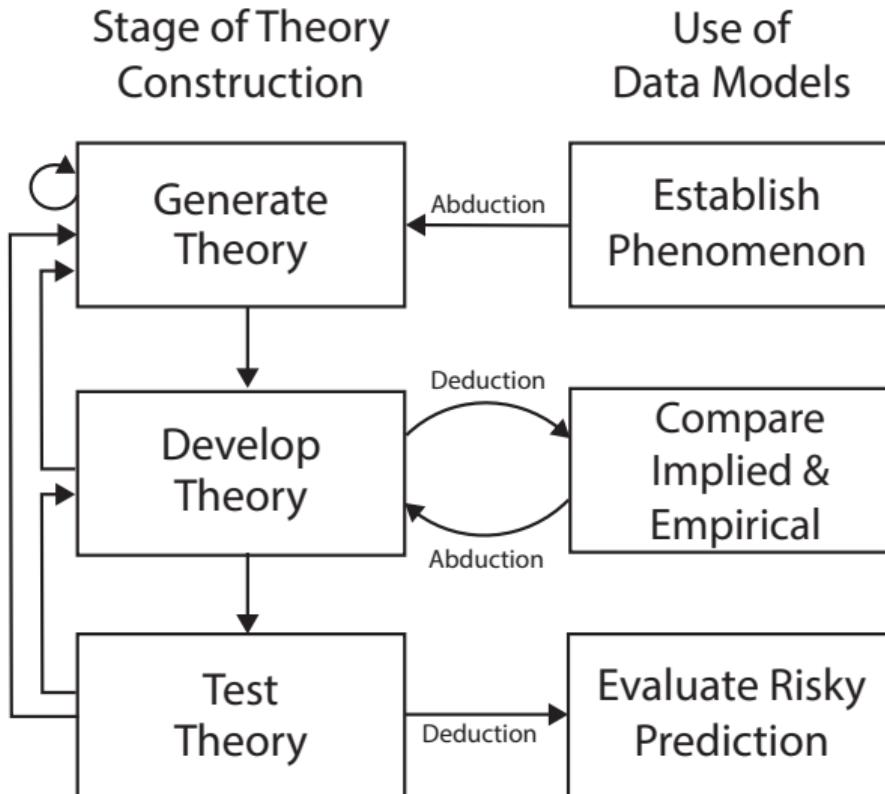
Step 2: Specify components and relations of target system

- ▶ Use plethora of verbal theories, identify weaknesses
- ▶ Use templates, lessons from other fields:
Reinforcement learning, dynamical systems,
agent based models



(Wimsatt, 1987; Smaldino, 2017; Haslbeck*, Ryan*, Robinaugh*, et al., 2021)

From Data Models to Formal Theories



From Data Models to Formal Theories

Psychology has a theory problem

- ▶ Many weak / vague theories, rarely developed

Statistical modeling is not the same as theory development

- ▶ Data models are unlikely to be good theories
- ▶ Naive inferences are highly problematic

Formalizing theories as computational models is a potential remedy

- ▶ Abductive theory construction as a powerful way forward

Haslbeck, J.M.B.* , Ryan, O.* , Robinaugh, D. J.* , Waldorp, L. J., Borsboom, D. (2021). Modeling psychopathology: From data models to formal theories. *Psychological Methods*.

<https://psycnet.apa.org/record/2022-00806-001>

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