

Modeling Psychopathology: From Data Models to Formal Theories

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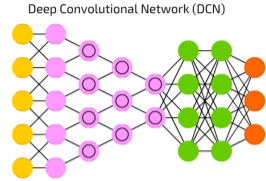
**Joint first authors*

M&S Colloquium 24 March 2022

Psychology has a theory problem

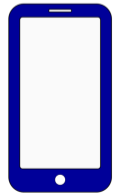
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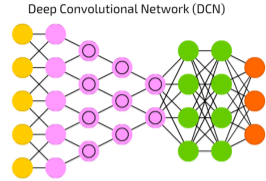
Statistics



Psychology has a theory problem

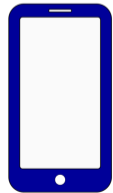
Statistics

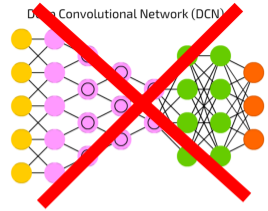




Psychology has a theory problem

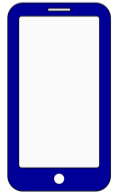
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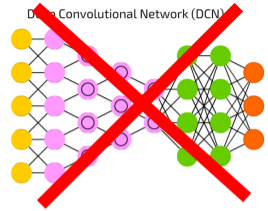




Psychology has a theory problem

Statistics

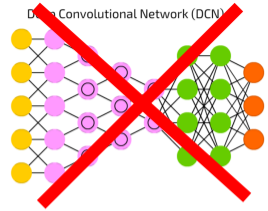




Psychology has a theory problem

Statistics





Psychology has a theory problem



Statistics



Theory \leftarrow ? \rightarrow 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)

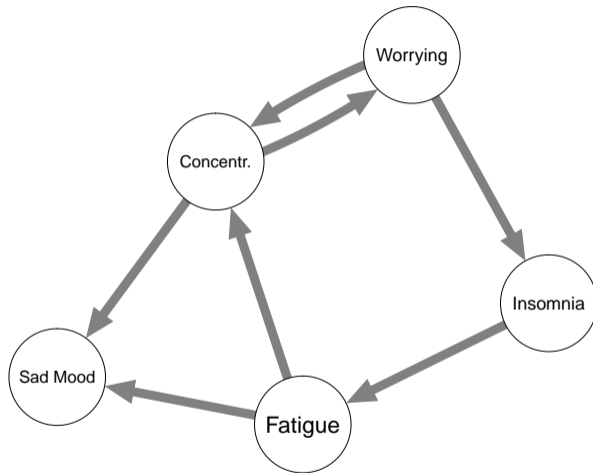
Formalizing theory as mathematical or computational models

- ▶ 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**

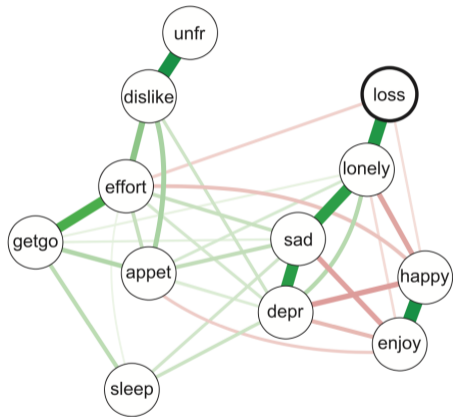
(Haslbeck* ,Ryan* ,Robinaugh* , et al., 2021; Oberauer & Lewandowsky 2019; Smaldino 2017; Borsboom et al. 2020; Guest & Martin 2020; van Rooij & Baggio 2020; Fried 2020)

Network Approach to Psychopathology



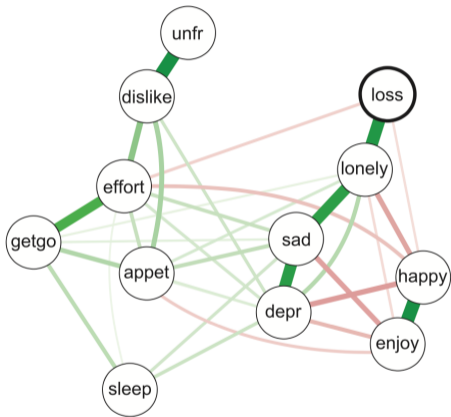
(Cramer et al, 2010; Borsboom et al. 2013; Schmittman et al, 2013; Borsboom, 2017)

Statistical Network Analysis

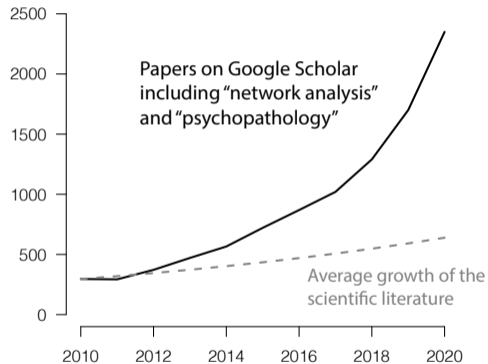


(Figure from Fried et al., 2015)

Statistical Network Analysis

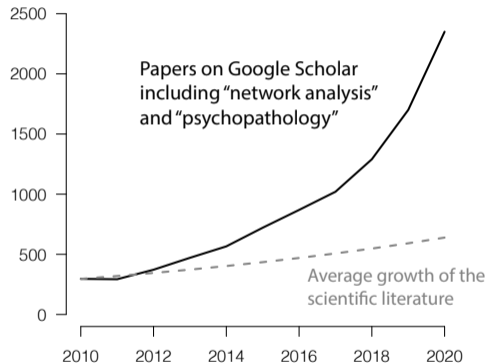


(Figure from Fried et al., 2015)



Statistical Network Analysis

Theories?



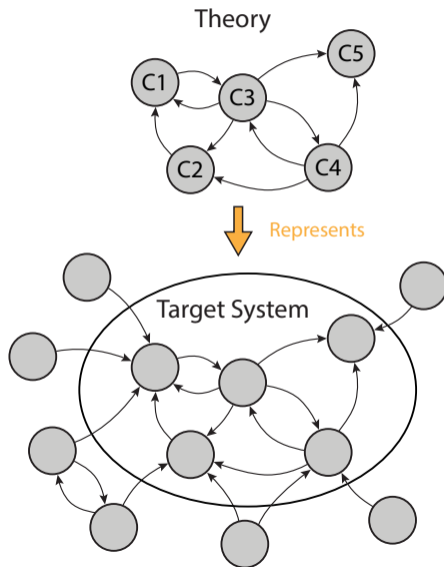
What are theories?

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

Verbal Theory

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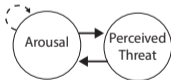
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Causal Diagram

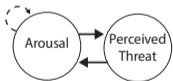


Verbal Theory

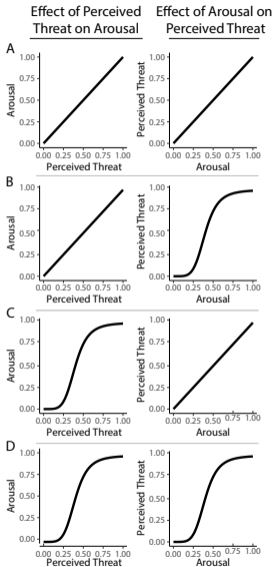
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Causal Diagram



Formal Theory

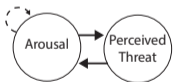


Verbal Theory

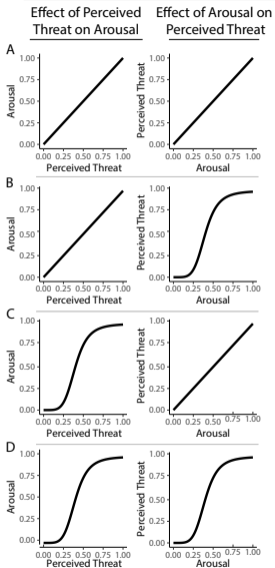
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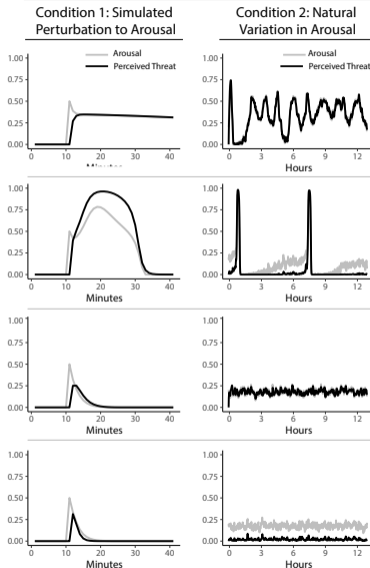
Causal Diagram



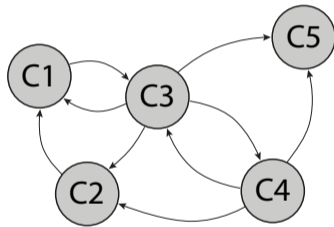
Formal Theory



Theory-Implied Behavior



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

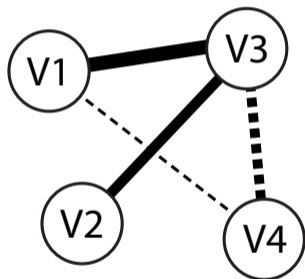
Outside of cognitive and mathematical psychology, *formalized theories are rare*

- ▶ Notable exception: Robinaugh et al 2019

Data

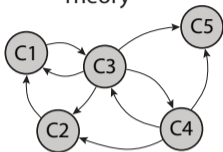
V1	V2	V3	V4
1.58	3.00	2.47	4.01
2.83	6.13	4.89	2.33
4.82	3.46	6.73	5.44
0.64	5.72	3.91	2.54
5.11	4.49	2.27	4.03

Data Model

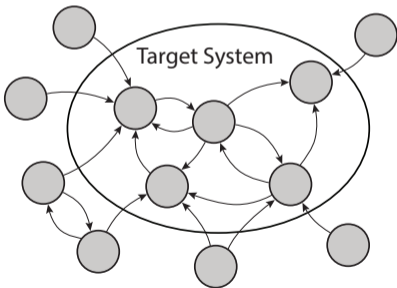
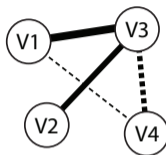


Target systems, Theories, Data and Data Models

Theory



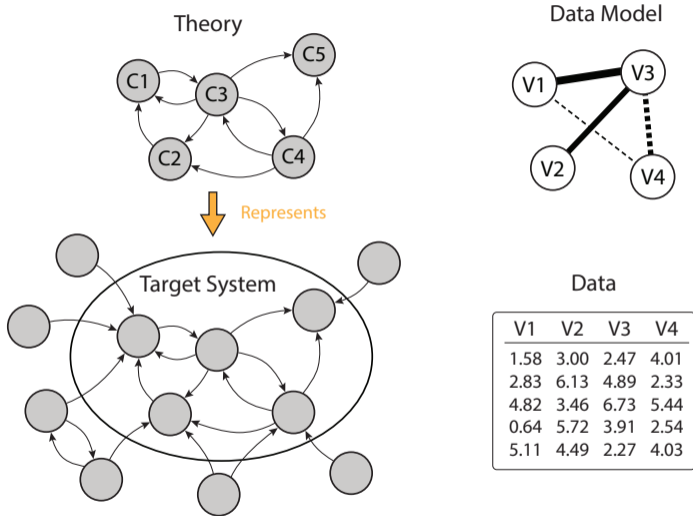
Data Model



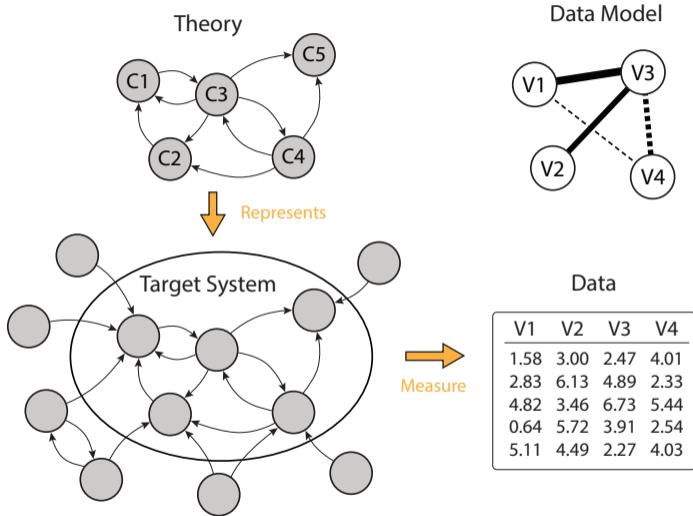
Data

V1	V2	V3	V4
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Target systems, Theories, Data and Data Models

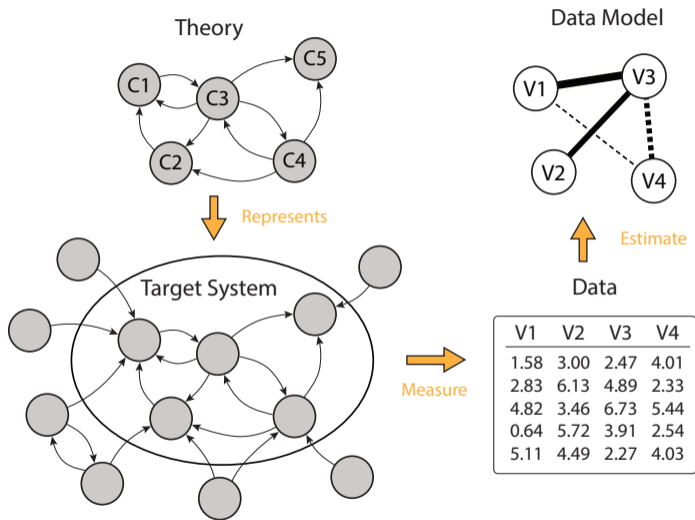


Target systems, Theories, Data and Data Models



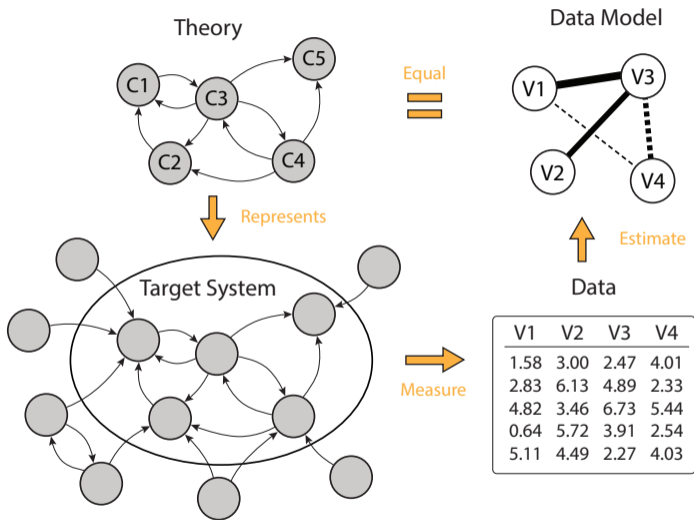
(Suárez & Pero, 2019; Haslbeck*, Ryan*, Robinaugh*, et al., 2021)

Target systems, Theories, Data and Data Models



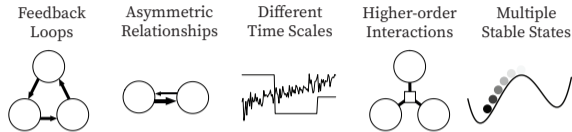
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Target systems, Theories, Data and Data Models



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



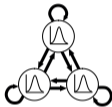
Higher-order
Interactions



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					
VAR Model	✓	✓	✗	✗	✗
GGM		✗	✗	✗	✗
GGM	✓	✗	✗	✗	✗
Ising Model		✗	✗	✗	✓
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.”

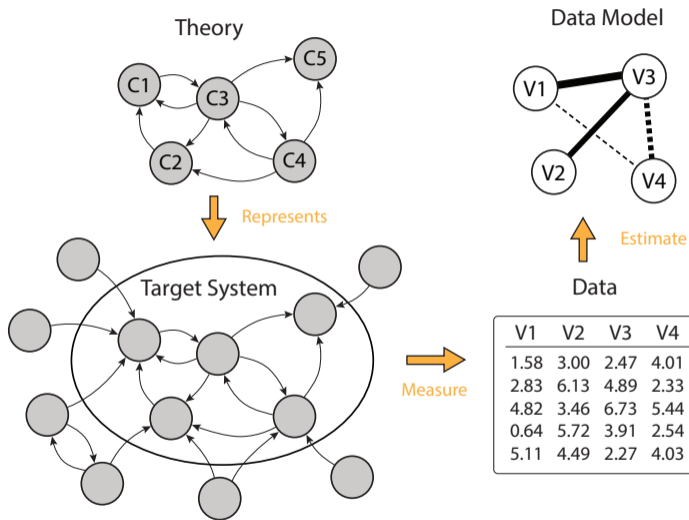
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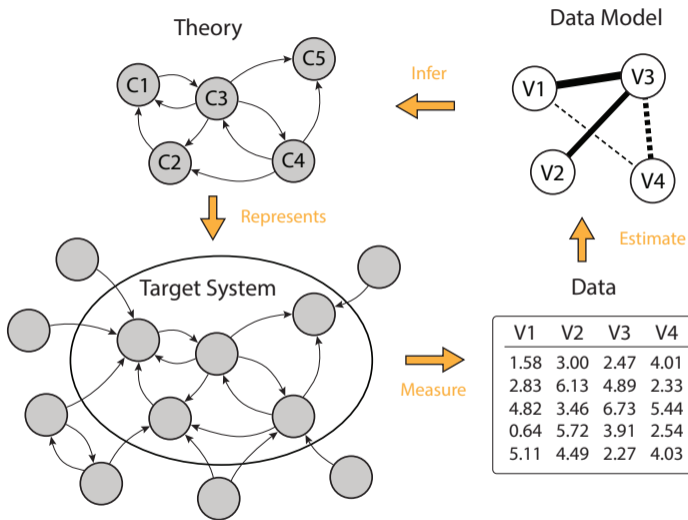
Data Models are not **Theories**

Target systems, Theories, Data and Data Models

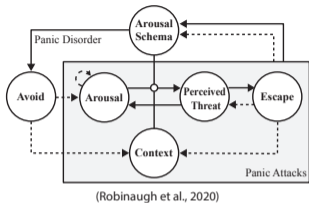


(Suárez & Pero, 2019; Haslbeck*, Ryan*, Robinaugh*, et al., 2021)

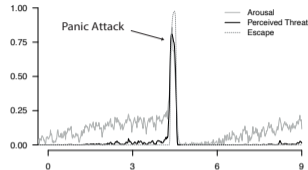
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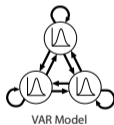
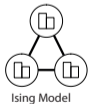
Infer Theories from Data Models?



Generate



Try to infer
true formal theory

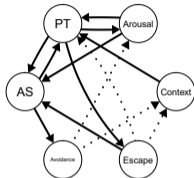


Estimate

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

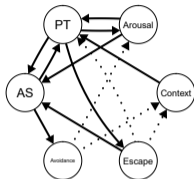
Infer Theories from Data Models?

(a) True Causal Graph

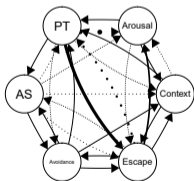


Infer Theories from Data Models?

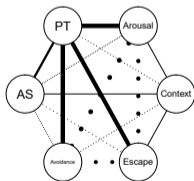
(a) True Causal Graph



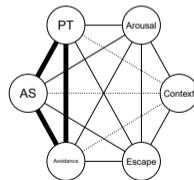
(b) VAR Model



(c) Gaussian Graphical Model

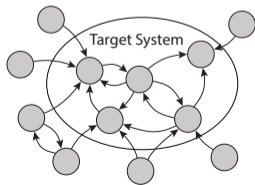
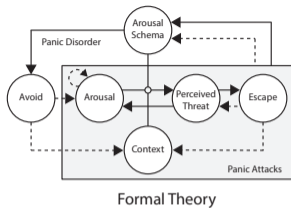


(d) Ising Model

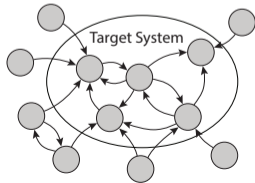
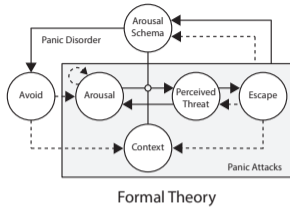


(Haslbeck*, Ryan*, Robinaugh*, et al., 2021; Ryan, Bringmann, Schuurman, 2020)

Alternative: Abductive Theory Construction



Alternative: Abductive Theory Construction

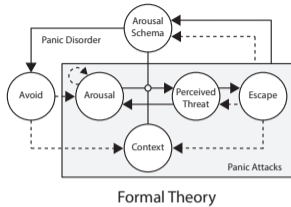


Measurement
➔

Empirical
Data

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

Alternative: Abductive Theory Construction



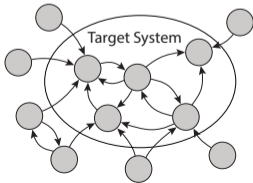
Formal Theory

Emulated
Measurement

Simulated
Data

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

Represents

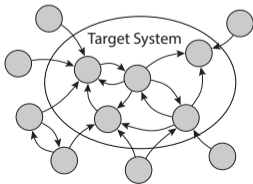
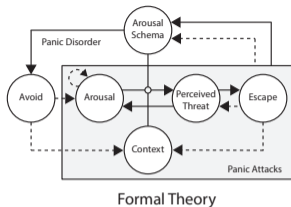


Measurement

Empirical
Data

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

Alternative: Abductive Theory Construction

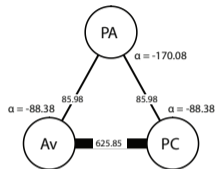


Simulated Data

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



Implied Data Model

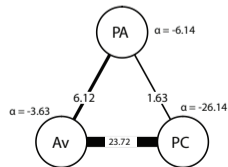


Empirical Data

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



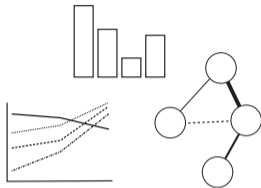
Empirical Data Model



How to generate an initial theory?

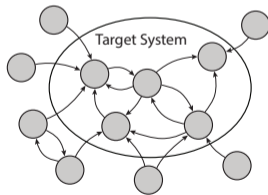
Step 1: Specify phenomenon to be explained

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

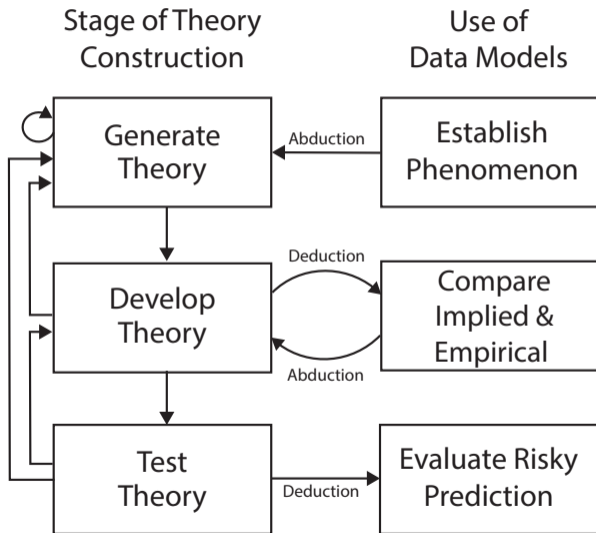


Step 2: Specify components and relations of target system

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



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>

`o.ryan@uu.nl | ryanoisin.github.io | slides with thanks to JMBH`

References

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- Guest, O., & Martin, A. E. (2021). How computational modeling can force theory building in psychological science. *Perspectives on Psychological Science*, 16(4), 789-802.
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