

# Formal Theories in Psychology:

## What they are, Why they matter

### How to build them

Oisín Ryan

Jonas Haslbeck

Donald Robinaugh

*Saarland University, 13 May 2022*

**Closing Session**

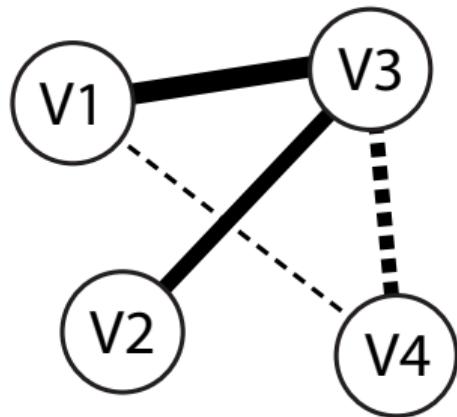
## Schedule for today

- ▶ **10:00-11:15:** Why Formal Theory?
- ▶ **11:15-11:30:** (Break)
- ▶ **11:30-13:00:** Target Systems & Phenomena: First Step Toward Formal Theory
- ▶ **13:00-14:30:** (Lunch)
- ▶ **14:30-16:00:** Formalizing Theories with Difference Equations
- ▶ **16:00-16:15:** (Break)
- ▶ **16:15-17:00:** Developing Formal Theories & Conclusion

## Data

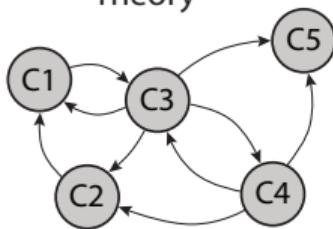
V1	V2	V3	V4
1.58	3.00	2.47	4.01
2.83	6.13	4.89	2.33
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## Data Model

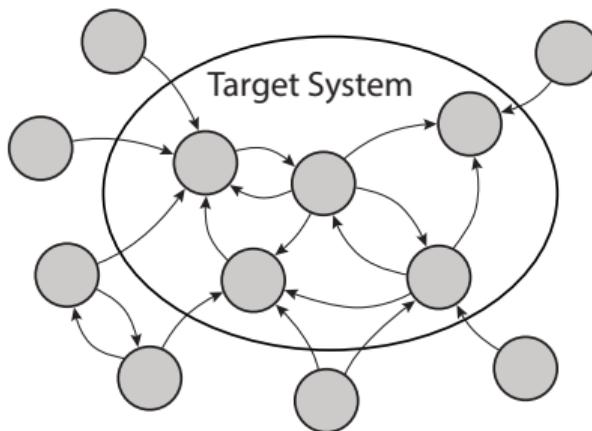
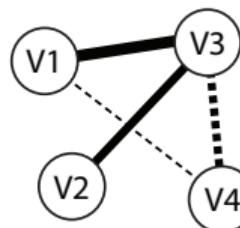


# Target systems, Theories, Data and Data Models

Theory



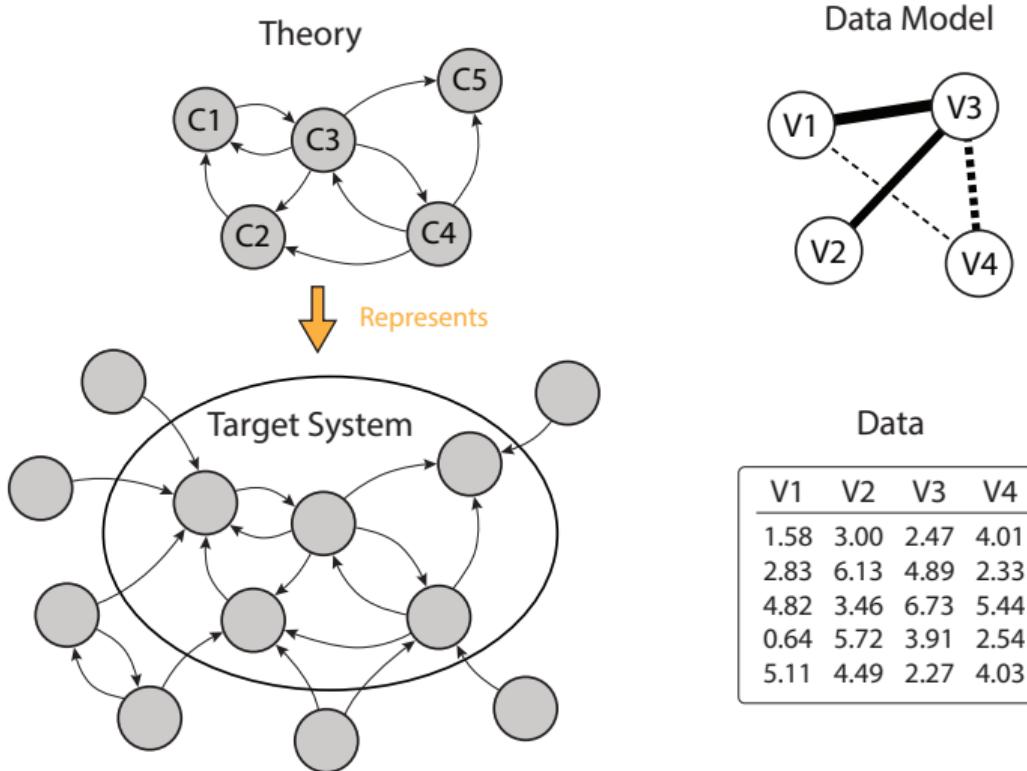
Data Model



Data

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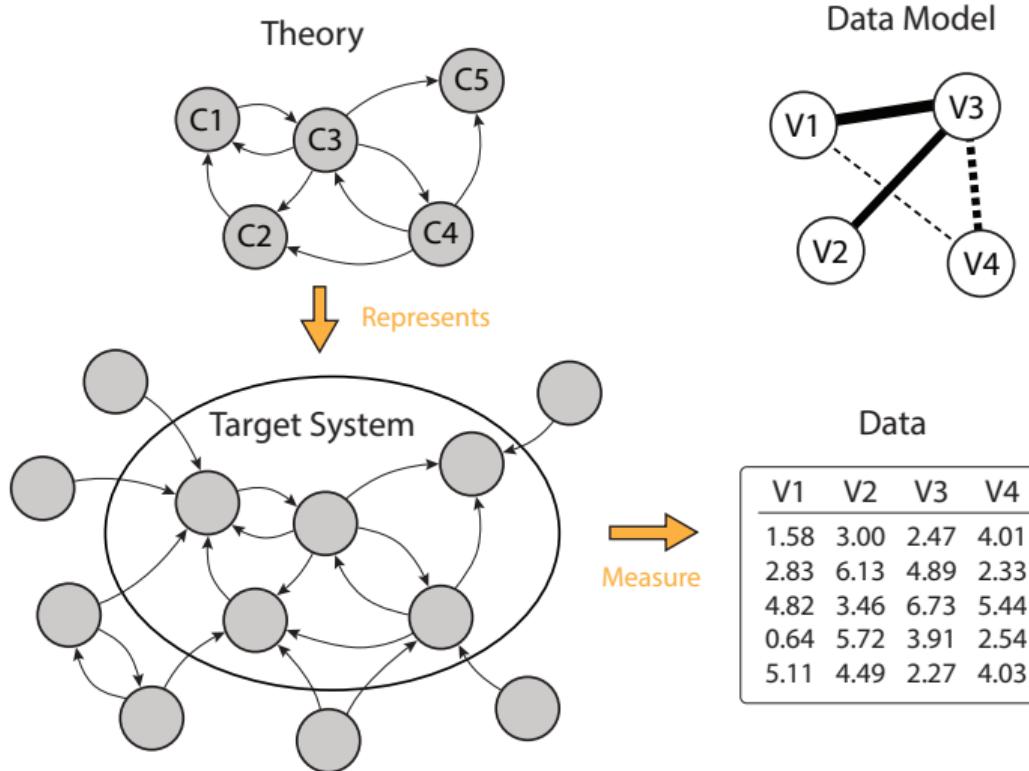
# Target systems, Theories, Data and Data Models



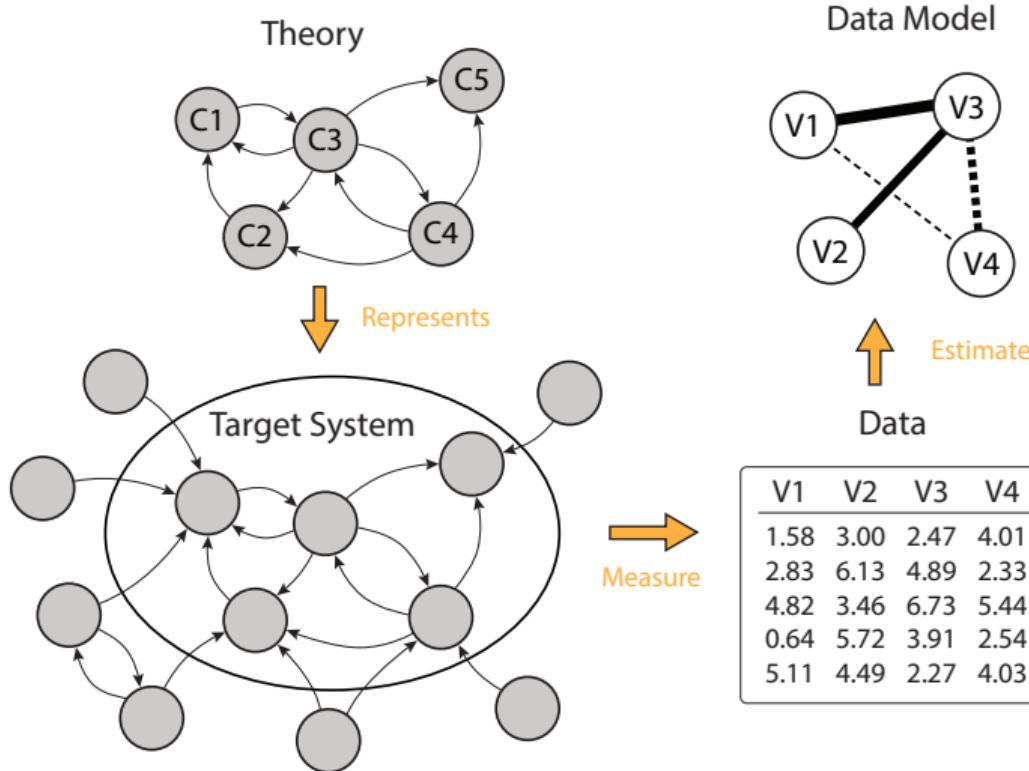
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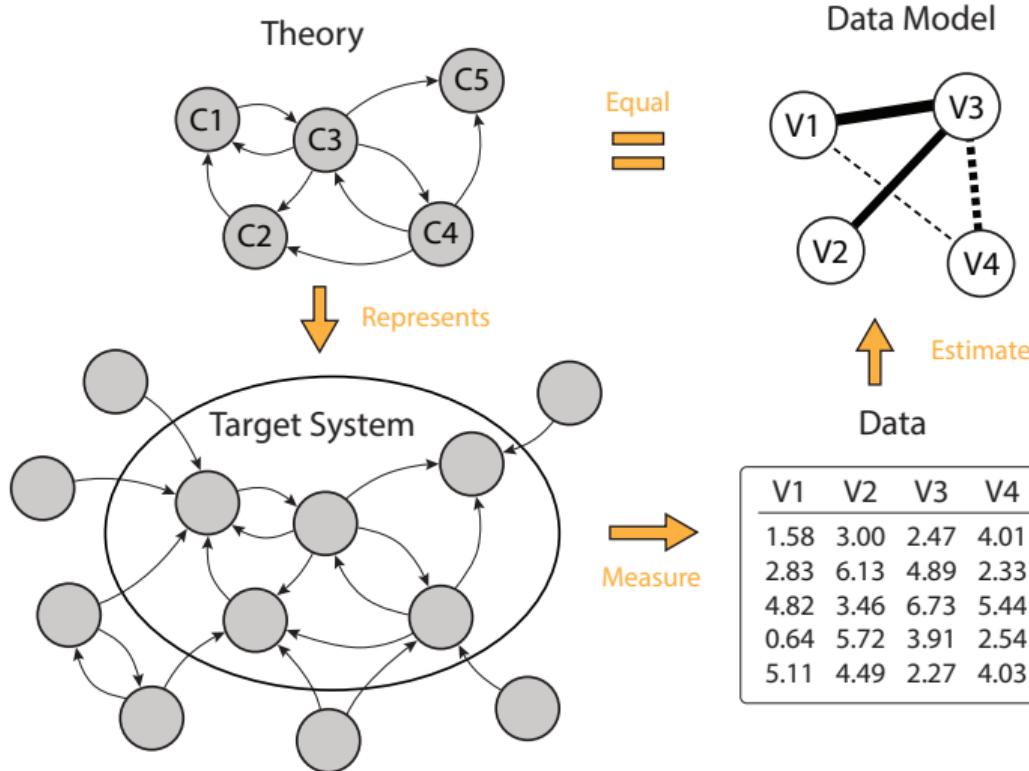
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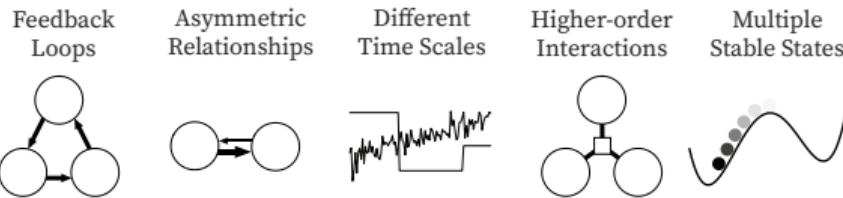


# Target systems, Theories, Data and Data Models



# Network Data Models as Theories?

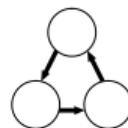
# Network Data Models as Theories?



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

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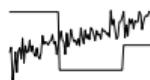
Feedback Loops



Asymmetric Relationships



Different Time Scales



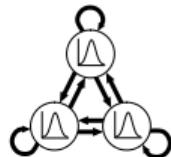
Higher-order Interactions



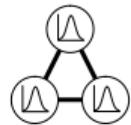
Multiple Stable States



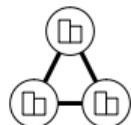
VAR Model



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)

## The Problem (in a nutshell)

We want formal theories that represent our target system and explain phenomena

- ▶ The target system is complex, and the phenomena multi-faceted
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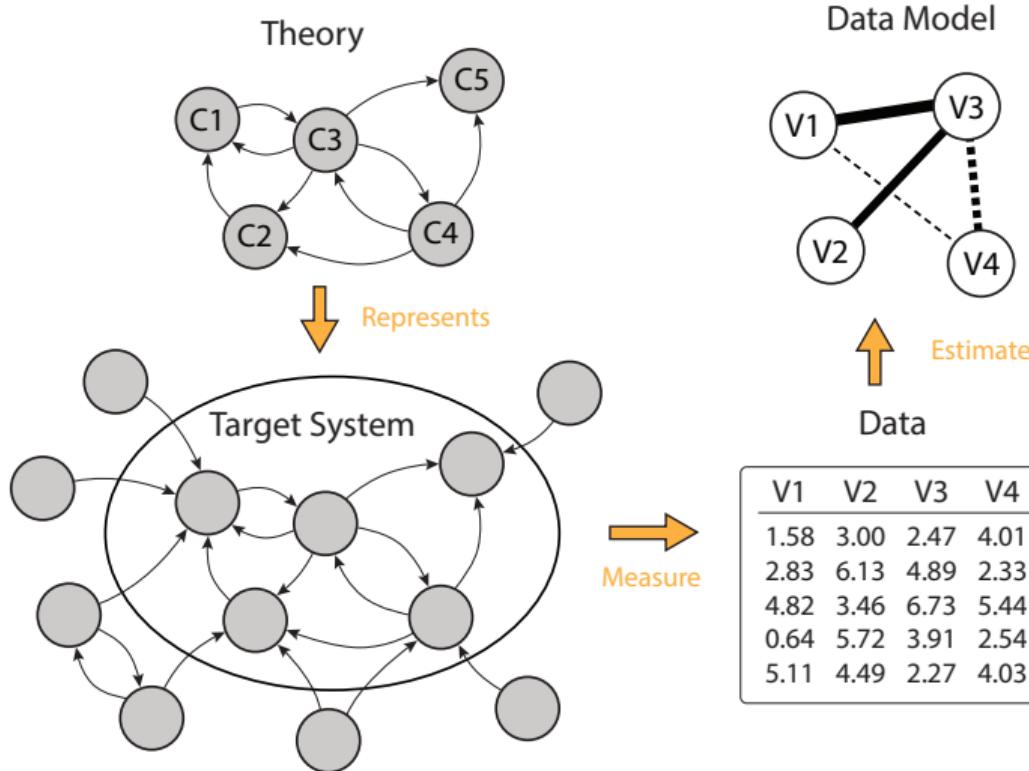
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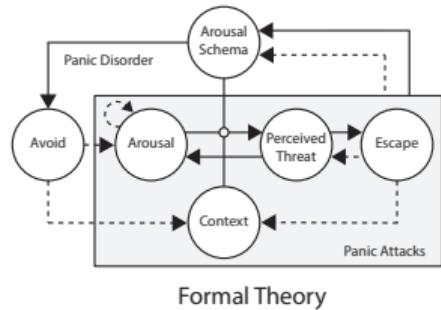
- ▶ But we are often limited in the amount and quality of data we can obtain
- ▶ This limits the complexity of the statistical models that we can fit **directly** to data

Unless we have a) amazing data or b) a very simple theory, we probably cannot directly identify / estimate computational model parameters in the usual way

# Target systems, Theories, Data and Data Models

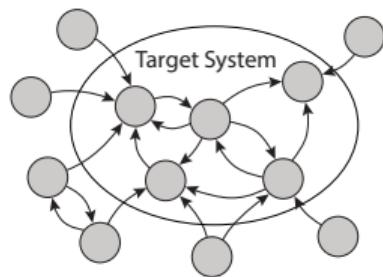


# Alternative: Abductive Theory Development

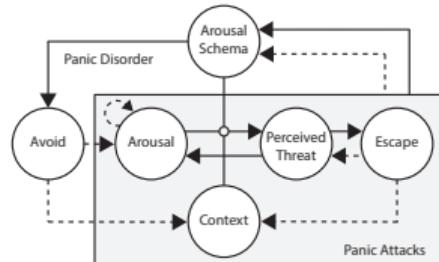


Formal Theory

↓  
Represents

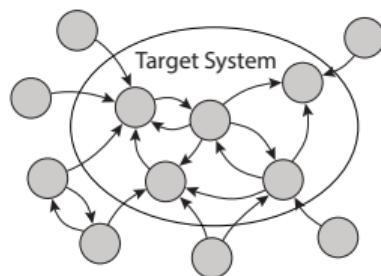
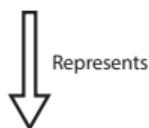


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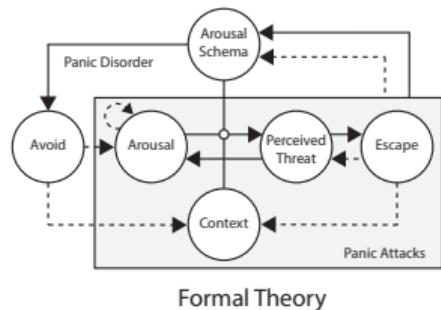
Measurement



Empirical  
Data

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

# Alternative: Abductive Theory Development



Emulated Measurement →

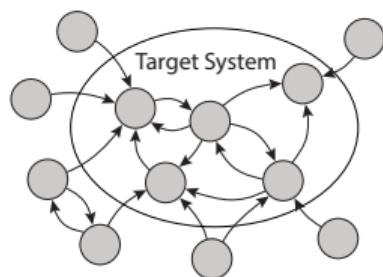
Simulated Data

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

Formal Theory

Represents

↓

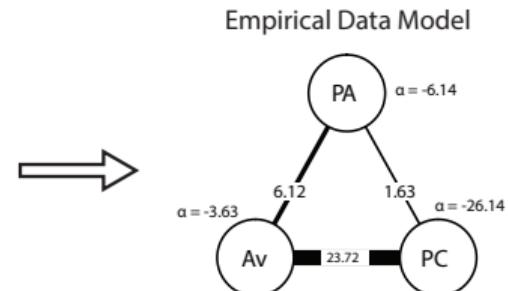
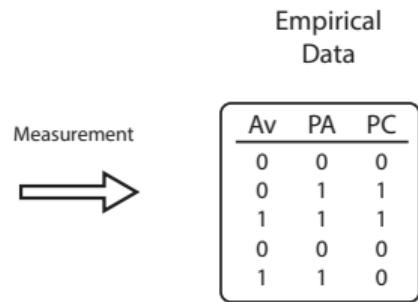
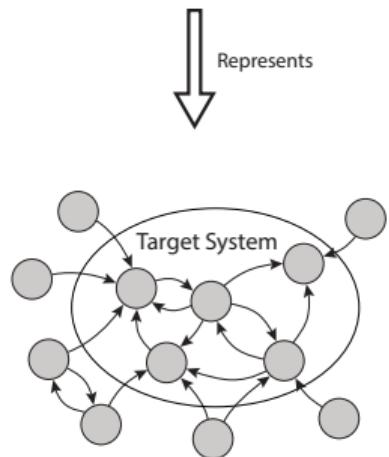
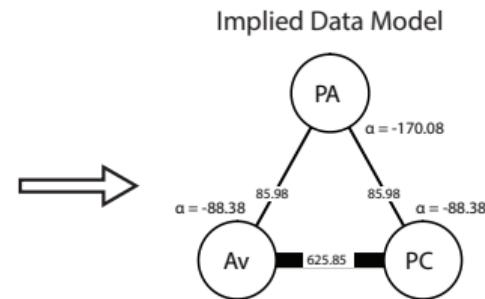
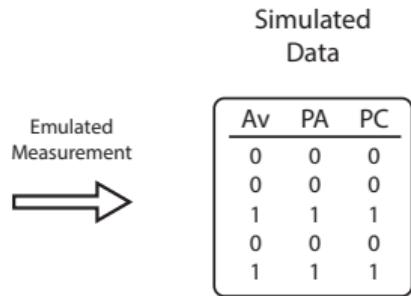
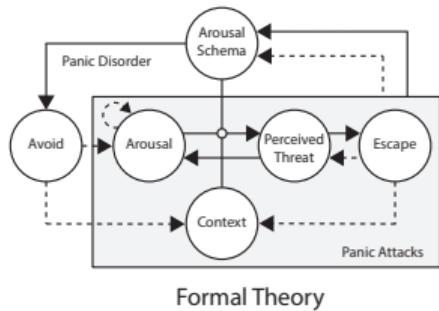


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**Indirect** procedure for using data to evaluate the theory at hand

- ▶ Evaluates implications of the theory in the form of a data model
- ▶ Discrepancies between Implied and Empirical Data Models are used to infer discrepancies between theory and target system
- ▶ Insights may be *qualitative* as well as *quantitative*
- ▶ E.g.: In reality, some people experience panic attacks, but do not avoid!
- ▶ See <https://osf.io/fk276/>

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This approach can also be leveraged to evaluate **competing theories**

- ▶ Likelihood of data given theory 1 vs likelihood of data given theory 2

## Alternative II: Indirect Parameter Estimation

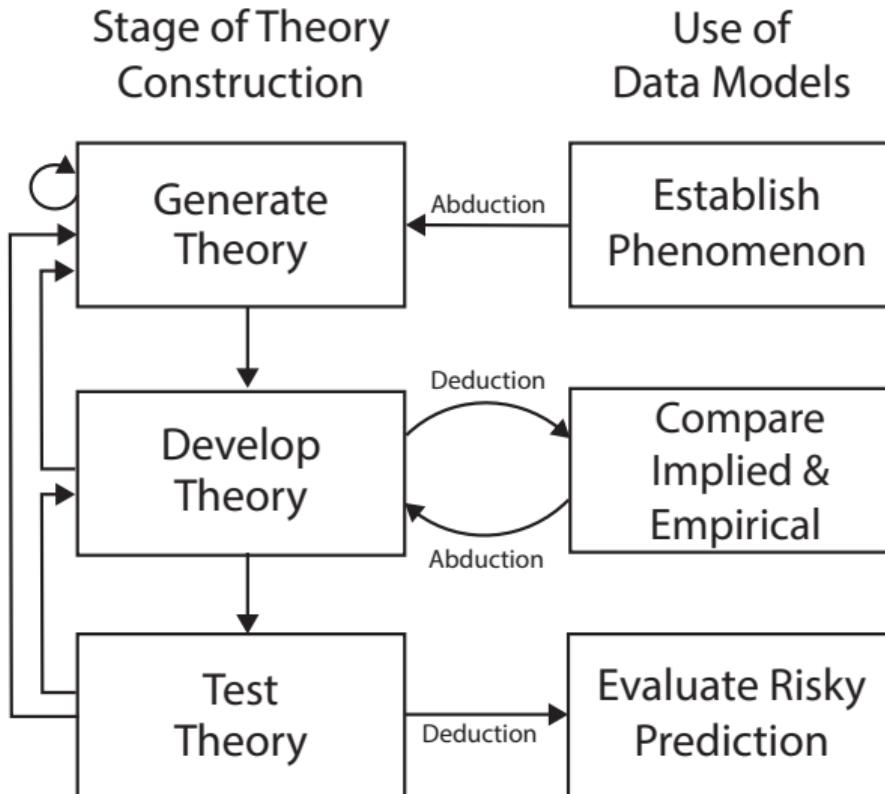
The same principles could in theory be used to *estimate parameter values*

- ▶ What value of the Arousal → Perceived Threat relationship produces an implied feature (e.g., mean PT, symptom frequency etc.) that most closely matches what we see in empirical data?

This type of approach has been used in the depression models of Hosseinichimeh & Wittenborn

More generally known as likelihood-free or simulation-based inference

# From Data Models to Formal Theories



# Data Models and Formal Theories: Challenges and Opportunities

- ▶ Which data types and data models best distinguish competing theories?
  - ▶ Can this inform study design?
- ▶ How well does indirect estimation work in realistic scenarios?
  - ▶ Parameter identifiability
- ▶ Which configurations of our theory produce the phenomena, and which don't?
  - ▶ Sensitivity Analysis / Parameter space characterization
- ▶ Can we isolate and learn about *parts* of the same model using different sources?
  - ▶ Data triangulation - observational, cross-sectional, time-series, physiological

# Conclusion

# Formal Theories: What, Why and How?

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

Formalizing theories as computational models is a potential remedy

1. Define phenomena to be explained
2. Define theory components, relationships
3. Build a model: don't trust an explanation you can't simulate!
4. Develop further by comparing model-implied and empirical data & data models

# Formal Theories in Psychology

Formalizing theories as computational models makes theory

- ▶ Explicit
- ▶ Transparent
- ▶ Widely accessible to researchers across disciplines
- ▶ Potentially able to integrate with theories on different levels (e.g. computational and biological psychiatry)

Collaboration and integration across researchers necessary to leverage empirical literature for theoretical advances!

Q & A

Robinaugh, D., Haslbeck, J., Waldorp, L., Kossakowski, J., Fried, E. I., Millner, A., ... Borsboom, D. (2019). Advancing the network theory of mental disorders: A computational model of panic disorder. PsyArxiv:  
<https://psyarxiv.com/km37w/download>

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

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