NACS 645 – **Quantitative Perspectives**

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Evolution of practices in hypothesis-testing (2015-2025; non-exhaustive)

p-value

effect-sizes

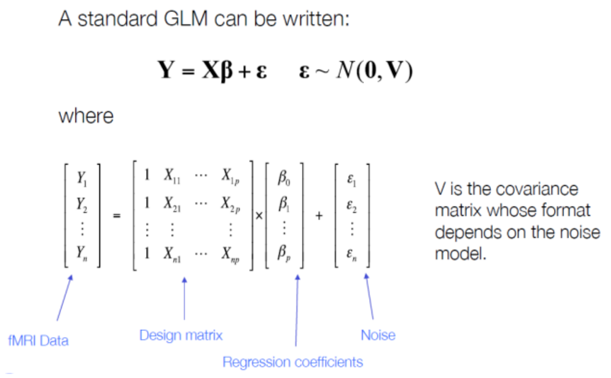
probabilities

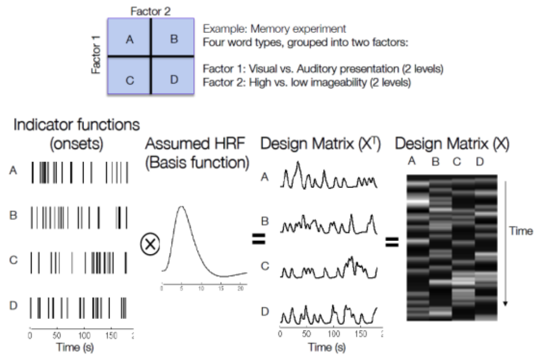
Statistics:

- t-test, ANOVA
- z-test, kolmogorov-smirnov, etc.
- Effect sizes
- Linear models, link functions
- Simulating power, sim. increasing {n, x}
- SEM, MLM (partial pooling)
- emmeans
- Comp. modelling: DDM, RL, Bayesian
- Distributions in the Bayes. domain, Bayes factor
- Bayesian estimation: MCMC, VBA

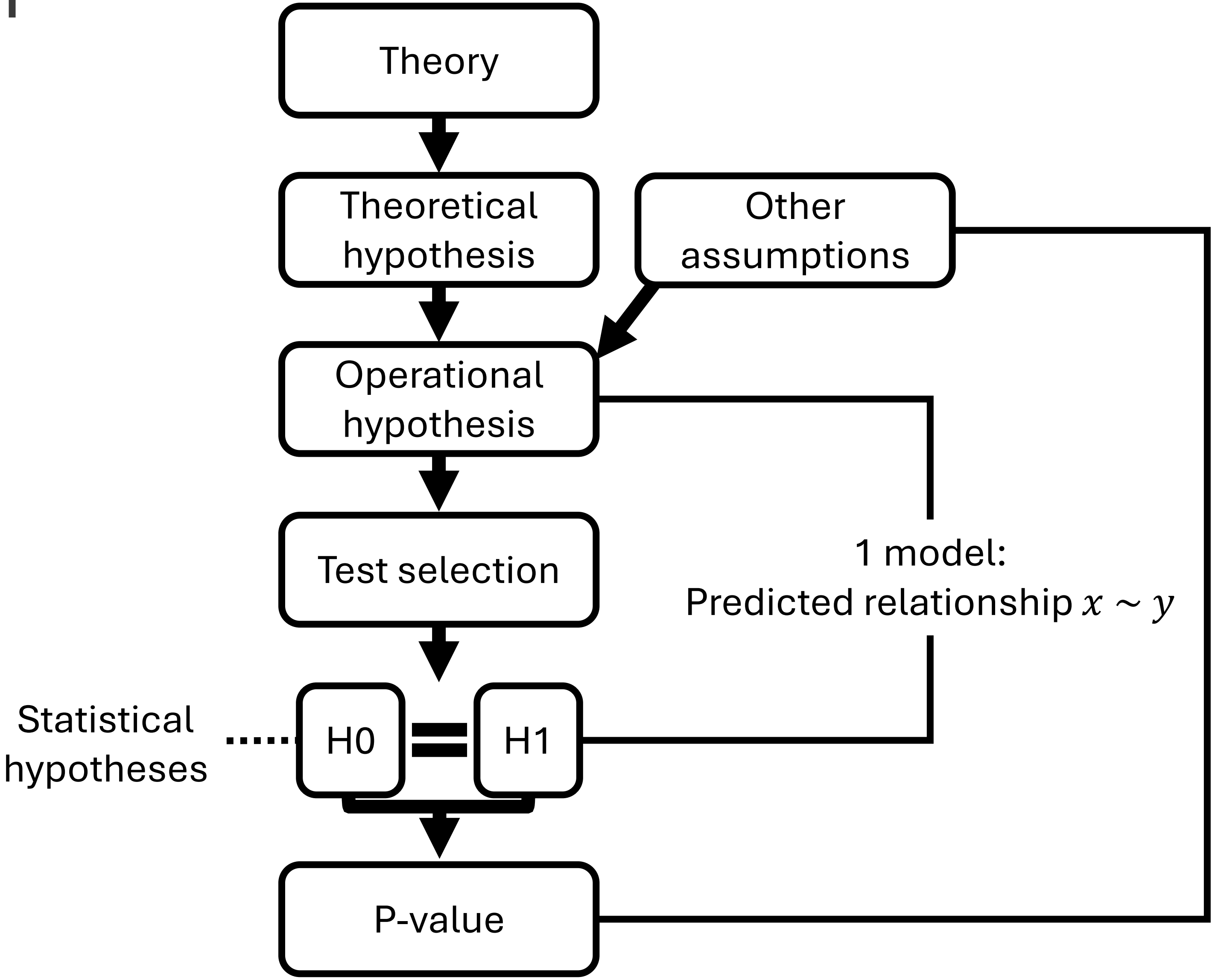
fMRI:

- GLM then t-test, ANOVA
- Increasing covariants
- 2^{nd}-level analysis
- Model-based fMRI





NHST & Reverse inference



Reverse inference: the engagement of a particular Y is inferred from finding the activation of a particular X.

Avoid the problem of reverse inference with

-> Hierarchical, model-based fMRI (verify the presence of cognitive processes first)?

-> Bayesian hypothesis testing?

-> Activation maps as priors?

Point-Null Fallacy: exactly zero-difference is virtually never true

-> Biology/social domain introduces small effects through complex causal relationships

-> Many underlying assumptions (Duhem-Quine thesis) (e.g., preprocessing)

Operational level

1. Relationship $x \sim y$
2. We predict y varies with x
3. $y{\sim}x_1$ and $y{\sim}x_2$ generate 2 different data point **distributions**

NHST

Statistical level (test-level)

- 2 statistical hypotheses: H0 (no difference) and H1 (difference - **can be anything**)
- Distributions from our 2 samples come from the same population distribution (cond. 1 & 2 follow H0)

$p < 1 - \alpha$ (i.e., p<.05):

- *Significant difference* = the risk to be wrong at (effect-value) is low enough.
  We can reject the Null Hypothesis because it is likely to be false.
- We reject H0; <u>we don’t accept H1</u> (**H1 can be anything**).
  We learn: it is very likely that our non-control condition doesn’t follow H0.

$p > 1 - \alpha$:

- *No significant difference* = the risk at (effect-value) to be wrong is too high.
  We failed to reject H0 because it is very not likely to be false
- We can’t conclude about conditions 1 & 2 except:
  We failed to reject a non-difference between cond.1 & 2. **We learn nothing** regarding H0 nor H1.

What evidence does NHST provide?

- What we can learn is restricted to our conclusions regarding H0 for 1 model via 1 NHST test

&

- We know nothing about how probable our results are

Null hypothesis significance testing: a **review** of an old and continuing controversy.

RS Nickerson - Psychological methods, 2000 - psycnet.apa.org

Null hypothesis significance testing (NHST) is arguably the most widely used approach to hypothesis evaluation among behavioral and social scientists. It is also very controversial. A ...

NACS 645 – The need for paradigms

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Scientific revolutions

A paradigm can be defined as the generally accepted concepts and practices of a field.

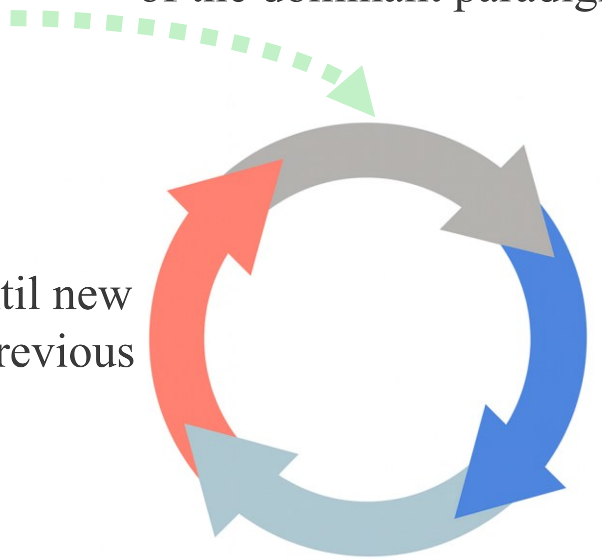
A paradigm shift is different from incremental developments

Pre-paradigm

Lack of consensus on procedures, theories, presuppositions, etc.

Normal Science

Puzzles are solved within the context of the dominant paradigm



Paradigm Shift

Competition among ideas until new paradigm that accounts for previous puzzles & anomalies

Accumulating Anomalies

Anomalies unaccounted by paradigm
Undermines the practice of normal science

Crisis

Widespread failure of confidence in paradigm

Kuhn, 1962. *The Structure of Scientific Revolutions*

Paradigms

More specifically, a paradigm is the shared set of symbolic generalizations, models, values, and examplars that organize how a scientific community defines, investigates, and evaluates problems.

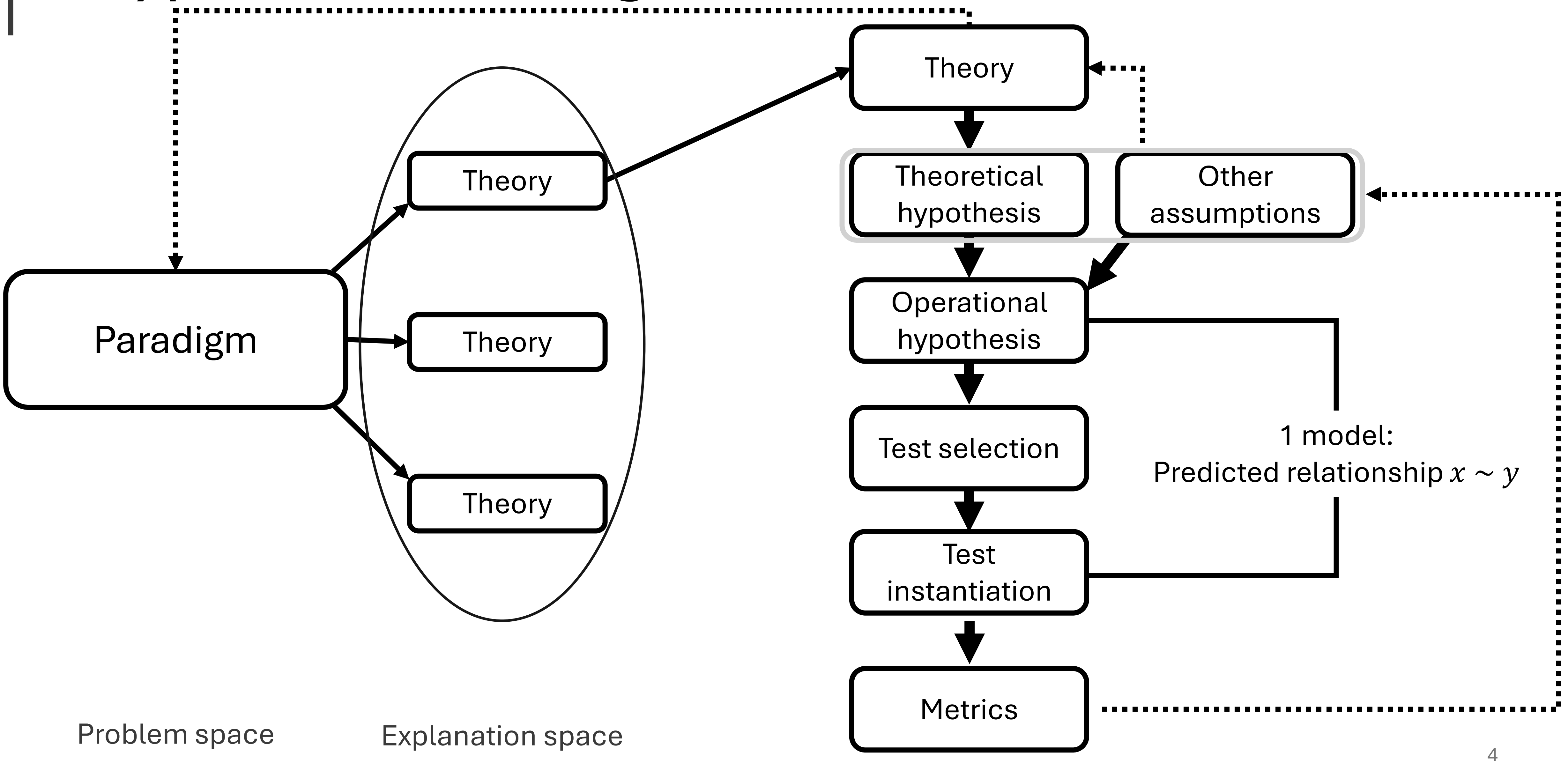
- **Behavior:**
  - **Behaviorism** *(black box)*,
  - **Cognitivism** *(*information-processing),
  - **Symbolism** *(steps)*,
  - **Connectionism** *(*distributed networks),
  - **Embodied and enactive cognition**
- **Explanation:**
  - **Reductionism** *(reduced to physical)***,**
  - **Emergentism** *(emerges from physical)***,**
  - **Pluralism?** *(multiple explanatory levels)*
- **Brain:**
  - **Localizationism,**
  - **Functionalism,**
  - **Computational neuroscience ,**
  - **Dynamic systems / Networks?**

- **Any domain-level, area-level, function-level, process-level, …**
- **Methodology** *(not Kuhnian):*
  - **Neurophysiology** *(electrophy, single-unit),*
  - **Neuroimaging** *(PET, fMRI, EEG, MEG),*
  - **Interventional** *(tDCS, TMS, optogenetics)*

Not aware of any consensus on taxonomy of paradigms

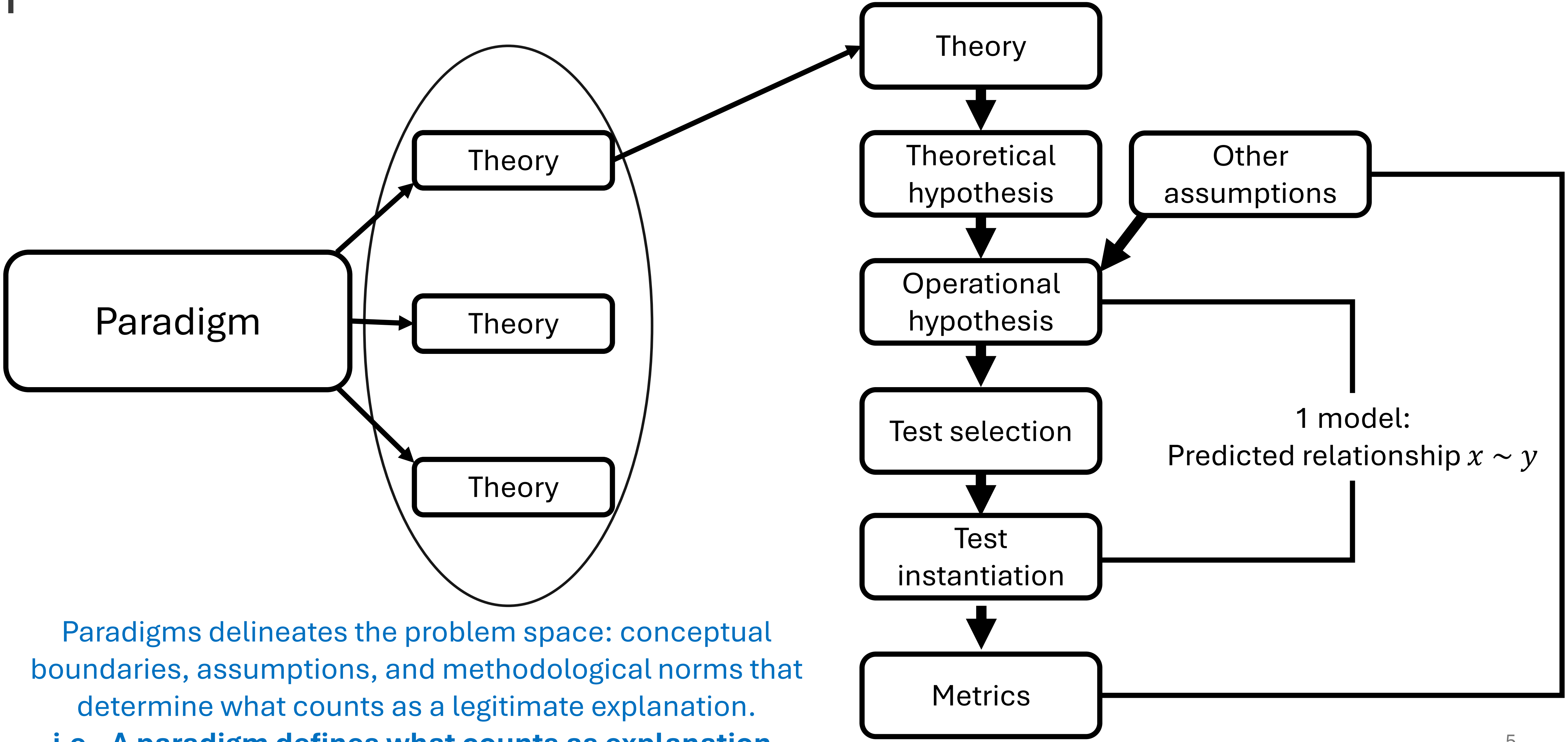
Hypothesis testing

Paradigm: shared set of symbolic generalizations, models, values, and examplars



Hypothesis testing

Paradigm: shared set of symbolic generalizations, models, values, and examplars



Paradigms delineates the problem space: conceptual boundaries, assumptions, and methodological norms that determine what counts as a legitimate explanation.

i.e., A paradigm defines what counts as explanation.

One cannot escape paradigms

All hypotheses have underlying assumptions.

All assumptions are grounded in a body of work (~axioms) that cohere within a given paradigm.

Accepting some assumptions automatically (& logically) rules out competing assumptions.

One cannot escape paradigms.
All hypotheses have underlying assumptions.
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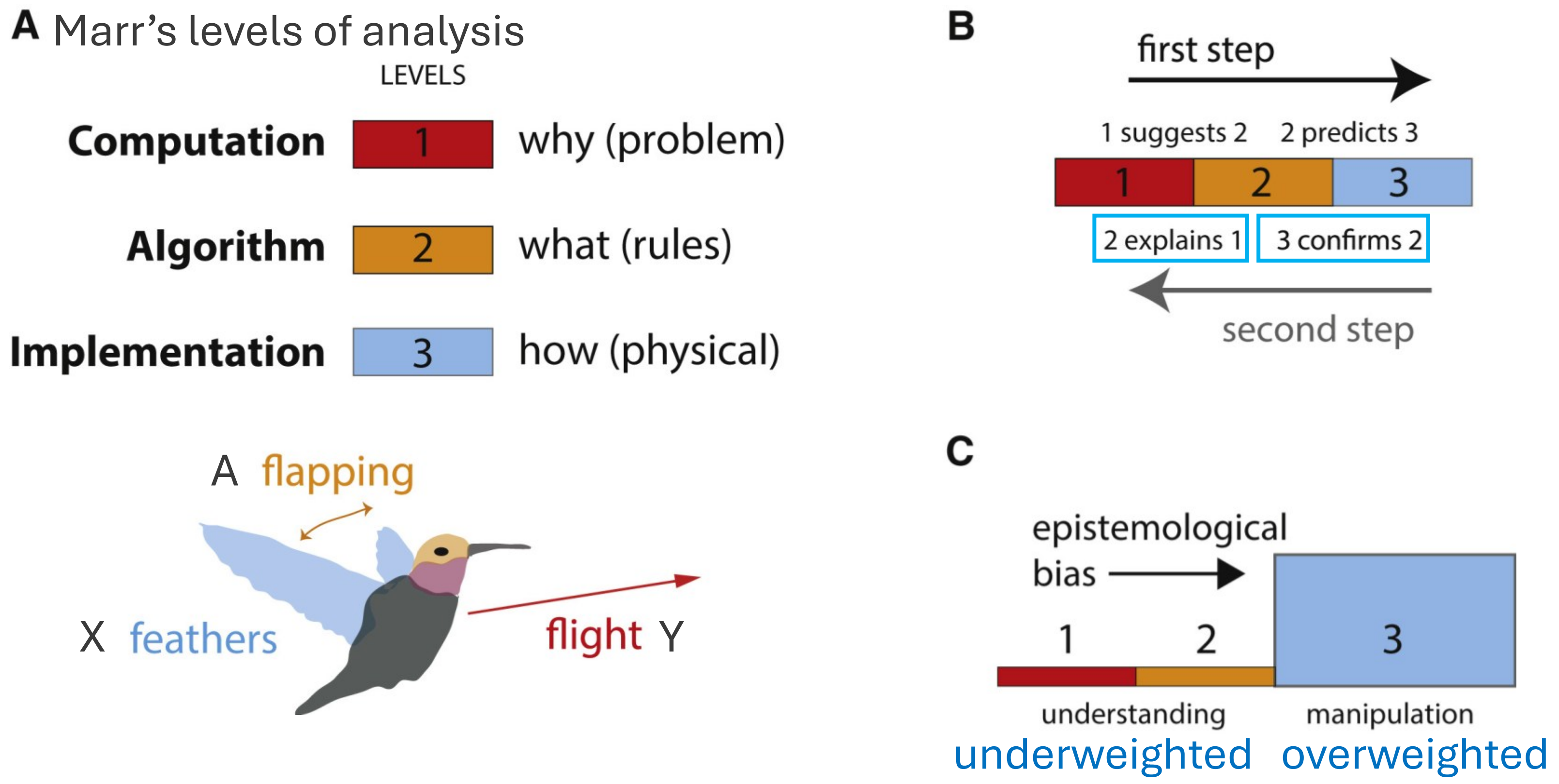
Accepting some assumptions logically rules out competing assumptions.

Krakauer et al., 2017. *Neuron*

What are theories for



Marr:
A model only counts as explanatory if it captures a sufficient range of the processes it claims to represent.

1. **Describe**: We observe X, Y; X is *involved* in Y
2. **Explain**: Y occurs *because* the system is solving a problem by algorithm A implemented via X
3. **Predict**: Given state S and model M (Y~X), the system will produce $\hat{Y}$

Confirmation: A is likely because X is present

Reverse inference: Y is present because X is present

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- **Bickle, 2016. *Frontiers in Systems Neuroscience***

Neuroscience advances through "tool-driven revolutions": moments when a new technique transforms experimental practice and thereby shifts what counts as legitimate explanation.

- **Parker, 2018. *Biology & Philosophy***

Paradigm shifts in neuroscience are primarily conceptual. Tools were necessary for empirical progress but insufficient to drive Kuhnian revolutions.

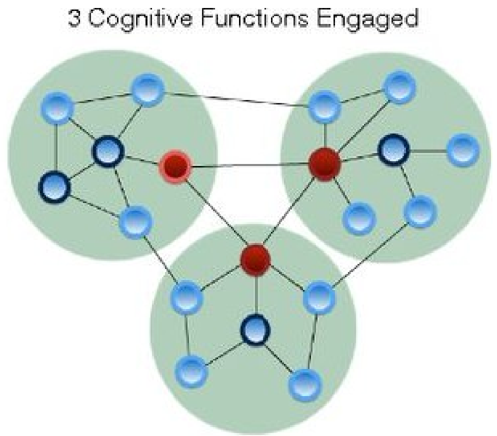
Not aware of any consensus on taxonomy of paradigms

The need for qualitative leaps

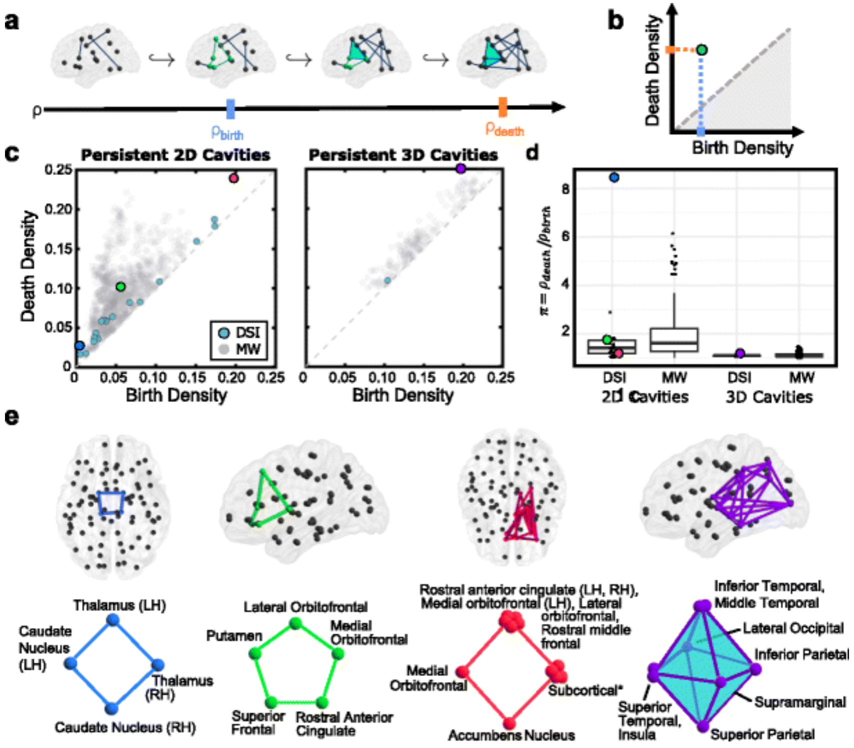
Paradigms impose constraints on problem formalization and grammar

Fodor’s (1983) modularity

1. **Domain specificity**
2. **Mandatory operation**
3. **Limited central accessibility**
4. **Fast processing**
5. **Informational encapsulation**
6. **‘Shallow’ outputs**
7. **Fixed neural architecture**
8. **Breakdown patterns**
9. **Ontogenetic pace**



Bertolero, Yeo & D’Esposito, 2015. PNAS.
Model of *modular functional architecture*



Sizemore et al., 2017. *Journal of Computational Neuroscience*
Dynamics of cliques and cavities

Old paradigm
Structural

Qualitative leap
Connectionist

New paradigm?
Topological

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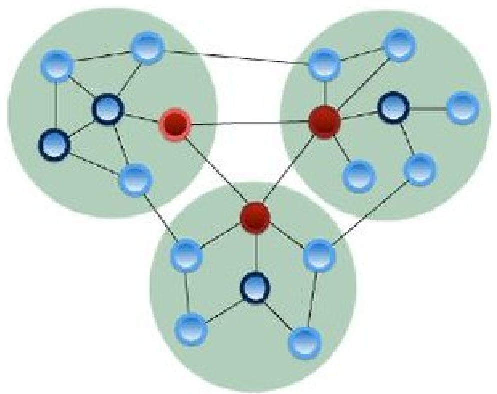
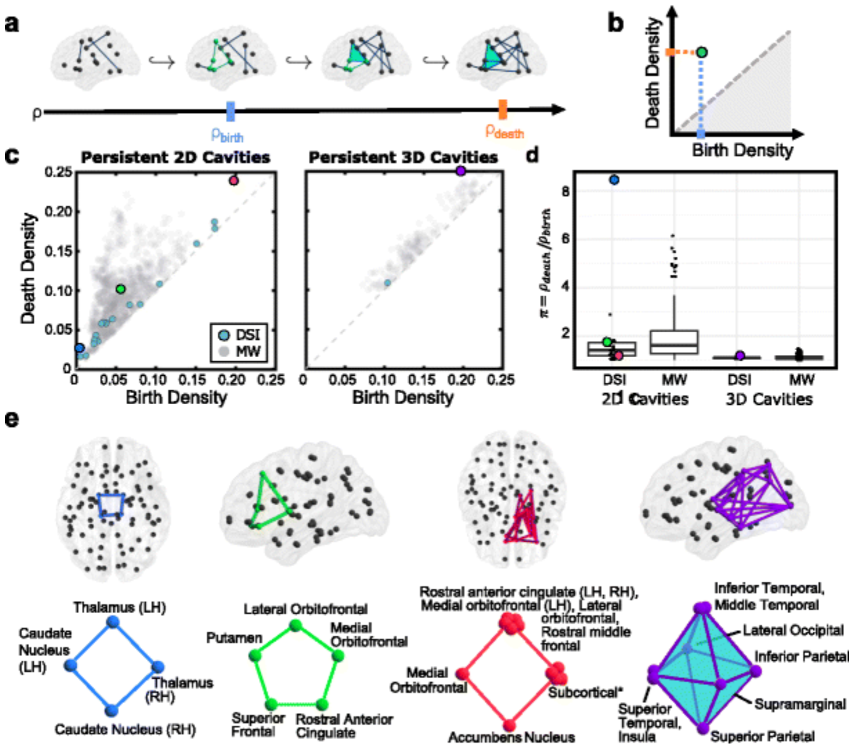


Bertolero, Yeo & D'Esposito, 2015. PNAS.



Sizemore et al., 2017. *Journal of Computational Neuroscience*

What counts as explanation?

If the current paradigm is topological, does a structural account counts as explanation?

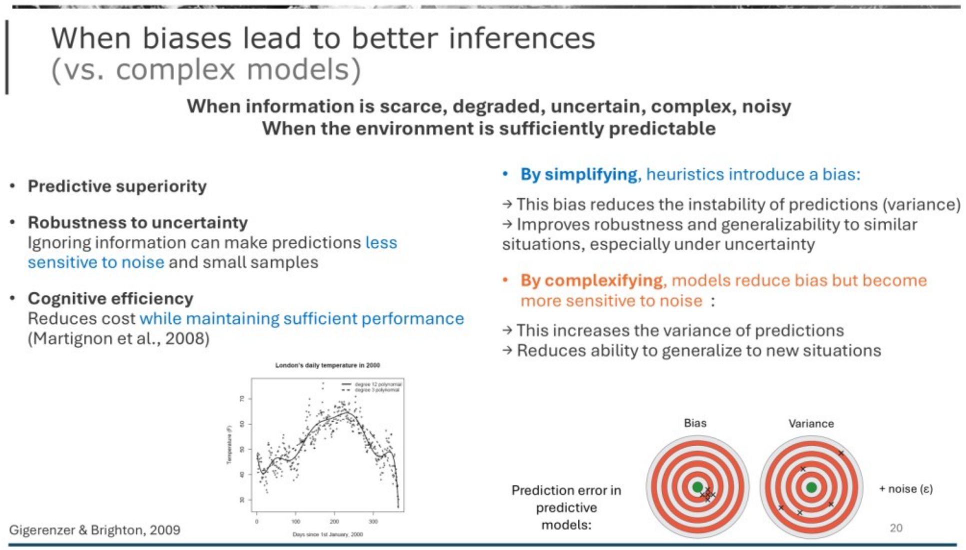
Implementing Occam’s razor Or Flatland fallacy?

Gigerenzer & Brighton, 2009. *TICS*
Jolly & Chang, 2019. *Topics in Cognitive Science*

Parsimony can lure us toward simplistic accounts of high-dimensional problems (flatland fallacy).

- If parsomonious is preferred between many explanations (Occam’s Razor, higher truthlikeness) &
- If psychological phenomenon are high-dimensional,
- How can we form an ethos for evaluating the plausibility of hypotheses that account for psychological phenomenon?
    - Are parsimonious hypotheses/models better?

When small sample sizes and high-dimensional signals, lower dimensional models with greater bias error make more accurate out-of-sample predictions.



- **We benefit from parsimony and bias** (low-dim hypotheses) **when predicting complex psychological phenomenon from small, degraded, uncertain, noisy datasets.**
- **We benefit from complexity and total evidence** (high-dim hypotheses) **when predicting complex psychological phenomenon from large datasets.**