

Models as testable hypotheses

Readings for today

- A Survey of Some Fundamental Problems. In Popper, K. (1959). The logic of scientific discovery. Routledge.
- Guest, O., & Martin, A. E. (2021). On logical inference over brains, behaviour, and artificial neural networks. *Psyarxiv*

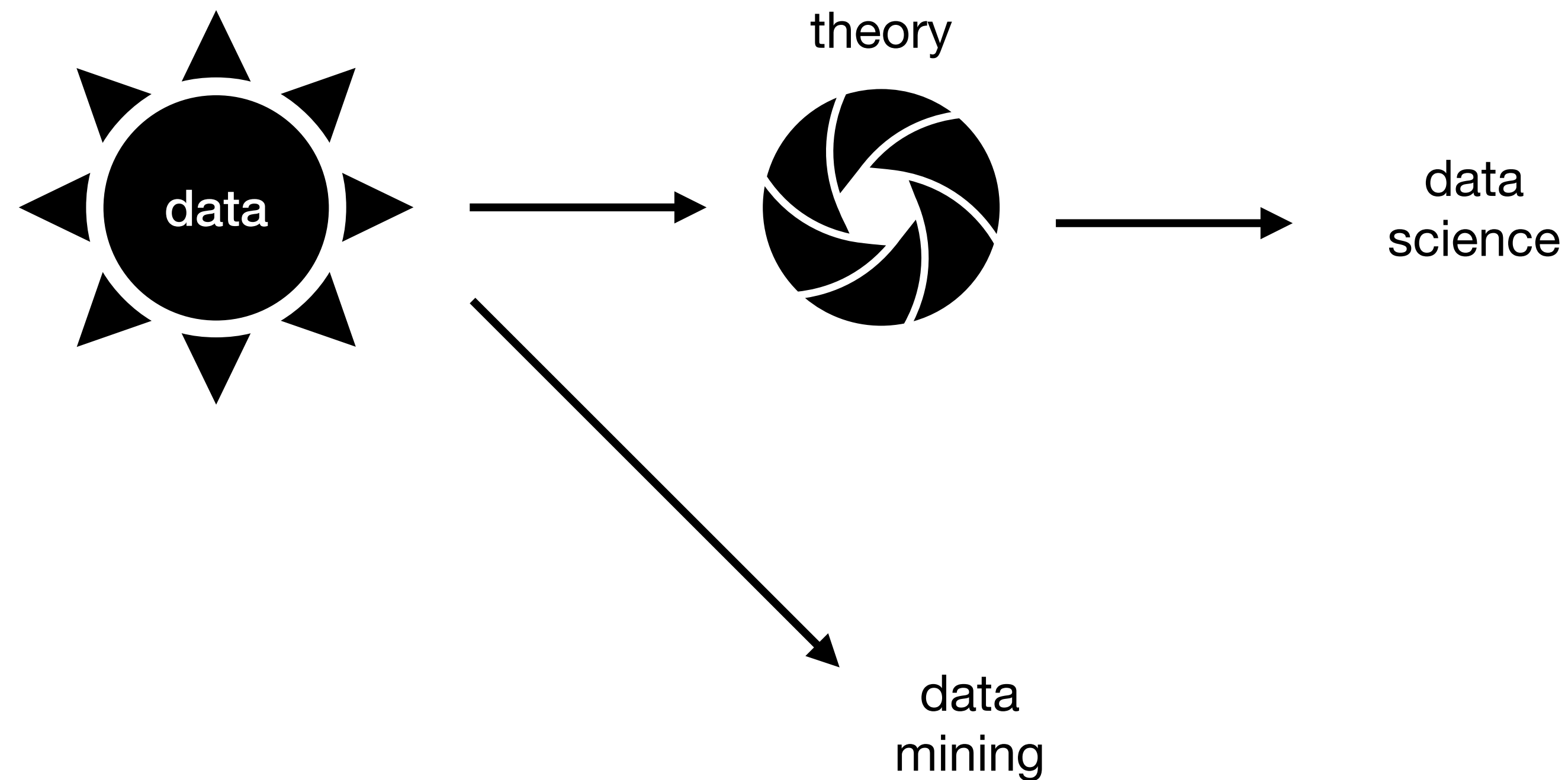
Topics

1. Science vs. metaphysics
2. Models as mediators
3. Theory vs. hypothesis
4. A naturally testable hypothesis

Science vs. metaphysics

Data science is a *science*

Goal: Develop a clear and veridical understanding of the story *behind* your data by evaluating it from a theoretically driven perspective.



The problem of demarcation

Problem: What distinguishes a scientific (aka- empirical) theory from a metaphysical theory (aka- non-empirical)?

Modus ponens (induction)

$$P \rightarrow Q, P \vdash Q$$

If P then Q , thus if P is true Q is also true.

Example: “There are black swans.”

↖
Exhaustive search required.

Modus tollens (deduction)

$$P \rightarrow Q, \neg P \vdash \neg Q$$

If P then Q , thus if P is false Q is also false.

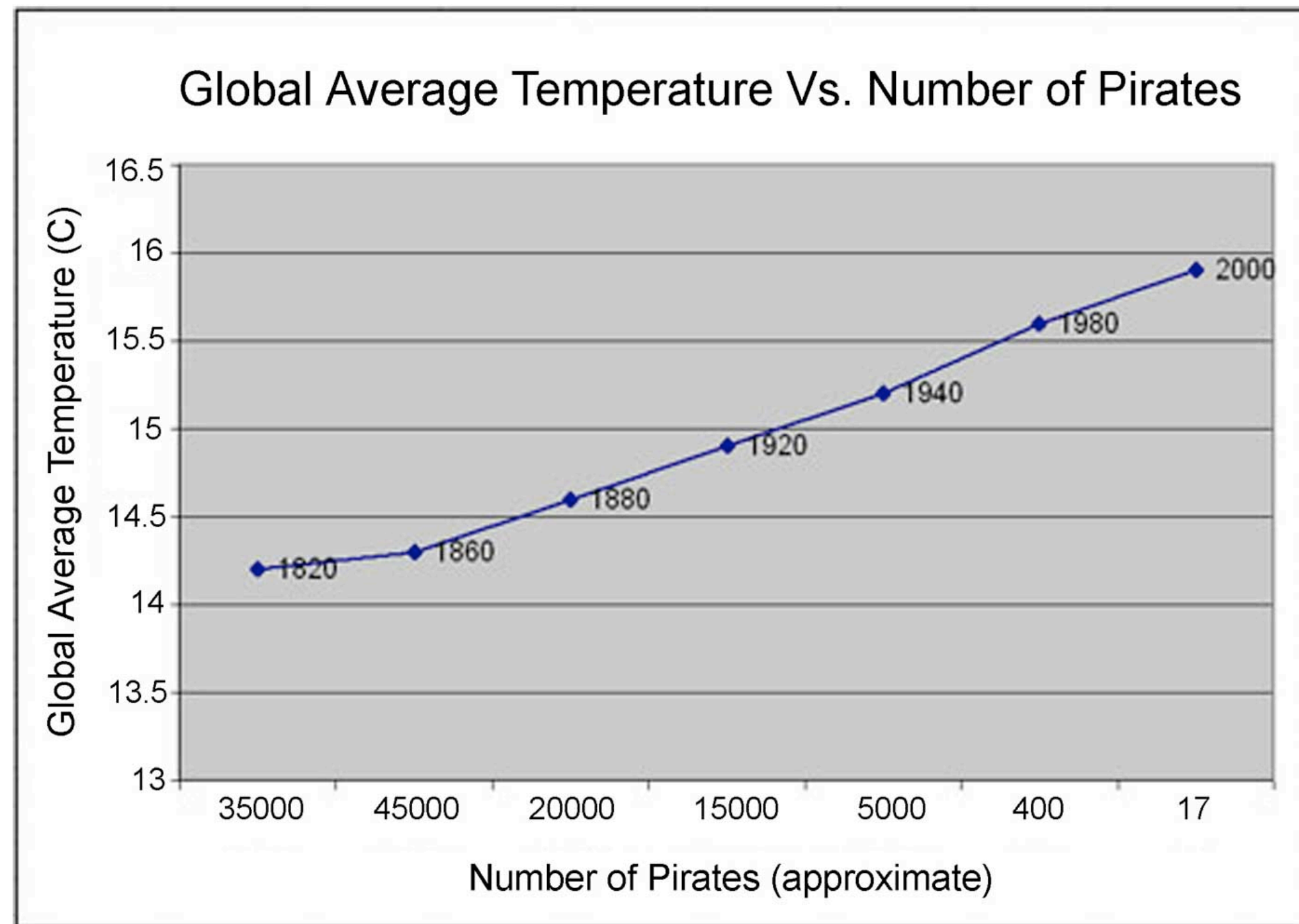
Example: “All swans are white.”

↗
Just 1 counter point to disprove.

The problem of induction

Example: “Pirates (P) prevent global warming (Q).” $P \rightarrow Q, P \vdash Q$

STOP GLOBAL WARMING: BECOME A PIRATE



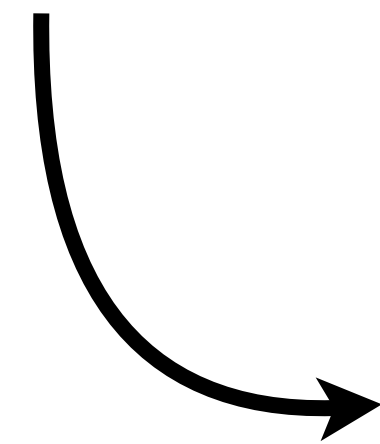
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- Positive evidence (e.g., negative correlation between pirate population and global temperature) confirms.
- Ambiguous evidence is inconclusive.
- Negative evidence (e.g., association in the opposite direction) is still used as evidence of the existence of $P \rightarrow Q$

Requirements

A deduction-based theoretical system must:

1. Be a *synthetic*, non-contradictory representation of a *possible* world.
2. Represent the world of physical experience (i.e., satisfy the criterion of demarcation).
3. Be distinguishable from other representations of the world of experience.



The only empirical statements are those that can be proven wrong

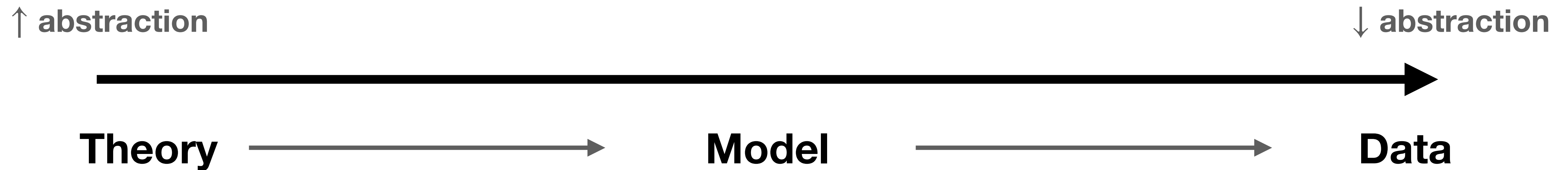
Degrees of falsifiability

1. A statement x is said to be 'falsifiable in a higher degree' or 'better testable' than a statement y , or in symbols: $Fsb(x) > Fsb(y)$, if and only if the class of potential falsifiers of x includes the class of the potential falsifiers of y as a *proper subclass*.
2. If the classes of potential falsifiers of the two statements x and y are identical, then they have the same degree of falsifiability, i.e. $Fsb(x) = Fsb(y)$
3. If neither of the classes of potential falsifiers of the two statements includes the other as a proper subclass, then the two statements have non-comparable degrees of falsifiability ($Fsb(x) \parallel Fsb(y)$).

↑ **Falsifiability** \longrightarrow ↑ **Empirical content**

Models as mediators

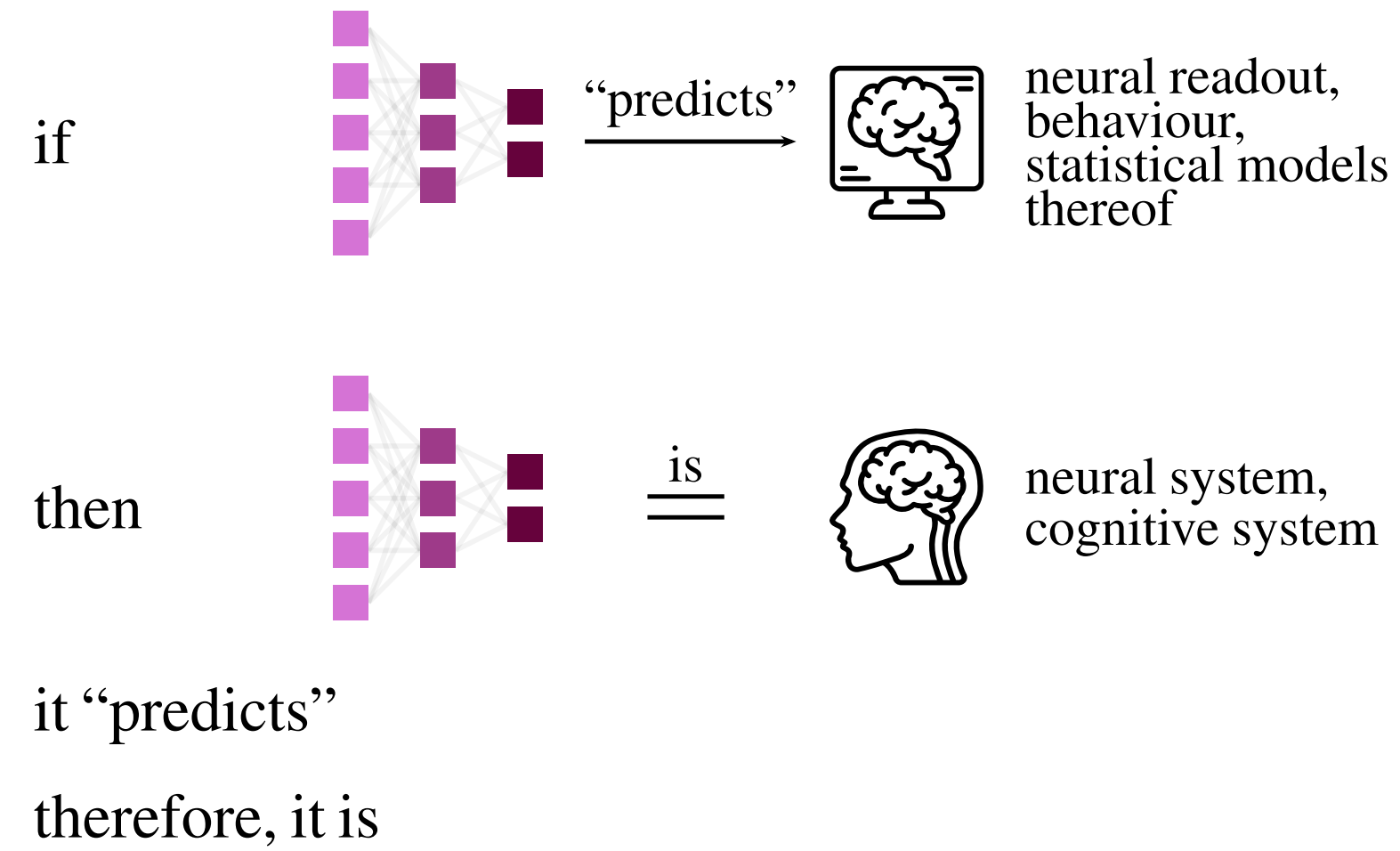
Role of models in science



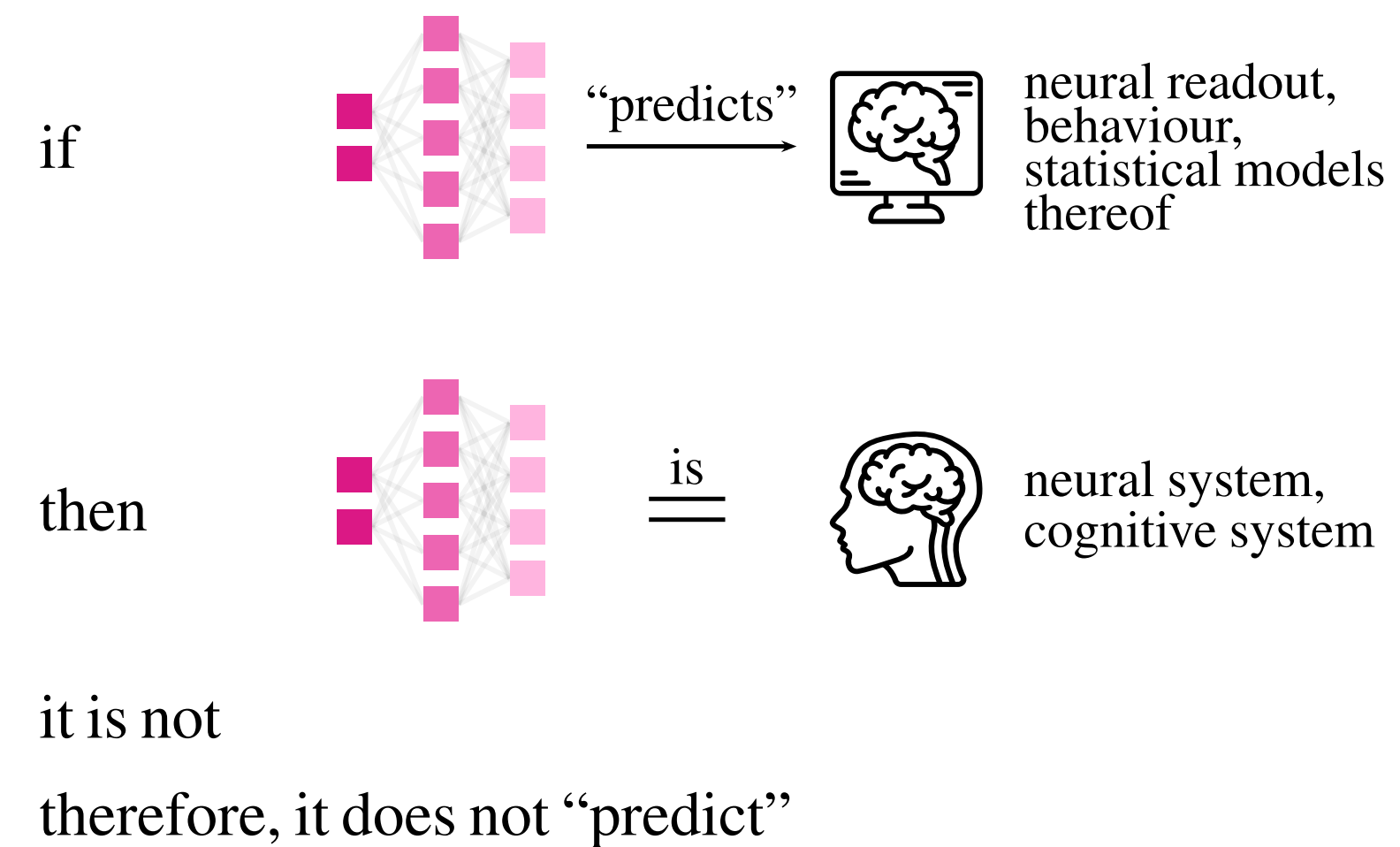
Models act as mediators between theory and empirical experience (i.e., data)

Proper inference from models

Modus ponens (induction)



Modus tollens (deduction)



Affirming the consequent

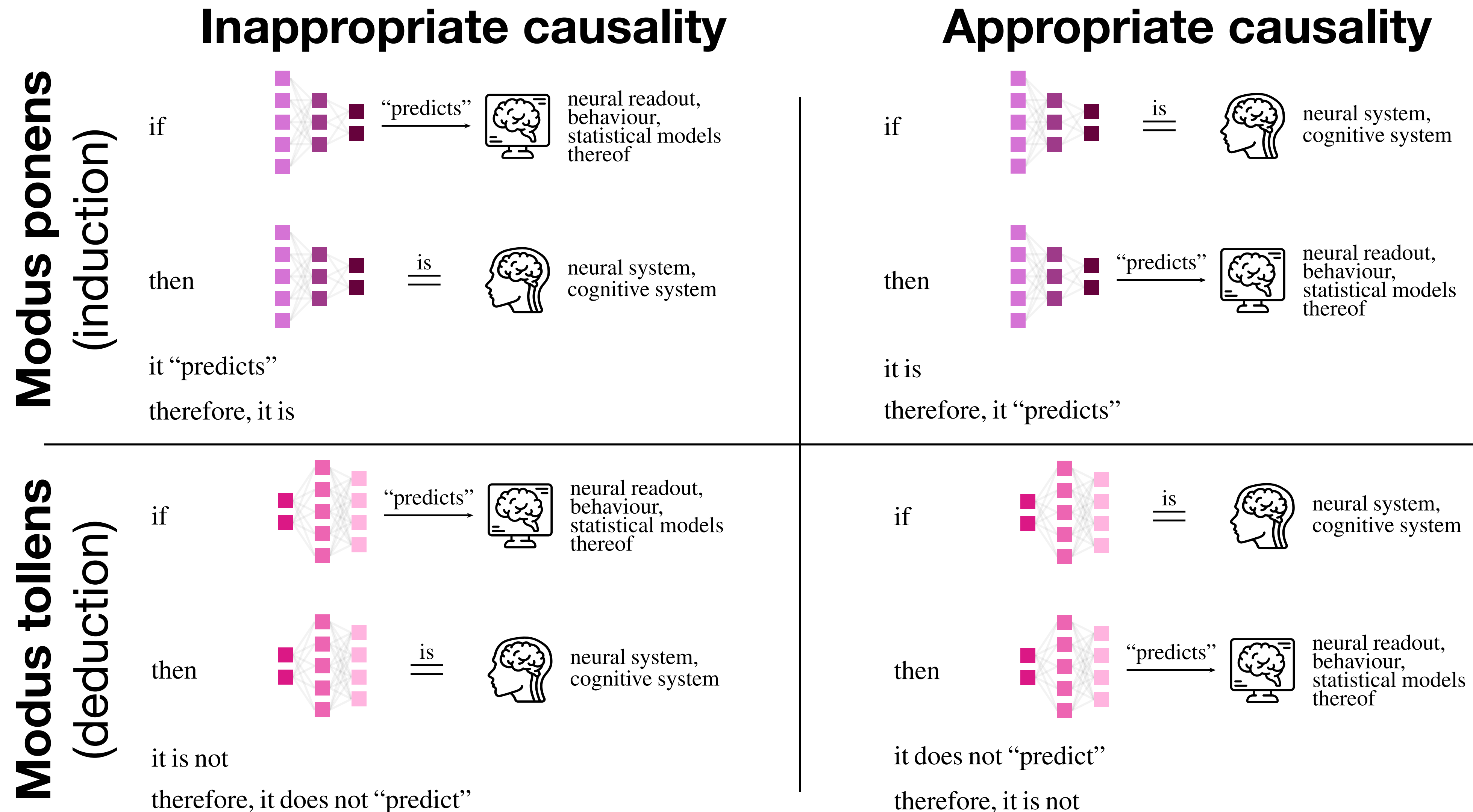
Modus ponens with inappropriate causality

If the model correlates with human behavioural and/or neuroimaging data, then the model does what humans do.

$$(P \rightarrow Q)$$

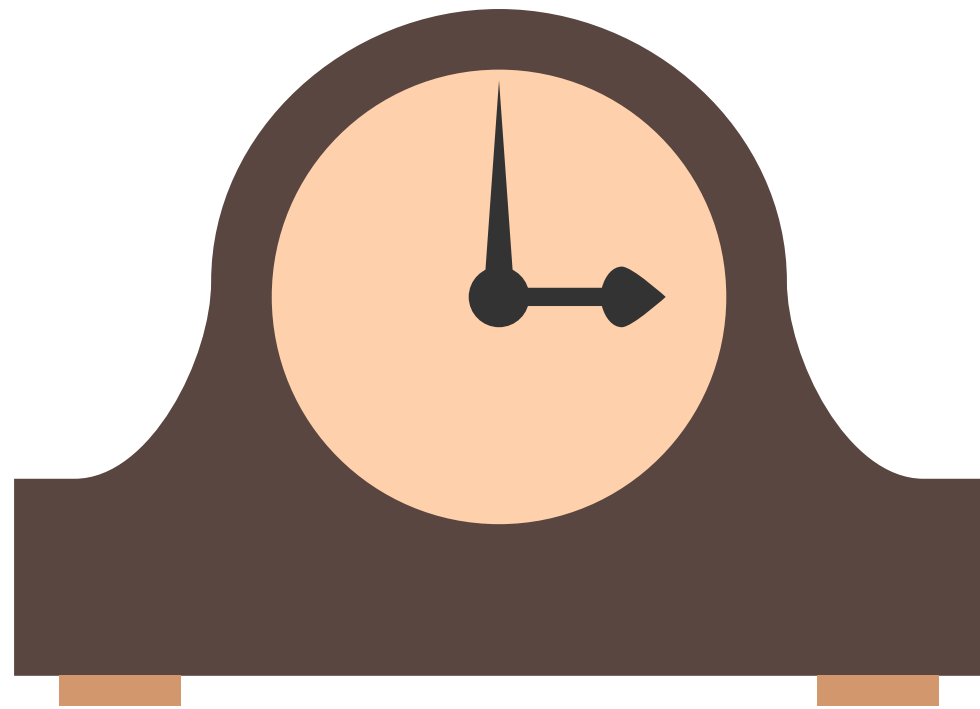
- Inverts the causal direction
- “The ‘sense’ of Q is not contained in the ‘sense’ of P — but vice versa.” (Sundholm, 1994)
- Justifies the explanation as the thing to be explained.
- All correlations are valid causal mechanisms.

Proper inference from models



The problem of multiple realizability

Function



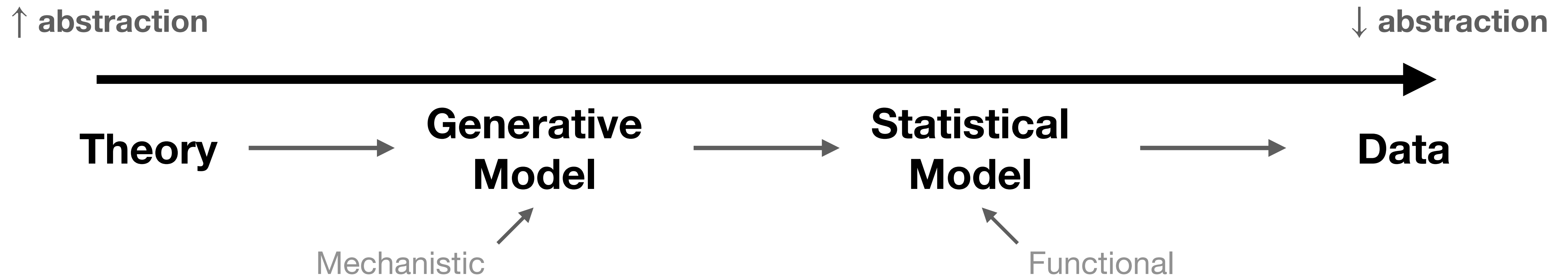
Functional role:

The high-level description in terms of how inputs are transformed into outputs.

Mechanistic role:

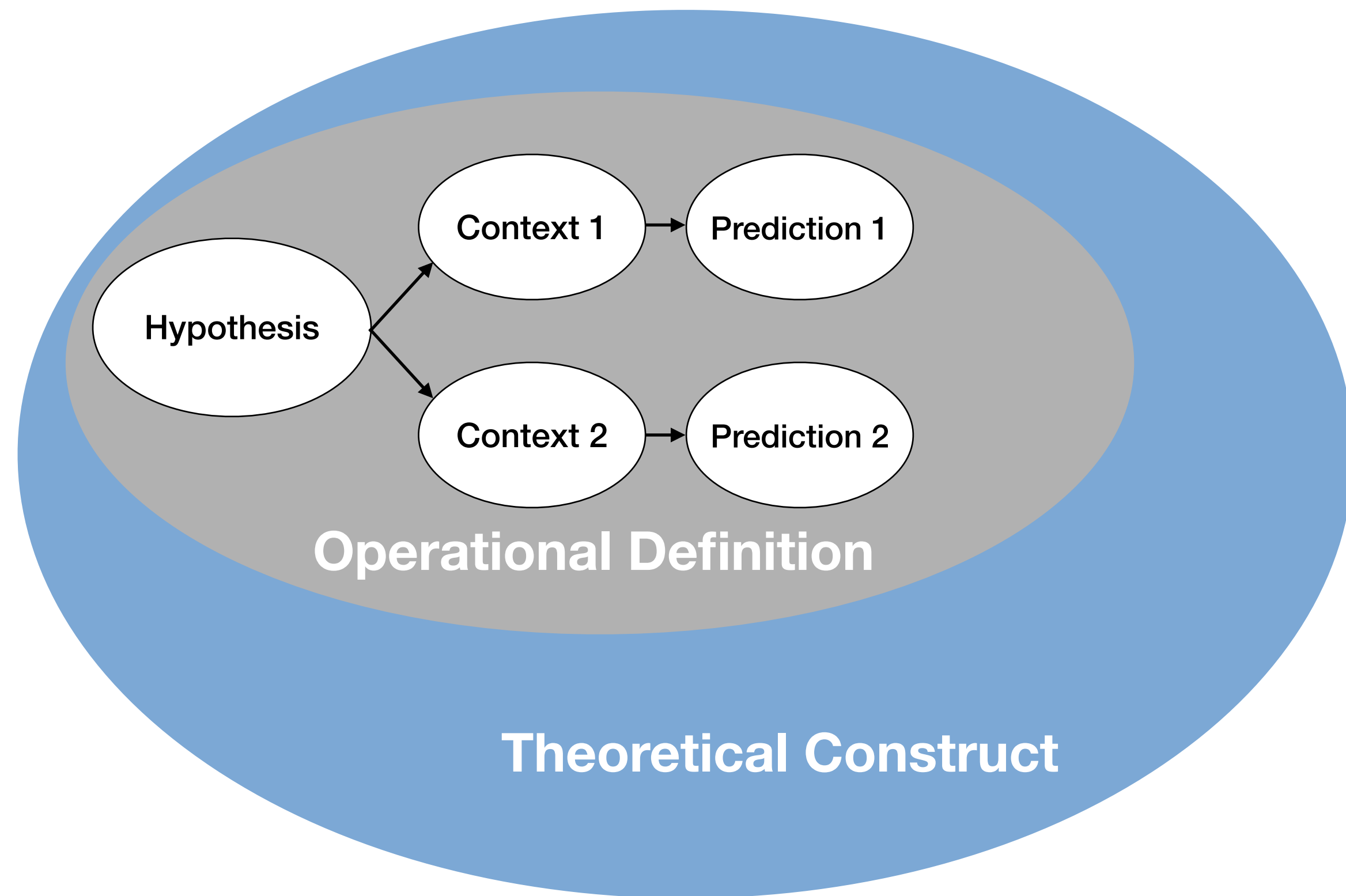
The way in which a function is implemented in a physical substrate.

Two types of models



Theory vs. hypothesis

Refining focus from theory to tests



Theoretical Construct: A general description of a process or capacity (e.g., working memory)

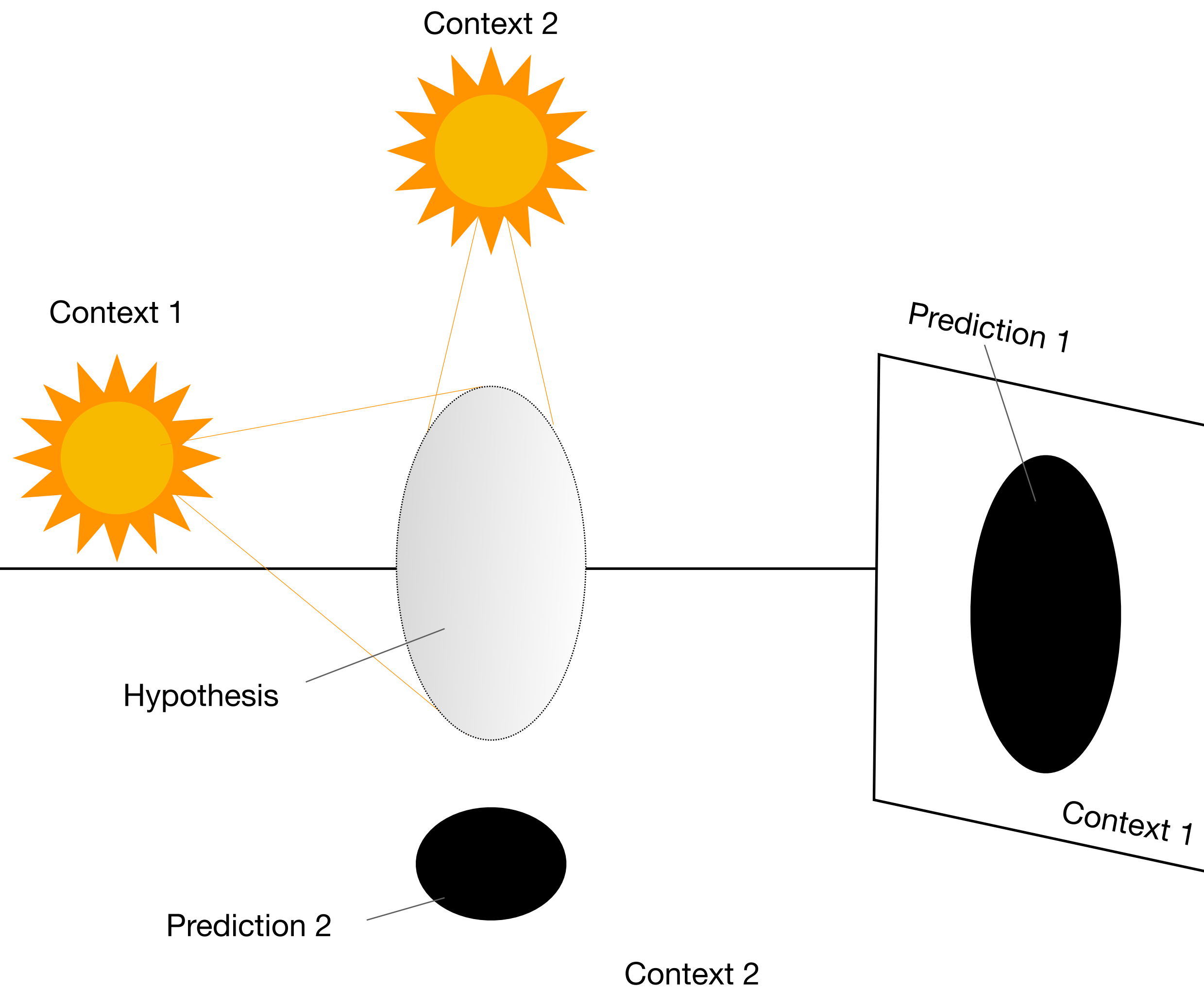
Operational Definition: Reformulation of the theory in terms of a process that can be tested (e.g. number of items that can be recalled after a short delay).

Hypothesis: A testable statement about the operational definition as a set of relations (e.g., humans have an upper limit to the number of items they can recall after a 1min delay).

Context: Specific environment that the hypothesis is evaluated in (e.g., digit span task).

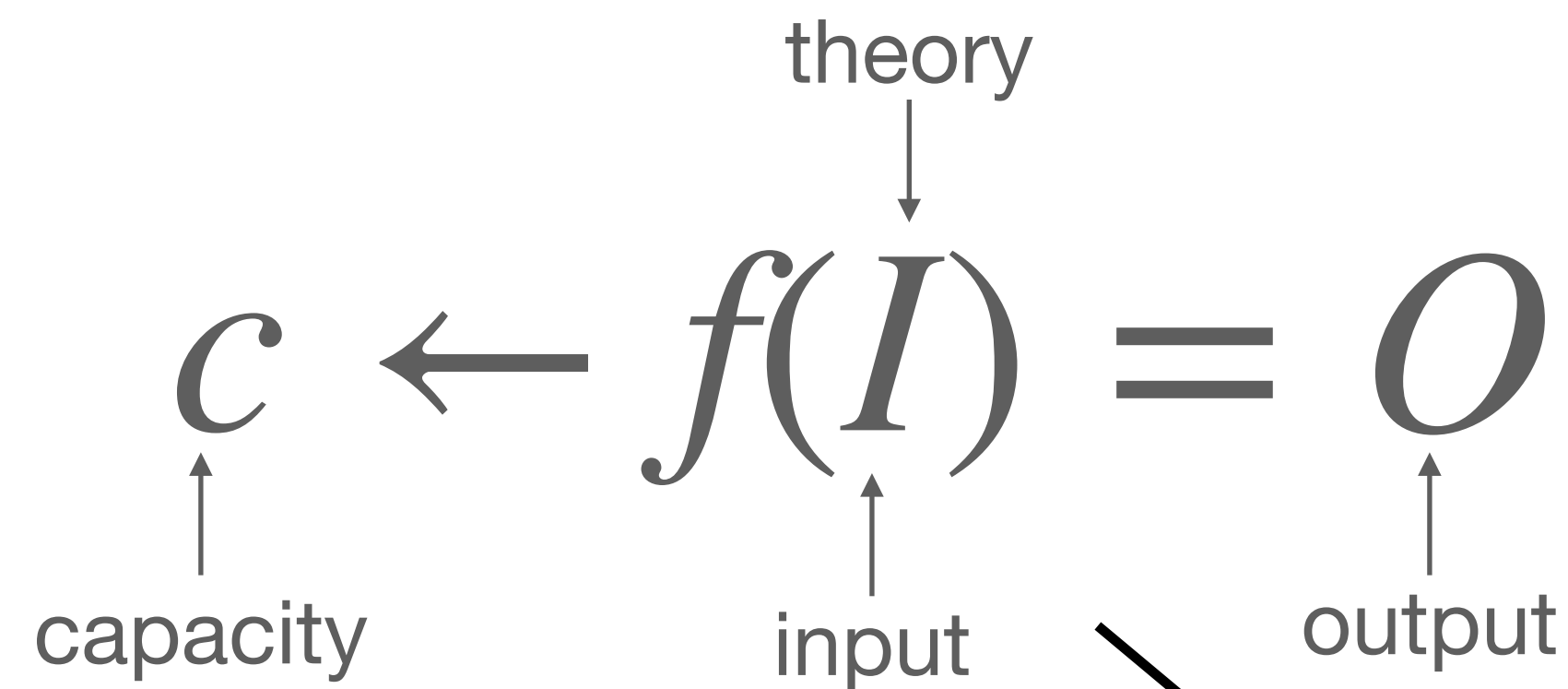
Prediction: Specific formulation of the hypothesis in a specific context (e.g., recall errors will increase as digit span increases).

Predictions as projections of theory



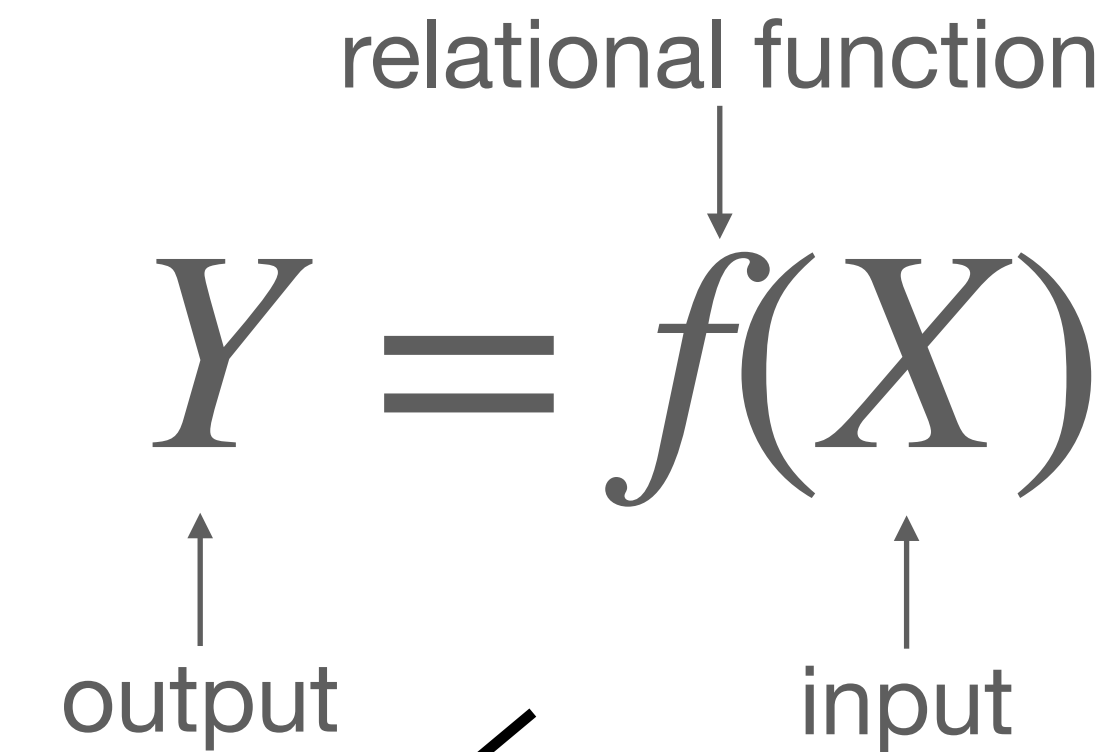
Theory → Hypothesis → Statistical Model

Fundamental form of a theory



(van Rooij & Baggio 2020)

Fundamental form of a statistic



f

The form of a statistical test, f , is a **quantitative** description of a specific hypothesis being evaluated (whether or not a p-value is calculated)

quantitative = testable = falsifiable

A naturally *testable* hypothesis

Types of hypotheses

Null (H_0) Hypothesis: The hypothesis that needs to be rejected based on your theoretical premise.

- The status quo if your theory is wrong.

Research (H_i) Hypothesis: An alternative to the H_0 that is consistent in form to your theoretical premise

- One of many.

Identification of a null hypothesis (or space of null hypotheses) to be rejected immediately frames your hypothesis as falsifiable and, thus, testable.

Theory → Hypothesis → Statistical Model

Theory: Hunger impairs working memory.

Operational Definitions:

1. Hunger is the bodily state that occurs when no food is consumed for 4 or more hours.
2. Working memory is how many items that can be recalled after a short period of time in the Digit Span task.

Hypotheses:

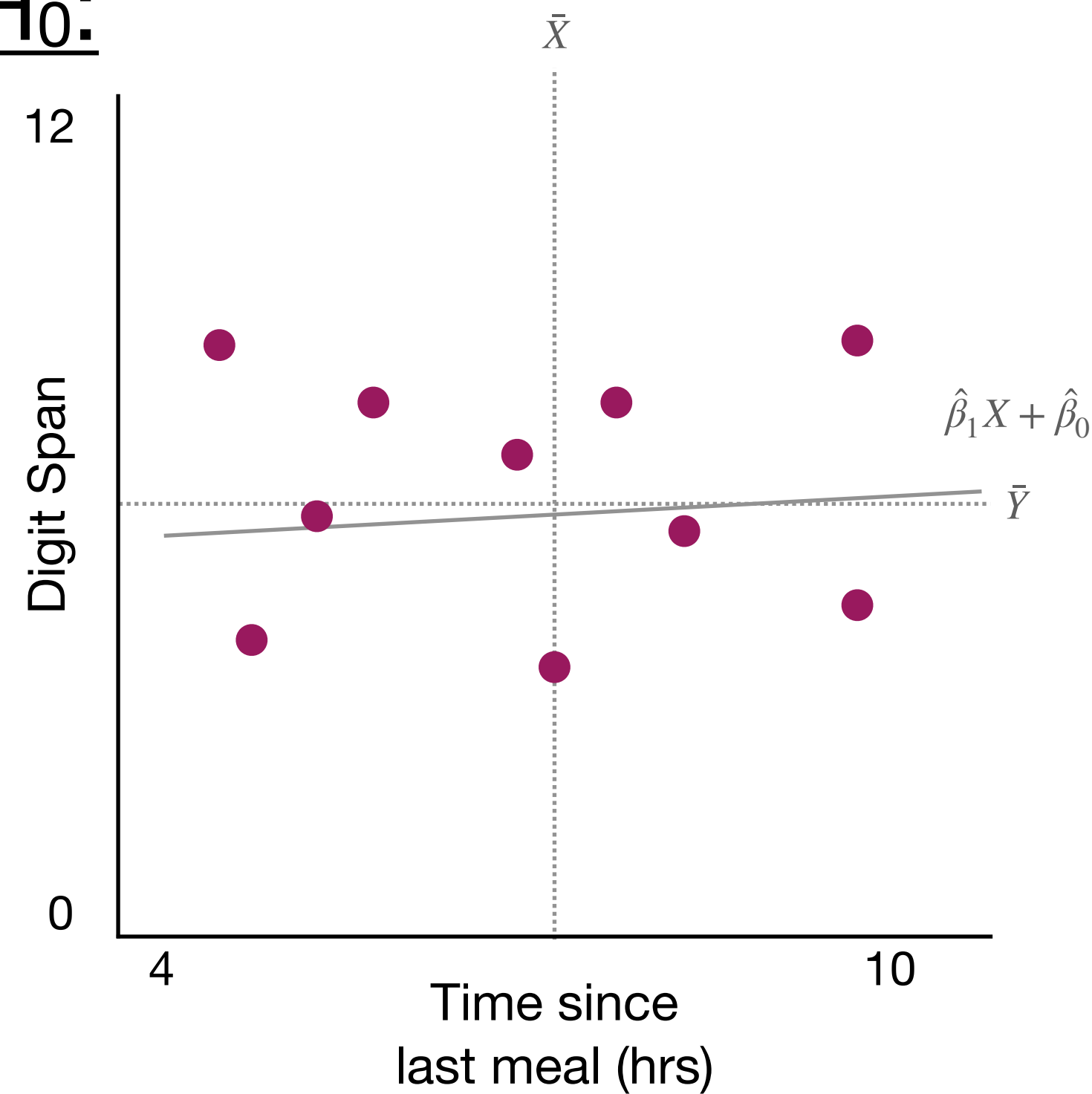
H_0 : Digit recall does not change with hours since last meal.

H_A : Digit recall reduces with time since last meal.

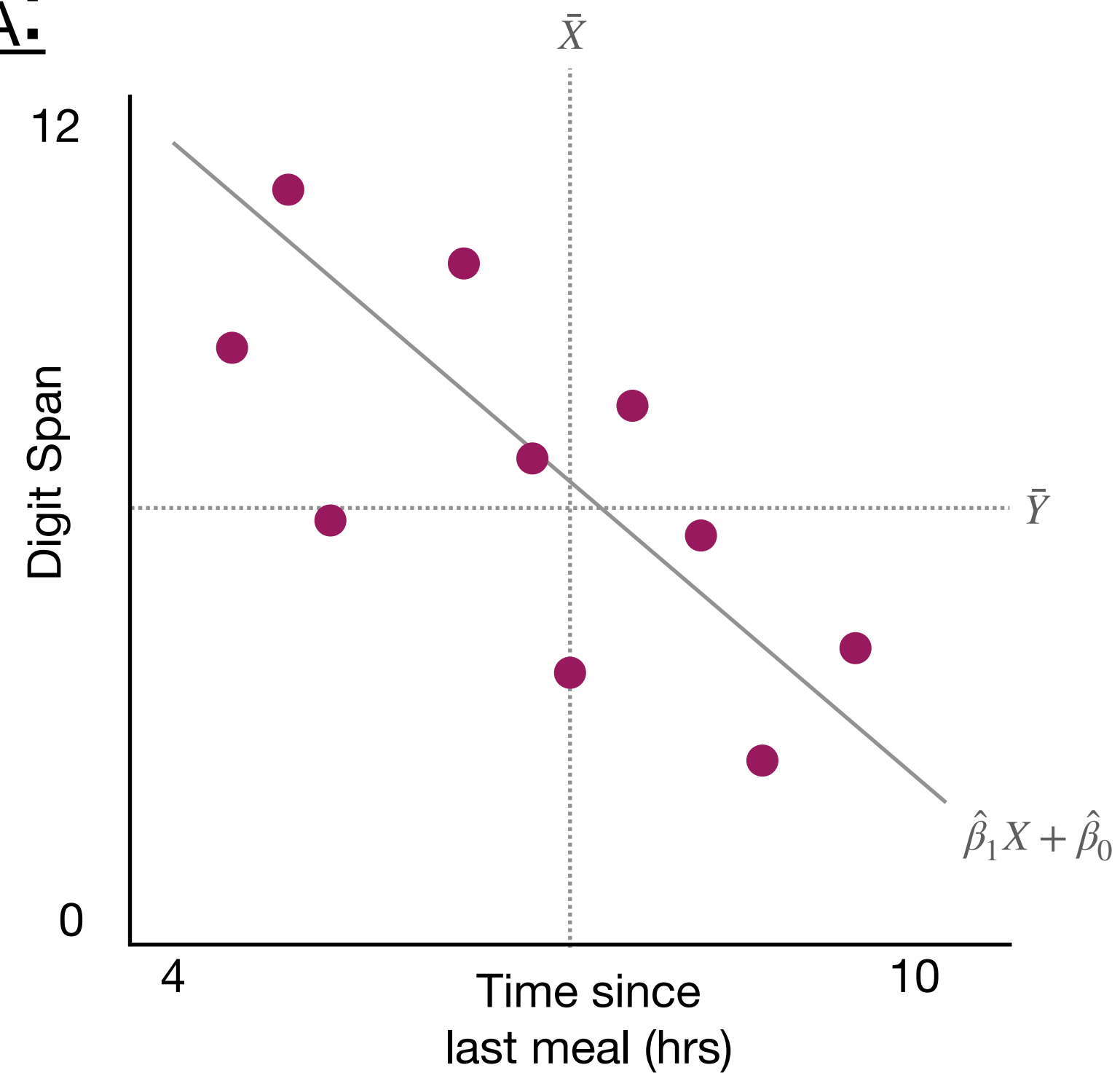
H_B : Digit recall increases with time since last meal.

Theory → Hypothesis → Statistical Model

H₀:



H_A:



Functional form:

$$Y_{ds} = \beta_1 X_{time} + \hat{\beta}_0$$

Hypotheses:

$$H_0: \beta_1 = 0$$

$$H_A: \beta_1 < 0$$

$$H_B: \beta_1 > 0$$

Take home message

- Falsifiability is the main demarcation distinguishing science from non-scientific inquiry.
- Models act as mediators linking high level theory to empirical data (aka-experience).
- Statistical models function as inherently falsifiable hypotheses generated from high-level theories.