What is a theory?

Readings for today

- van Rooij, I., & Baggio, G. (2020). Theory before the test: How to build high-verisimilitude explanatory theories in psychological science. PsyArXiv
- Guest, O., & Martin, A. E. (2020). How computational modeling can force theory building in psychological science. PsyArXiv

Topics

1. What is a theory in psychology & neuroscience?

2. Formulating a “good” theory

What is a theory in psychology & neuroscience?

The theories we have

Schemata Theory

Prospect Theory

Psychodynamic Theory

Reinforcement Learning

Embodied cognition

Affordances

Social contamination

Associative Learning

Psychosocial stages

Connectionism

(Verbal) ⟷ (Quantitative)

What is a theory?*

* in psychology & neuroscience

Set of abilities

Theory: A description of a set of *capacities*.

Primary explananda (things to be explained)

Informal theory: Building a description based on a collection of observed effects.

Formal theory: Constructing a description using formal logic prima facie via a *constructive strategy.*

1) Plausibility constraints

2) Theoretical cycle

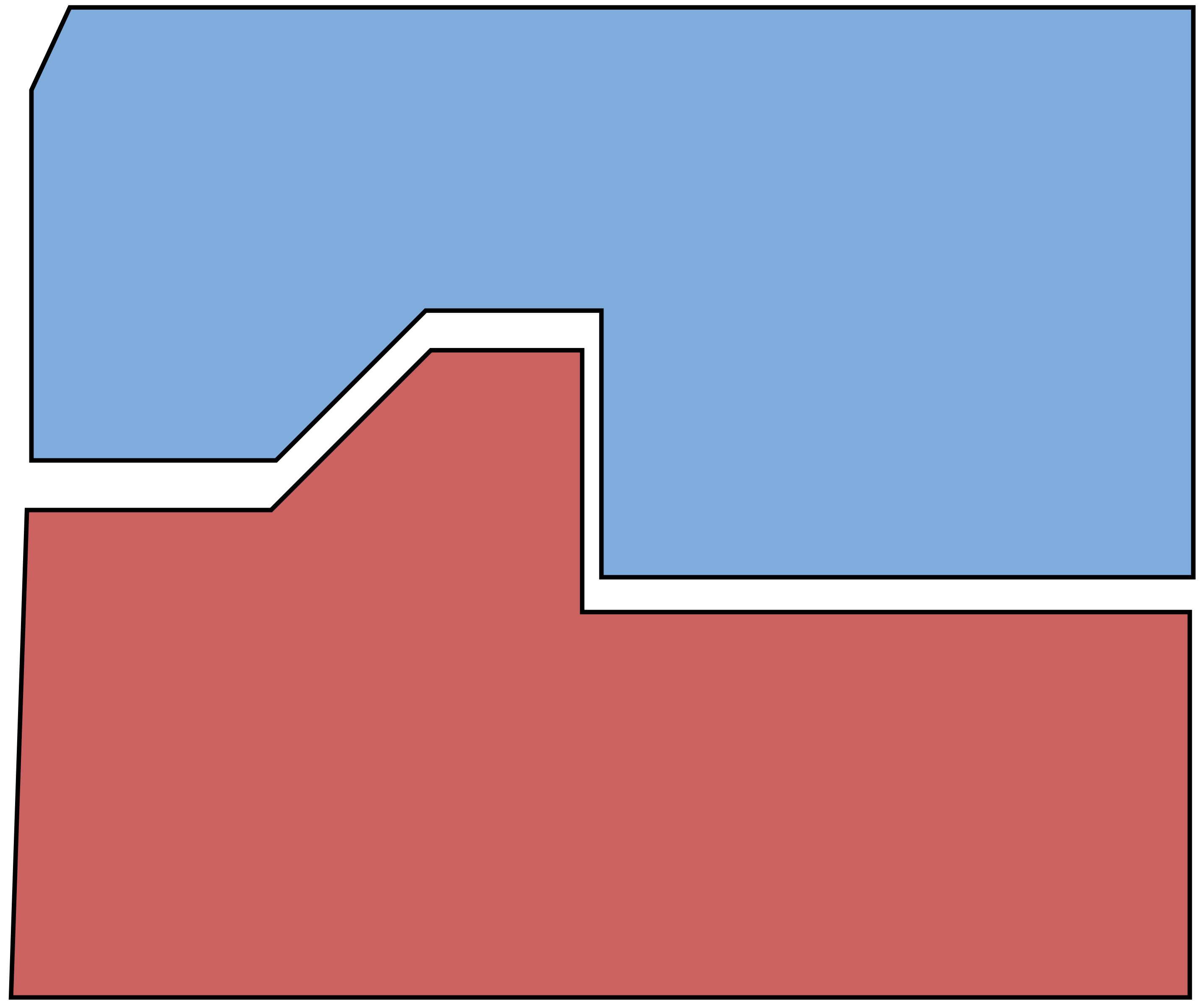
(van Rooij & Baggio 2020)

Plausibility constraints

Assumptions:

1. Theory must provide a means for making rigorous tests possible.

2. Should restrict the number and types of theories/hypotheses considered for testing.



(van Rooij & Baggio 2020)

Marr’s levels of analysis

	LEVELS
Computation	1
Algorithm	2
Implementation	3

(van Rooij & Baggio 2020; Marr 1982; Krakauer et al. 2017)

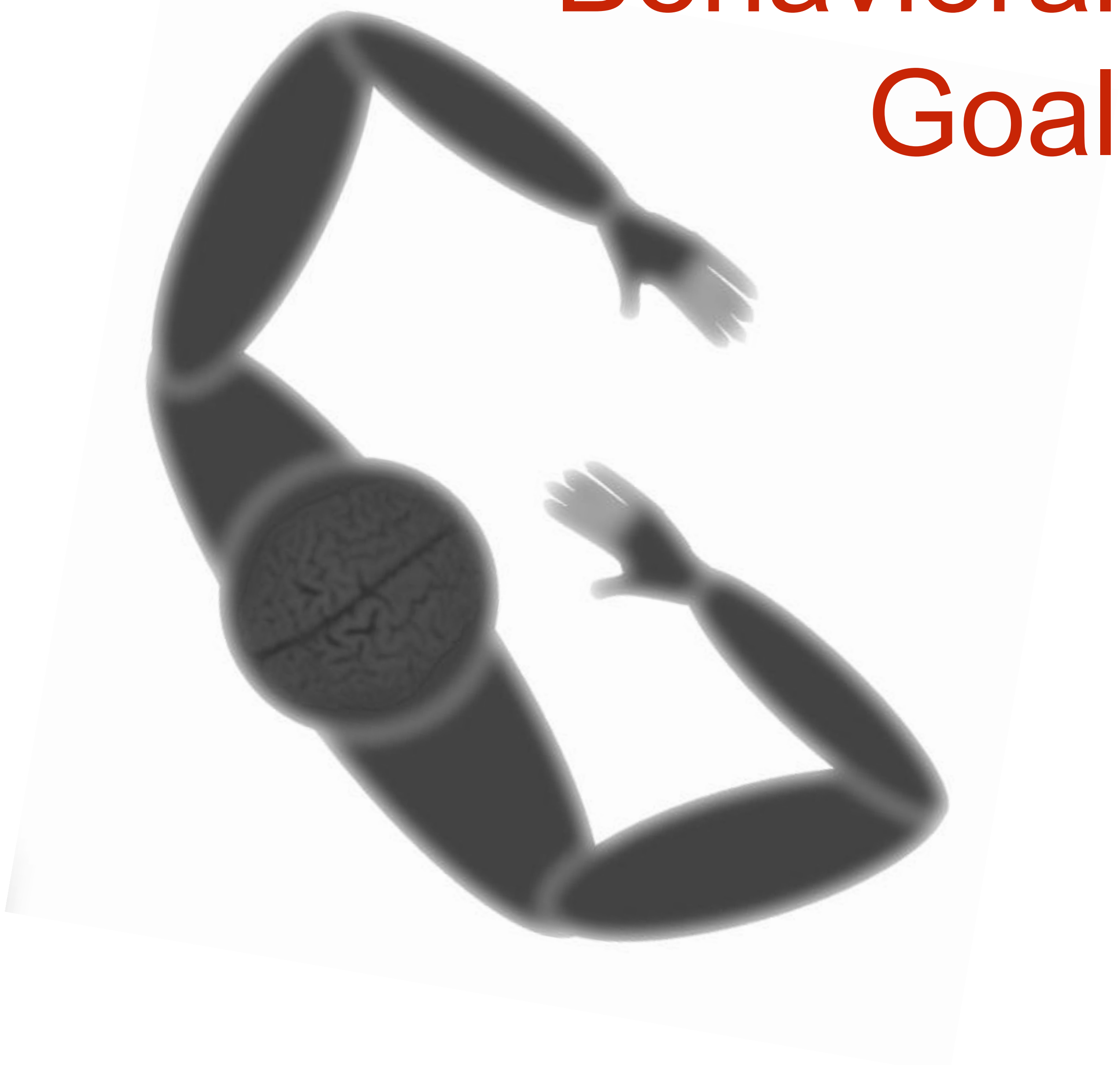
Marr's levels of analysis

	LEVELS	Informal theory:	Formal theory:
Computation	1	*People make decisions by weighing costs and benefits.*	$f : (S, U, P) \rightarrow a$
Algorithm	2	*People rely on heuristics rather than full optimization*	$f(x, y) = xy$
Implementation	3	*Decision-making happens in prefrontal cortex networks*	*Neural network with defined units, update rules, and dynamics implementing belief updating or planning.*

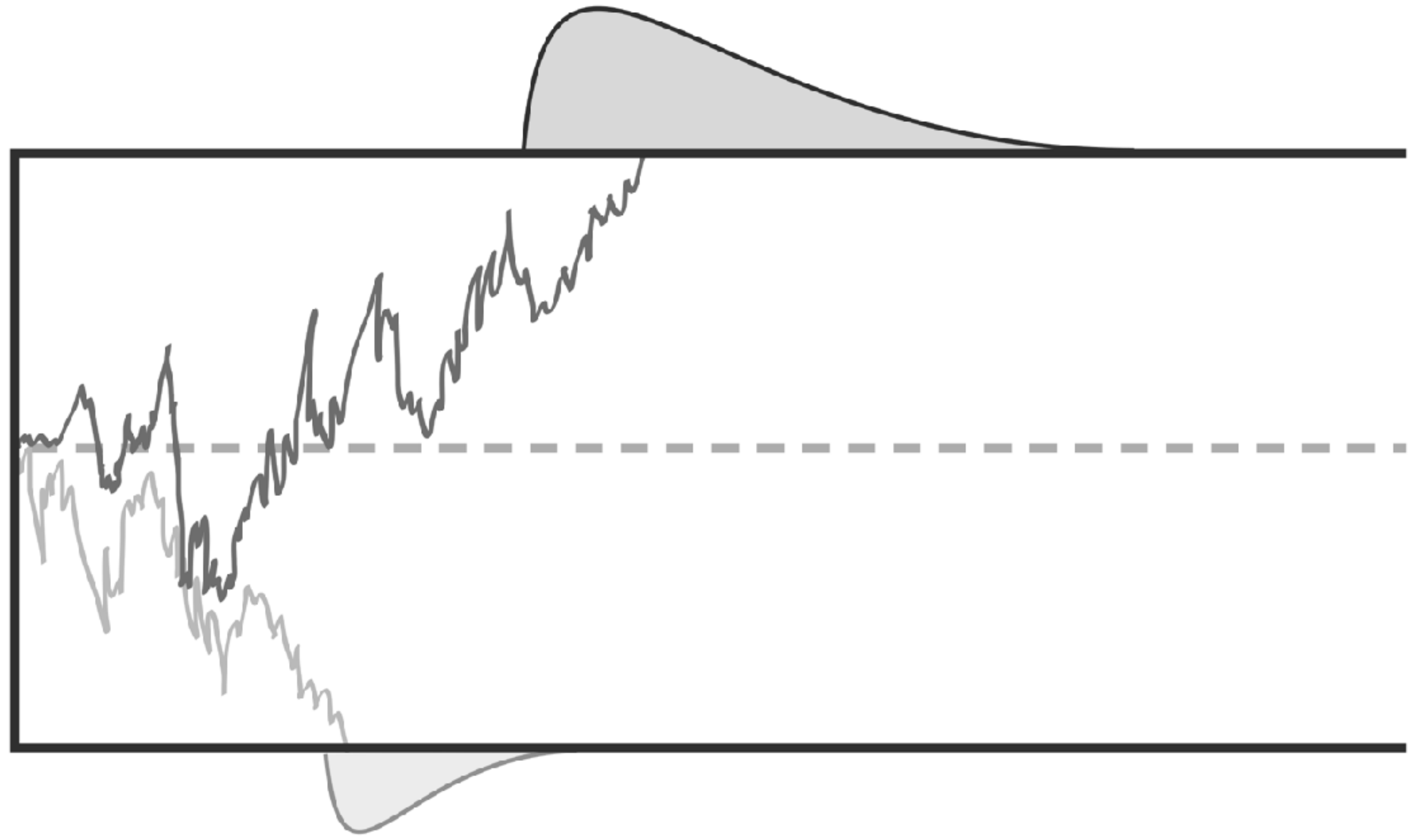
(van Rooij & Baggio 2020; Marr 1982; Krakauer et al. 2017)

Psychological theories: computational level

Behavioral Goal



Cognition



Neural Substrate

Computation 1

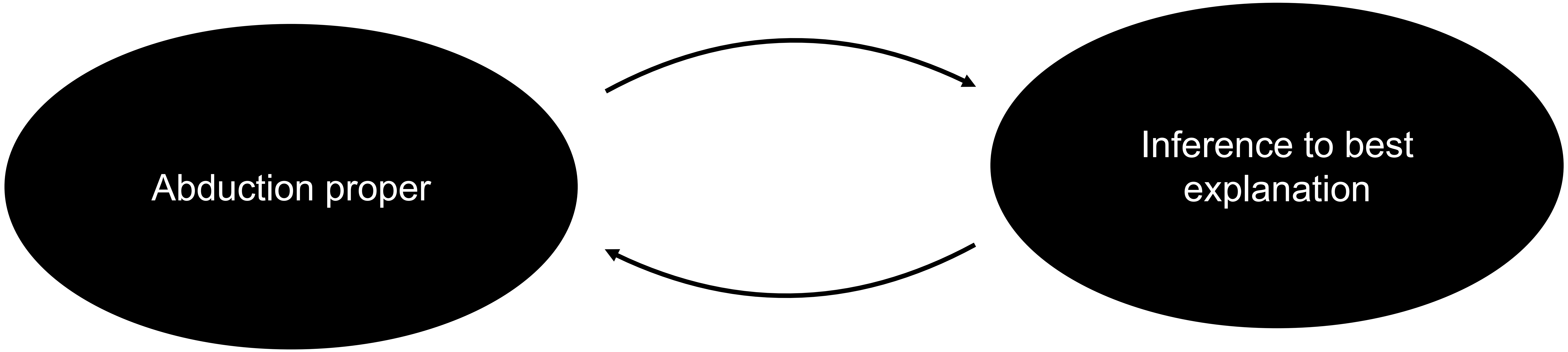
Algorithm 2

Implementation 3

(van Rooij & Baggio 2020; Marr 1982; Krakauer et al. 2017)

How to build a theory, *f*, of capacities, *c*?

<u>Abduction</u>: Reasoning from observations to generate possible explanations.



Generate candidate hypotheses

Selecting the “best” explanatory hypothesis

(van Rooij & Baggio 2020)

Structural form of a theory

theory

$$c \leftarrow f(I) = O$$

capacity input output

<u>e.g</u>:

$$O = f(I) = \beta_1 I_1 + \beta_2 I_2 + \epsilon$$

$$O = f(I) = \beta_1 I_1^2 + g(I_2) + \epsilon$$

(van Rooij & Baggio 2020)

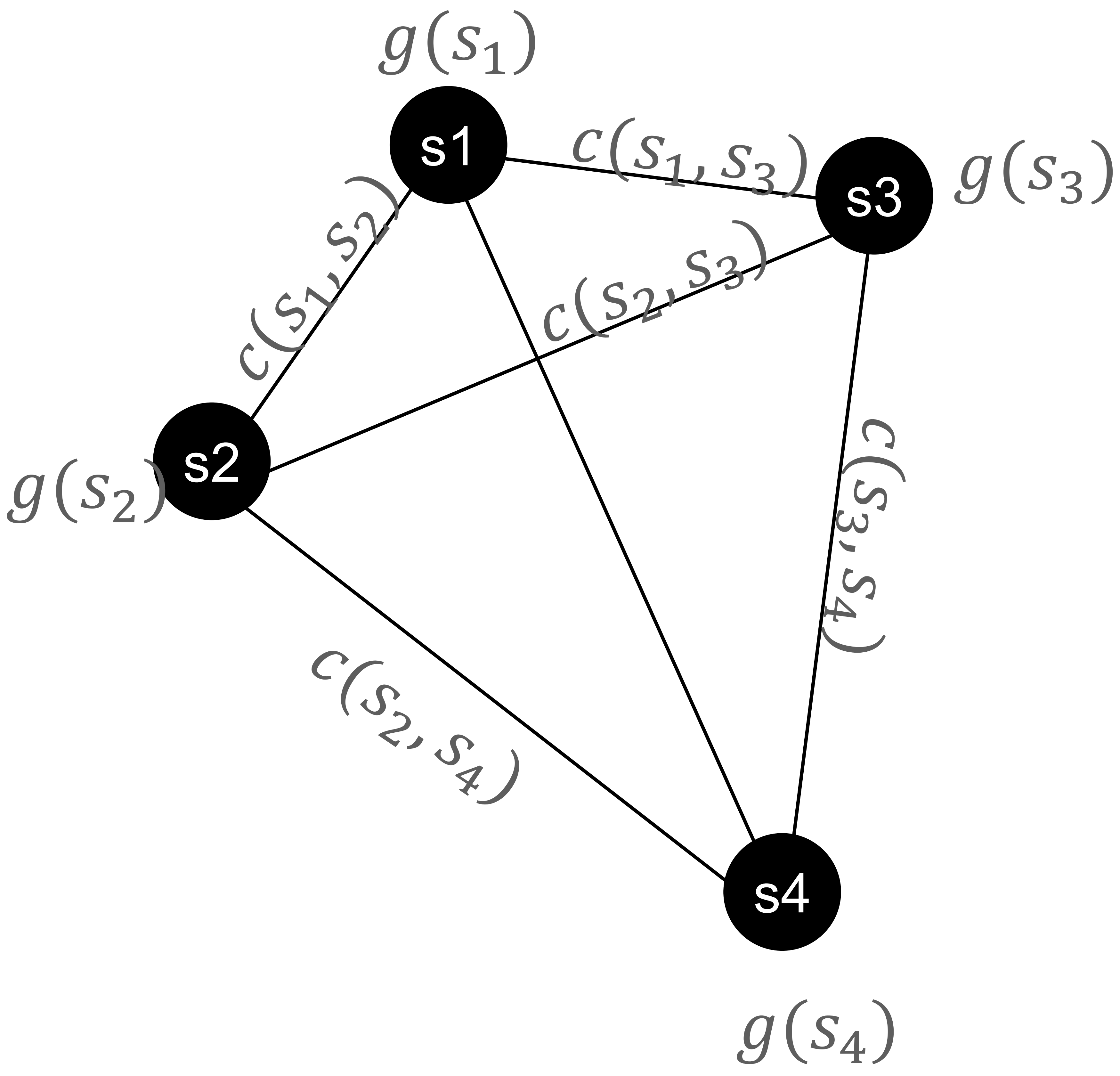
Example

Foraging f

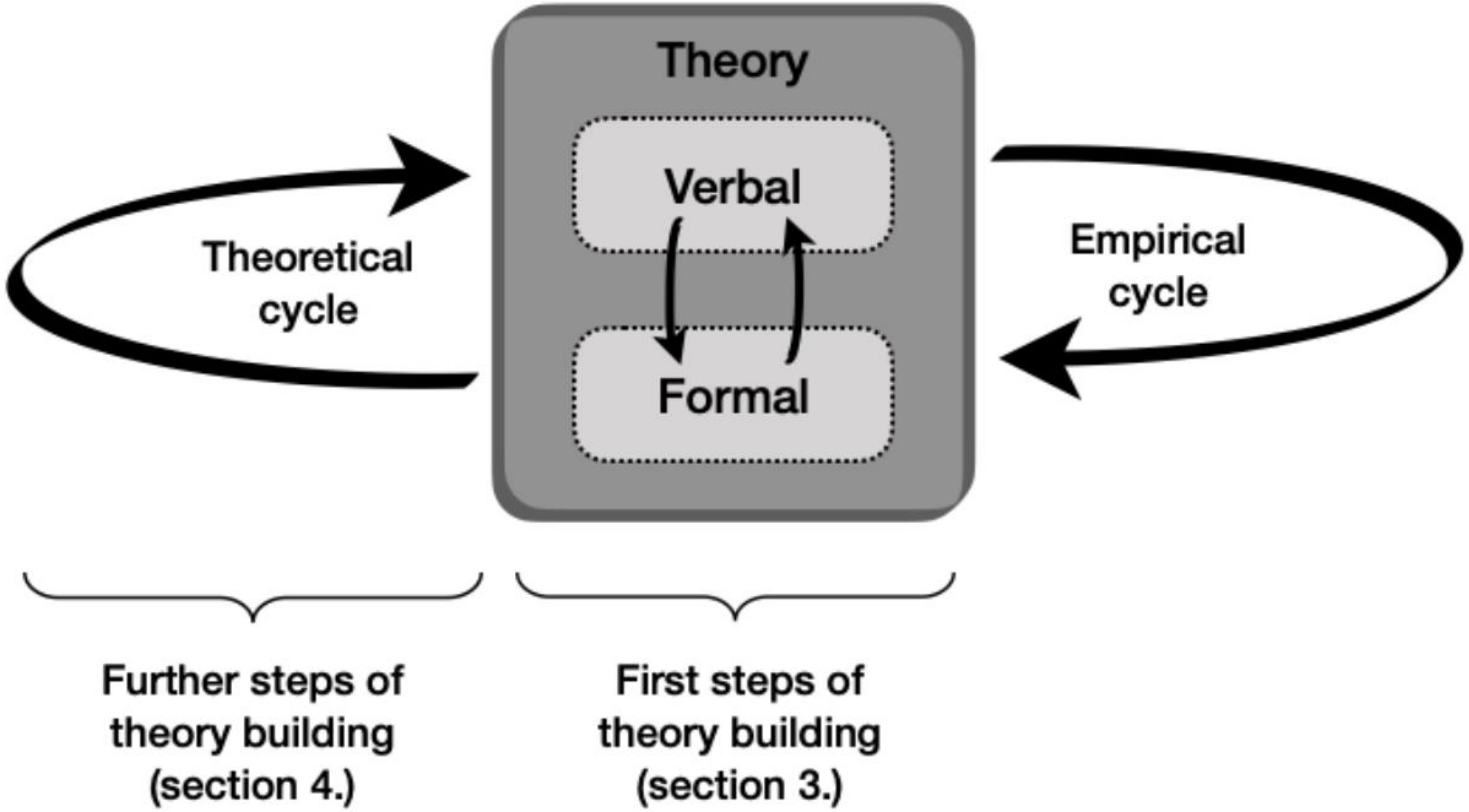
Input: A set of sites $S = \{s_0, s_1, s_2, \ldots, s_n\}$, each site $s_i \in S$ with $i > 0$ hosts a particular amount of food $g(s) \in \mathbb{N}$, and for each pair of sites $s_i, s_j \in S$ there is a cost of travel $c(s_i, s_j) \in \mathbb{N}$.

Output: An ordering $\pi(S) = [s^0, s^1, \ldots, s^n, s^0]$ of the elements in S such that $s^0 = s_0$ and the sum of foods collected at $s^1, \ldots, s^n$ exceeds the total cost of the travel, i.e.,

$$c \leftarrow f(S) = \sum_{s \in S} g(s) \geq c(s^n, s^0) + \sum_{s^i, s^{i+1} \in \pi(S)} c(s^i, s^{i+1})$$



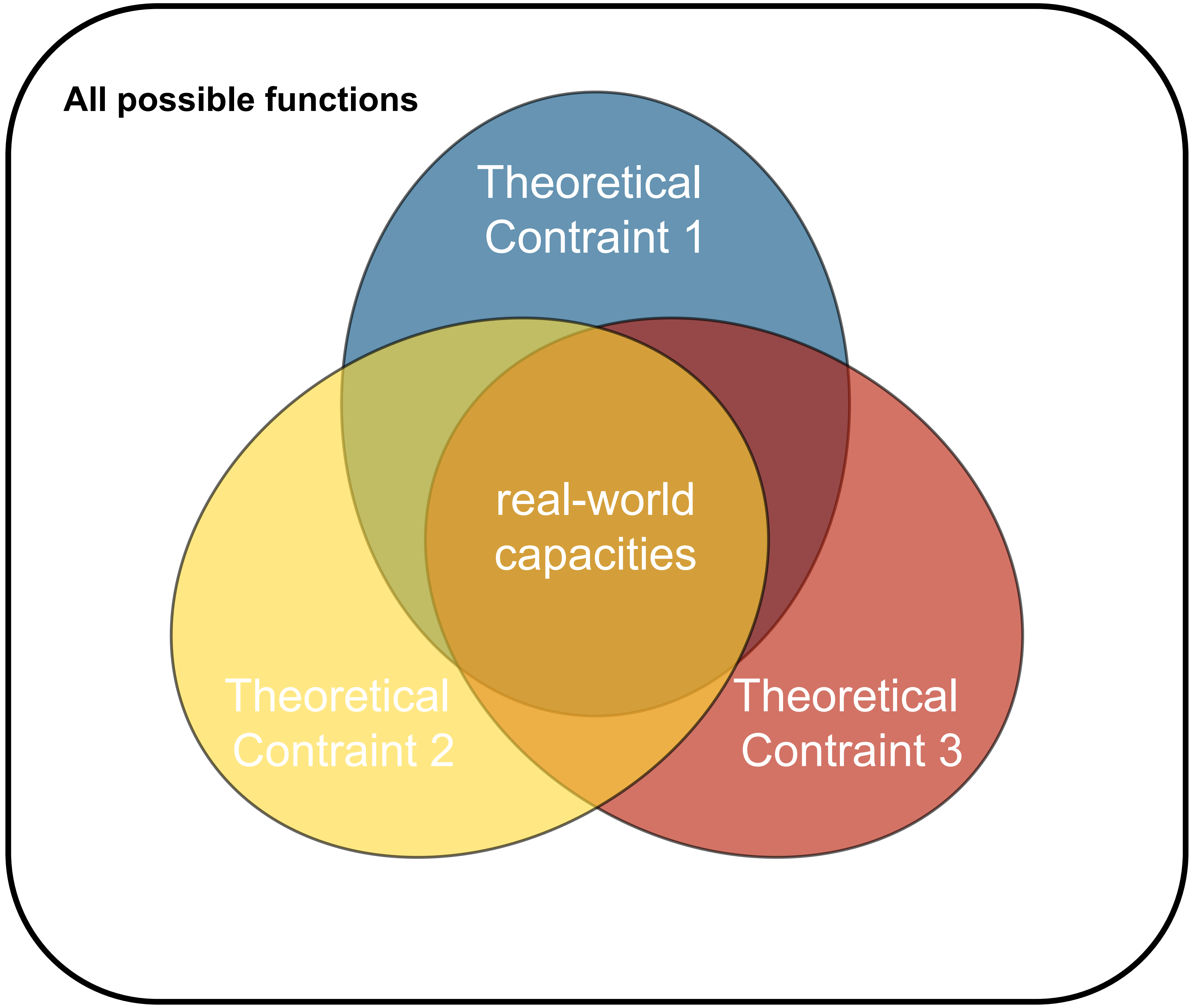
Evolution of a theory



- Start with an informal verbal theory to set conceptual frame.
- Operationalize it to a formal structure to make hypotheses (abduction)
- Design tests to evaluate the hypotheses.
- Use empirical results to refine the form of your theory.

(van Rooij & Baggio 2020)

Reducing the space of possible theories

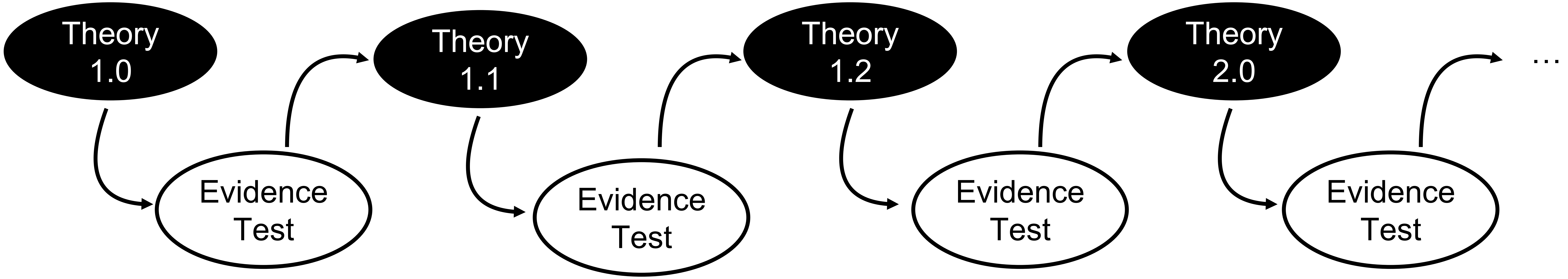


(van Rooij & Baggio 2020)

Formulating a “good” theory

Making transparent theories

Open Theorizing: Providing a transparent genealogy for where predictions, explanations, & ideas for experiments come from.



(Guest & Martin 2020)

~~Computational~~ model

Quantitative

The process by which relations are described using a formal logic (e.g., mathematics) that removes ambiguity and constrains the dimensions of a theory.

Benefits:

1. Automatically conforms to open theorizing (form & constraints of theory are explicitly described).

2. Makes the projection from theory to hypothesis and predictions easier.

(Guest & Martin 2020)

Example: The pizza deal

Your favorite pizzeria has a special: two 12” pies for the price of one 18” pie.

Is this a good deal?

Informal theory:

- 2 pies is 2x as much as 1 pie.
- 18” is only 50% more than 12”.

Answer: Yes

(Guest & Martin 2020)

Example: The pizza deal

Your favorite pizzeria has a special: two 12” pies for the price of one 18” pie.

Is this a good deal?

Quantitative theory:

Food estimate: $\phi_i = \sum_{j=1}^{N} \pi R_j^2$ ← number of pies (N) ← radius of pie j

Decision: $\omega(\phi_i, \phi_j) = \begin{cases} i, & \text{if } \phi_i > \phi_j \\ j, & \text{otherwise} \end{cases}$

Answer:

(Guest & Martin 2020)

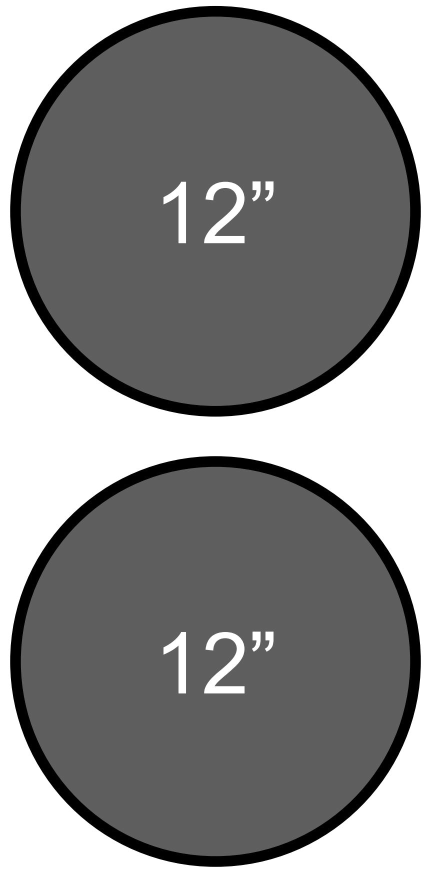
Example: The pizza deal

Your favorite pizzeria has a special: two 12” pies for the price of one 18” pie.

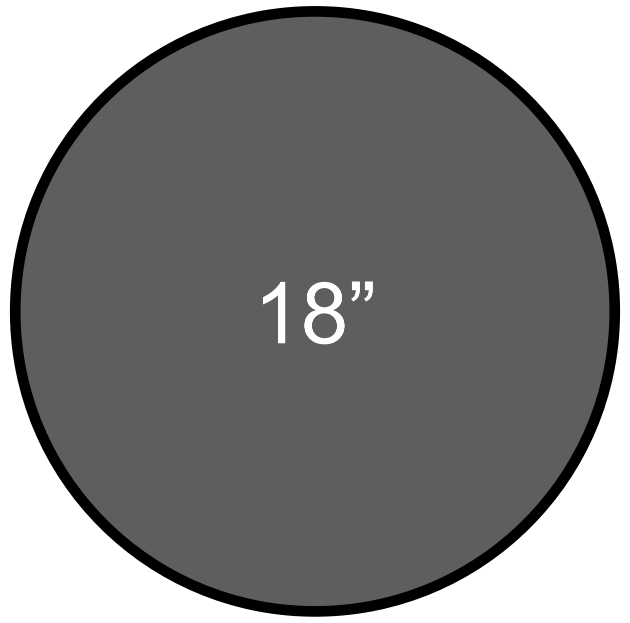
Is this a good deal?

Quantitative theory:

$\phi_i = 226 in^2$



$\phi_i = 254 in^2$



Answer: No

Implementation of quantitative theory

Quantitative theory:

Food estimate: $$\phi_i = \sum_{j=1}^{N \leftarrow \text{number of pies}} \pi R_j^2 \leftarrow \text{radius of pie } j$$

Decision: $$\omega(\phi_i, \phi_j) = \begin{cases} i, & \text{if } \phi_i > \phi_j \\ j, & \text{otherwise} \end{cases}$$

Python implementation:

```
import numpy as np
import math

def food(ds):
    '''
    Amount of food in an order as a function
    of the diameters per pizza (eq. 3).
    '''
    return (math.pi * (ds/2)**2).sum()


# Order option a in fig. 1, two 12'' pizzas:
two_pizzas = np.array([12, 12])

# Option b, one 18'' pizza:
one_pizza = np.array([18])

# Decision rule (eq. 2):
print(food(two_pizzas) > food(one_pizza))
```


(Guest & Martin 2020)

Path functions in theory cycle

Framework	ACT-R, connectionism, Soar, working memory.	Conceptual system of building blocks (context of formalism)
Theory	prospect theory, Rescorla-Wagner, SUSTAIN.	Scientific proposition that describes causal relations.
Specification	mathematics, natural language, TLA+, Z.	A formal(isable) description of the system to be implemented based on theory.
Implementation	models written in code, e.g., C, Python, R.	Instantiation of model using physical methods (including software)
Hypothesis	“Group A will be faster than group B.”	A narrow testable statement involving measurable terms (operational definitions)
Data	ANOVA, linear regression, MVPA, SEM, t-test.	Observations collected from the “real world”

(Guest & Martin 2020)

Take home message

- Having a formalized theory, preferably in quantitative terms, makes it easier to communicate and test your ideas.

- Theory and evidence dance together. Theory defines where & how you look. Evidence revises the search.