UCLouvain

(Wandering) thoughts on symmetries in physics and philosophy

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5th of May, 2021

John Templeton Foundation

Facts

Some unquestionable facts…

- Symmetries play a paramount role in physics theorizing (e.g., Symmetry Groups at the core of physical theories)
- Symmetries play a paramount role in empirical exploration (e.g., in discovering new ”particles” through symmetry breaking; CPT violation)
- Abundance of kinds of symmetries –internal symmetries, external symmetries, local symmetries, global symmetries, gauge symmetries, space-time symmetries, dynamical symmetries, permutation symmetries…

Symmetries (in their various guises) are central elements in the representation of the physical world

Facts

Philosophy comes in. Some further unquestionable facts…

- Symmetries have lately drawn philosophers' attention.
- From Wigner and Weyl on, symmetries were construed as means to elucidate deeper issues –what is objective, what is natural, what is structural, what is fundamental, and so on and so forth.
- In the philosophical literature has been an increasing gliding from symmetries as representational tools to symmetries as means to uncover fundamental properties/structures of the natural world –"*symmetries as guides to reality*"
- Growing tendency to **symmetry realism** and **symmetry fundamentalism**–sort of **non-miracle argument**.

Facts

My assessment of what's going on…

- On the one hand, philosophers have found in symmetries a ***naturalistic tool*** to solve metaphysical issues (the problem of natural properties, the problem of the structure of space and time, specific issues in quantum theories, etc.) –in the trend of a **naturalistic metaphysics**.

- On the other hand, in order to make sense of physics theorizing, it seems that symmetries should be taken ontologically/metaphysically/epistemically seriously (it isn't just math, but they bear some semantic and, eventually, ontological meaning) –in the trend of a **realist tradition**.

Facts

What're the problems I see…

- Everything is going too quick!

- Symmetries are usually accounted for *in isolation* ⟶ Threatening a serious metaphysical program

There's an **argumentative gap** from symmetries as mathematical tools to symmetries as something more robust…

Wilfred Sellars

The aim of philosophy, abstractly formulated, is to understand how things in the broadest possible sense of the term ***hang together*** in the broadest possible sense of the term ("Philosophy and the Scientific Image of Man")

Hanging together

A Sellarsian view of symmetries…

How symmetries **hang together** within a more complex network of concepts in physics and philosophy

How we philosophically construe the notion of symmetry will depend on…

- What's a physical **theory**
- What's a **law**
- What role **idealization** plays in physics theorizing and in metaphysics
- What's the **underlying ontology** and its constraints

My **hypothesis** is that our understanding of symmetries will strongly depend upon which stand we take on these points

Symmetries (briefly)

A (purely) formal definition

- Symmetries are defined by their *symmetry transformation*
- Symmetry transformations apply upon **formal structures** (paradigmatically, *dynamical equations*)
- Symmetries are (formal) **properties of** dynamical equations
- In particular, the property of being left **invariant** (under the transformation)

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- Symmetries are defined by their *symmetry transformation*
- Symmetry transformations apply upon **formal structures** (paradigmatically, *dynamical equations*)
- Symmetries are (formal) **properties of** dynamical equations
- In particular, the property of being left **invariant** (under the transformation)
- **More formal definition**:

> A dynamical equation $E(s, O_i, D_j) = 0$, where s represents a state, the O_i represent the observables, and the D_j represent differential operators, is said **to be invariant** under the symmetry transformation g, which s $\rightarrow \tilde{s}$, $O_i \rightarrow \tilde{O}_i$, and $D_j \rightarrow \widetilde{D}_j$, *if and only if* $E(\tilde{s}, \tilde{O}_i, \widetilde{D}_j) = 0$

Symmetries (briefly)

A semantic or model-theoretic definition

- Symmetries transform **solutions into solutions**
- Symmetries **preserve the truth** of the law (represented by the dynamical equation) across different possible worlds

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> Let $\mathcal{M}$ be the set of a certain mathematical structure and let $\mathcal{M}_L \subset \mathcal{M}$ be the subset of the models satisfying the law (*L*). A symmetry *g* of the law *L* is a map $g: \mathcal{M} \to \mathcal{M}$ that preserves $\mathcal{M}_L$, that is, for any $m \in \mathcal{M}_L$, $g(m) \in \mathcal{M}_L$

1. A three fold distinction

1 A three-fold distinction

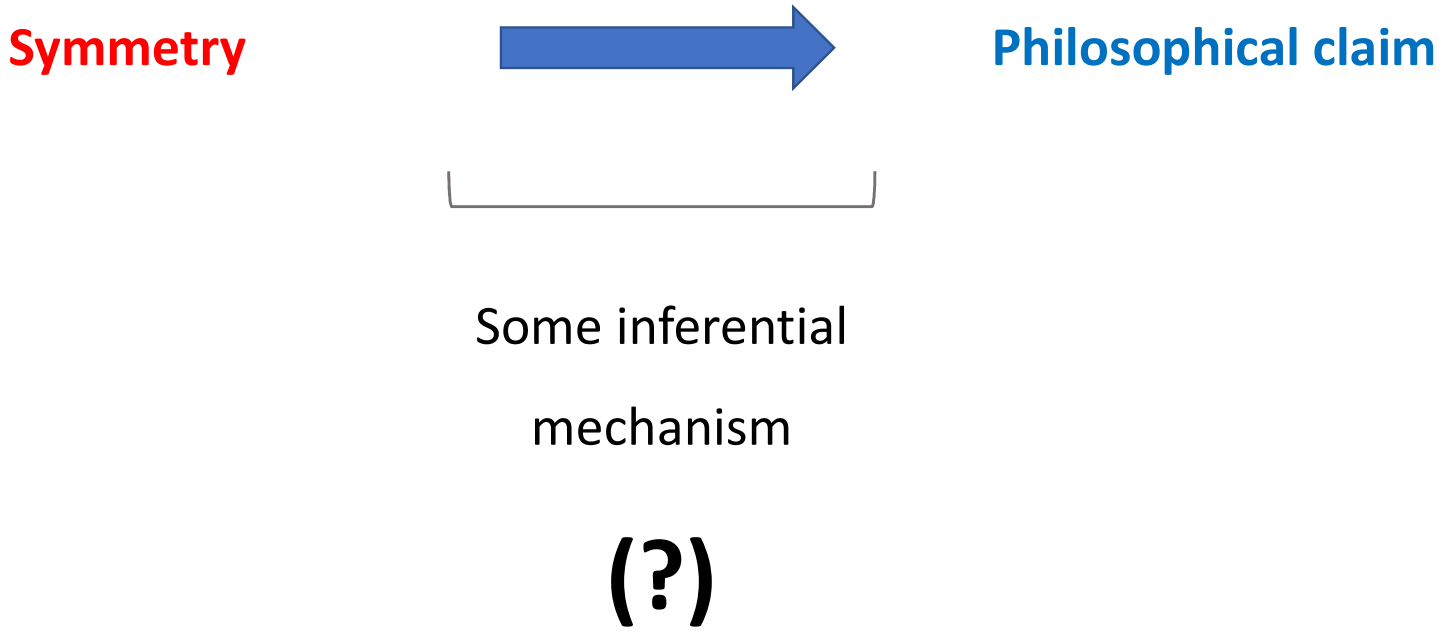
Symmetry Fundamentalism

Symmetry Realism

Symmetry Deflationism

Metaphysical Relevance

1. A three fold distinction



1. A three fold distinction

General argument

1. The law **L** governs our world
2. A property **F** (magnitude, observable, state) in **L** can change freely without changing the overall structure of **L**

Formal premises
equivalent to saying that a symmetry holds

3. Interpretation of (2): what means that **F** can vary freely?
4. Occam's razon upon (3): it'd be an epistemic vice to take **F** as part of our ontology because (3)

C. Therefore, the property **F** is not real

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Epistemic and metaphysical premises (interpretation!)

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General argument

1. The law **L** governs our world
2. A property **F** (magnitude, observable, state) in **L** can change freely without changing the overall structure of **L**
3. **F** is **unobservable (**Dasgupta 2016**)**
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General argument

1. The law **L** governs our world
2. A property **F** (magnitude, observable, state) in **L** can change freely without changing the overall structure of **L**
3. **F** is **superfluous (**Dirac 1950, Ismael and van Fraassen 2003**)**
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2. A property **F** (magnitude, observable, state) in **L** can change freely without changing the overall structure of **L**
3. **F** is **non-objective (**Nozick 2001, Allori et al. 2008**)**
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General argument

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2. A property **F** (magnitude, observable, state) in **L** can change freely without changing the overall structure of **L**
3. F is non-fundamental (French 2015, Schroeren 2020)

To connect these premises, we need more structure!

4. Occam's razon upon (3): it'd be an epistemic vice to take **F** as part of our ontology because (3)

C. Therefore, the property **F** is not real

1. A three fold distinction

- Symmetries are somewhat *real* in the sense they represent (or guides us to) ontological features

Symmetry Realism, which does not imply that symmetries are fundamental

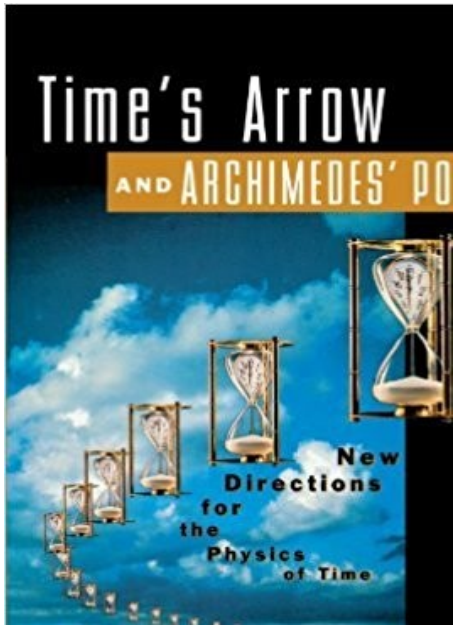
- Symmetries are *fundamental* (more than individuals, material stuff, etc.)

Symmetry fundamentalism depends on a **broader metaphysical framework**

(state-space substantivalism, ontic structural realism, etc)

1. A three fold distinction

Symmetry Realism



"to a very large extent, then, the laws of physics seem to be blind to the **direction of time** – they satisfy **T-symmetry,** as we may say" (Price 1996: 116)

1. A three fold distinction

Symmetry Realism

"In applying any transformation to a theory, we hope **to learn about the symmetry of the theory**, and **of the world that theory describes** (…) If the theory remains the same after the transformation—if it is *invariant* under the transformation—then it is symmetric under that operation. We conclude that a world described by the theory lacks the structure that would be needed to support an asymmetry under the operation. For example, **from the space-translation invariance of the laws**, we infer that **space is homogeneous, that there is no preferred location in space**"

(North, J. (2008). "Two views on time reversal". *Philosophy of Science, pp.* 202)

Symmetry

Metaphysical claim

1. A three fold distinction

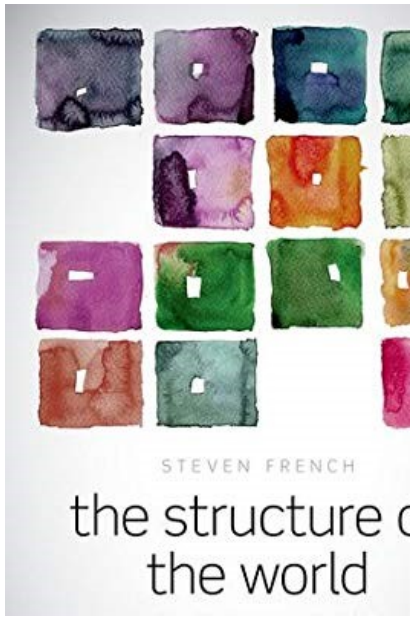
Symmetry Fundamentalism

"Symmetries are **fundamental aspects** of physical reality, whereas the physical entities that we would ordinarily have thought of as the fundamental building blocks of the physical world—such as elementary particles or fields—are ontologically derivative of these aspects" (Schroeren, 2020: 1-2)

Symmetry fundamentalism  **State-space-first view** (or **state-space substantivalism**)

1. A three fold distinction

Symmetry Fundamentalism



Here the difference between the object-oriented and the structural realist comes into play: the former reads her ontology off theories at some remove, by taking the laws and symmetries that the theories present to be underpinned by property-possessing objects to which we should be ontologically committed. The latter reads her ontology off these theories directly, by taking the very same **laws and symmetries as features of the structure of the world**.

Symmetry fundamentalism ⟷ **Ontic Structural Realism (or *modal structures)***

2. Idealization

2 The role of idealization

- The overwhelming majority of symmetries hold only in highly-idealized situations
- One needs to abstract away many elements
- In the case of dynamical/space-time symmetries, they are symmetries of the *general* equations. Different instantiations could easily violate the symmetry (for instance, when interactions/dissipative forces are introduced)

Why should we should take general dynamical equations / highly-idealized models *ontologically* seriously?

2. Idealization

Idealizations and symmetries

- You can go two ways…

> General equations just describe highly idealized models that shouldn't be given any ontological privilege (quite the opposite) (see, for instance, Hutchison 1993)

Or,

> General equations represent the fundamental reality, how the universe is structurally at bottom. So, they must be ontologically privileged (see Callender 1995)

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- Why the model of, for instance, a time-reversal invariant free-fall particle is ontologically more important than the model of a time-reversal non-invariant particle in an inhomogeneous field?

2. Idealization

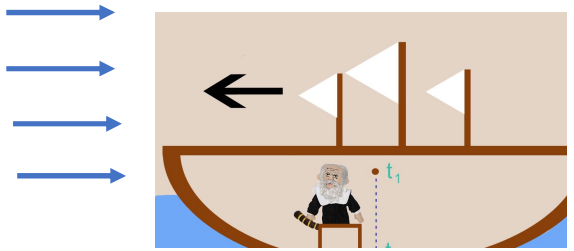
Real situation –Galileo of course knows!

2. Idealization

Ideal situation–Galileo knows?

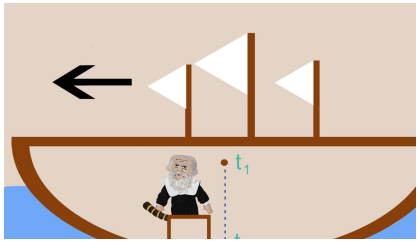
GPS

Air Resistance



2. Idealization

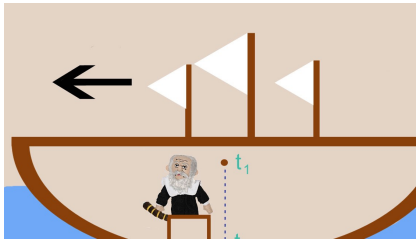
Ideal situation–Galileo knows?



2. Idealization

Ideal situation–Galileo knows?

- Why does this situation represent the reality “at bottom”?
- Why should it be taken metaphysically more seriously than the real situation?
- **Can’t it be just a representational strategy (a wonderful one) to formulate our physical theories in the simplest and most informative way?**

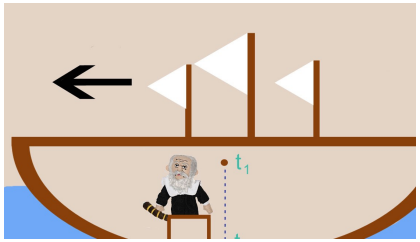


2. Idealization

Idealizations and symmetries

General equations/Highly-idealized models

Does symmetry fundamentalism/realism imply some sort of ***reification*** of general equation/highly-idealized models?



3. Symmetry and Laws –which laws?

3 A connection: Symmetries and Laws/Structures

Symmetry Fundamentalism

Symmetry Realism

Symmetry Deflationism

Symmetries are primarily **properties of laws**, but laws can be philosophically construed in different ways:

- **Governing** or **productive** view
- **Dispositional** view
- **No-law** view
- **Best System** Approach or **Humean** View

3. Symmetry and Laws –which laws?

3 A connection: Symmetries and Laws/Structures

Symmetry Fundamentalism

Symmetry Realism

Symmetry Deflationism

+ Metaphysical structure

- Governing view of laws
- Absolute state-space or space-time

- Metaphysical structure

- BSA- laws / no-laws / Humean laws
- Relational structures

4. Models vs Laws

4 **What's a theory: Symmetry of models vs Symmetry of laws**

Symmetry of Models

- Symmetry of *particular solutions* (models) of dynamical equations

Symmetry of Laws

- Symmetry of *general* dynamical equations

Two questions: (1) Does the distinction hold independently from how we understand what's a physical theory?, **(2)** which kind of symmetry is the relevant for metaphysics/philosophy?

4. Models vs Laws

4 **What's a theory: Symmetry of models vs Symmetry of laws**

?

5. By stipulation vs by discovery

5 By-stipulation vs by-discovery

There seem to be two ways to heuristically construe symmetries in physics:

By-stipulation

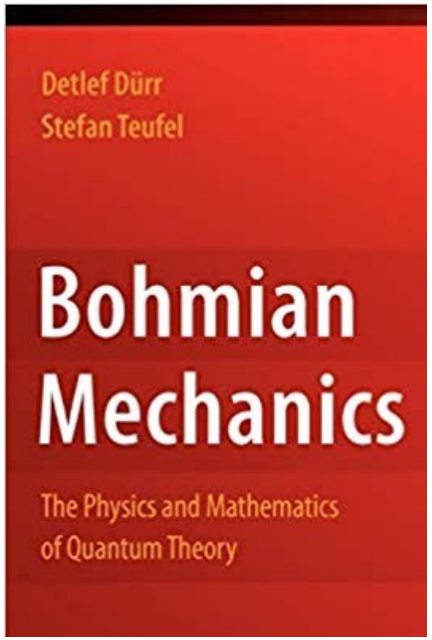
- Rule-prescribing principles, constraining the dynamics. Symmetries are fist stipulated, then the dynamics is built up from them

By-discovery

- A by-product of the law. Dynamics first, then we discover the symmetries in them.

5. By stipulation vs by discovery

By-stipulation or by-discovery? A tension



"**A symmetry can be a priori,** i.e., the physical law is built in such a way that it respects that particular symmetry by construction. This is exemplified by **spacetime symmetries**, because spacetime is the theater in which the physical law acts (as long as spacetime is not subject to a law itself, as in general relativity, which we exclude from our considerations here), and **must therefore respect the rules of the theater**". (Dürr and Teufel 2009: 43-44)

5. By stipulation vs by discovery

By-stipulation or by-discovery? A tension

"Next let us consider the electric and magnetic fields. How do they transform under time reversal? Well, **the standard procedure is simply to assume that classical electromagnetism is invariant under time reversal.** From this assumption of time reversal invariance of the theory (…) it is inferred that the electric field E is invariant under time reversal (…)"

Brit. J. Phil. Sci. (2009), 1–28

Time Reversal in Classical Electromagnetism

Frank Arntzenius and Hilary Greave

ABSTRACT

Richard Feynman has claimed that anti-particles are nothing but particles 'j backwards in time'; that time reversing a particle state always turns it int sponding anti-particle state. According to standard quantum field theory te is not so: time reversal does not turn particles into anti-particles. Feynm

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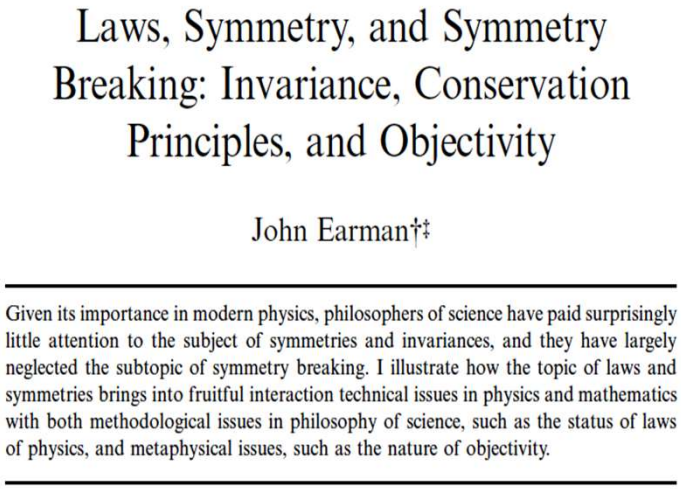

Laws, Symmetry, and Symmetry Breaking: Invariance, Conservation Principles, and Objectivity

John Earman†‡

Given its importance in modern physics, philosophers of science have paid surprisingly little attention to the subject of symmetries and invariances, and they have largely neglected the subtopic of symmetry breaking. I illustrate how the topic of laws and symmetries brings into fruitful interaction technical issues in physics and mathematics with both methodological issues in philosophy of science, such as the status of laws of physics, and metaphysical issues, such as the nature of objectivity.

"The received wisdom about the status of symmetry principles has it that one must confront a choice between **the *a posteriori approach*** (a.k.a. the bottom up approach) versus the ***a priori approach*** (a.k.a. the top down approach)". (2004: 1230)

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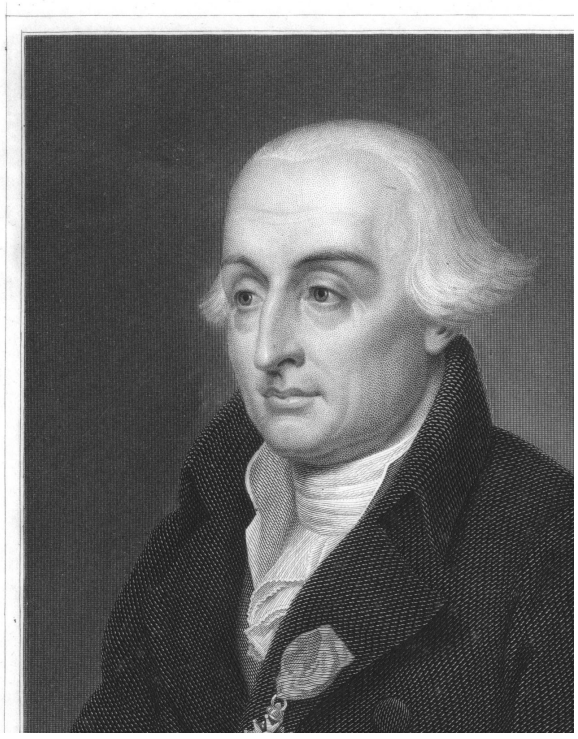
By-stipulation or by-discovery? A tension

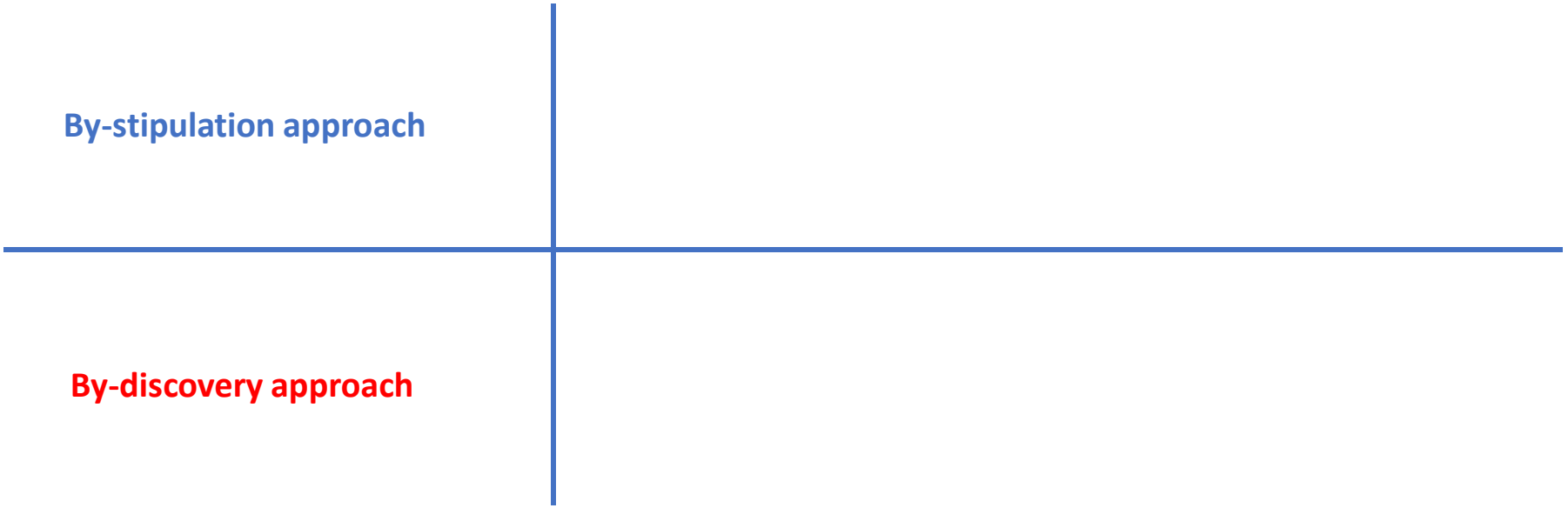


One of the advantages of the formula under discussion is that it provides immediately the general equations which **contain** the principles or theorems known under the names of the Conservation des Forces Vives, conservation of the motion of the center of gravity, conservation of the motion of rotation or principle of areas and the principle of the least quantity of action. **These principles must be viewed as general results of the laws of dynamics rather than fundamental principles of this science** (Lagrange 1811: 21)

5. By stipulation vs by discovery

By-stipulation or by-discovery? A tension

Two approaches to the status of dynamical symmetries…



5. By stipulation vs by discovery

By-stipulation or by-discovery? A tension

Two approaches to the status of dynamical symmetries…

By-stipulation approach	A dynamical symmetry must be regarded as **a priori** and **necessary** for a theory's dynamics
By-discovery approach	A dynamical symmetry must be regarded as **a posteriori** and **contingent** for a theory's dynamics

5. By stipulation vs by discovery

By-stipulation or by-discovery? A tension

Two approaches to the status of dynamical symmetries…

By-stipulation approach	• **Heuristic role** as they guide theory construction • **Common view in current physics**
By-discovery approach	• Based (at least partially) on world's features –we **discover** them in the laws • Much more common in 19th-century physics

5. By stipulation vs by discovery

By-stipulation or by-discovery? A tension

Two approaches to the status of dynamical symmetries…

By-stipulation approach

- **Heuristic role** as they guide theory construction
- **Common view in current physics**

- The **symmetry transformation** is frequently built under the assumption that a given structure is already symmetric.
- In any case, as Brading and Castellani (2003, 2007) mentions, **current physics** seems to imply some sort of by-stipulation view of symmetries.

5. By stipulation vs by discovery

By-stipulation or by-discovery? A tension

So, *if* current physics implies some sort of by-stipulation view, how should we interpret symmetry fundamentalism (or even symmetry realism)?

- Fundamental structures (as symmetries) are *a priori* stipulated?
- May we come to uncover fundamental structures through a priori stipulations?
- Are symmetries stipulated as well as the structures than support them?
- Why is it not a form of (radical) a priori metaphysics?

6. The road to symmetry deflationism

By-stipulation approach → Symmetries do seem to act like rule-prescribing principles, heuristically guiding theory construction. Then, they need be stipulated prior to the dynamics

General equations/Highly-idealized models

Realism about Laws

6. The road to symmetry deflationism

By-stipulation approach → Symmetries do seem to act like rule-prescribing principles, heuristically guiding theory construction. Then, they need be stipulated prior to the dynamics ✓

General equations/Highly-idealized models

Realism about Laws

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General equations/Highly-idealized models → Their ontological relevancy can be challenged by taking highly-idealized models (and general equations) as useful tools to encode information in the most effective, and the simplest way.

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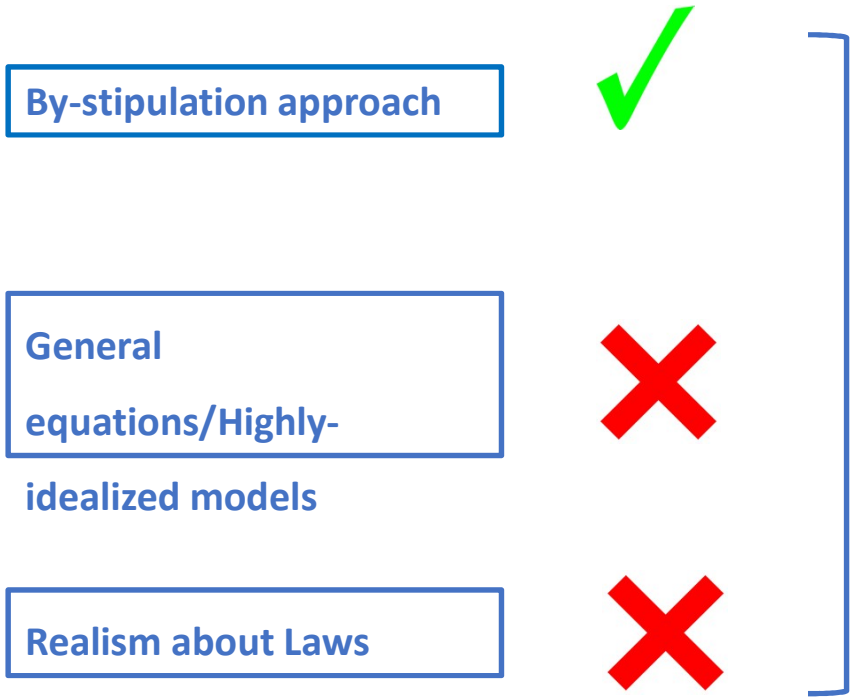

The first steps towards something like **symmetry deflationism**

- Symmetries play a heuristic role in the representation and systematization of our physical theories, but they neither guide us to the basic ontology, nor are part of the basic ontology.
- Symmetries are properties of the representational apparatus. As such, they are theoretical tools. Any problem with symmetries is a representational problem, which shouldn't be confused with an ontological problem.

Thank you!

John Templeton Foundation

This presentations was made possible through the support of grant 61785 from the John Templeton Foundation. The opinions expressed in this publication are those of the authors and do not necessarily reflect the views of the John Templeton Foundation.