Models and Representation: What structures are good for

Elena Castellani
Dipartimento di Lettere e Filosofia
University of Florence

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Based on joint work with **Tarja Knuuttila** and **Francesca Pero**

Synopsis

- **Issue**: How the notion of structure is **used**, and is to be used, in addressing the issue of scientific representation (SR)
- **Charting the landscape**: The notion of structure in current approaches to SR – **structuralists** or/and **pragmatists**
- **Criticism**: Misuses: an example

Models and representation: structures

Why structures?

→ **A natural choice**:

- Scientific models are often specified in structural terms
- **Models** often ‘represent’ by presenting a structure/pattern (→ **model-templates**)

→ How?

- **Issue**: **model** - **target** relationship
  - A relation between structures?
  - → Which relation type/s, which structures?
  - The role of the **user**
  - The nature of the **target**

An Agenda for Charting the Landscape

- What is the task of philosophers with respect to SR?
- What are the vehicles of SR?
- What are the appropriate questions concerning SR?

Distinction and Accounts

- DISTINCTION between **LEVELS**:
  - **Meta-Level** (ML) *vs* **Object-Level** (OL)
    - → Model_1 *vs* Model_2

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    $\rightarrow$ Model_1 *vs* Model_2

- ACCOUNTS: **STRUCTURALISTS** $\leftrightarrow$ **PRAGMATISTS**
  - Structuralist *vs* Pragmatist Account ($\Rightarrow$ usually in terms of Dyadic *vs* Triadic)
    - *Constitution* vs *Means*/*Use* (Suarez, 2004;...): opposed
    - *Informational* vs *Functional* (Chakravartty, 2010): "complementary"
  - Structuralist *and* Pragmatist Account
    - Bueno-Colyvan (2011): *Inferential account*
    - Frisch (2015) (based on van Fraassen, 2008): *Pragmatic and structural account*

Meta-Level (ML) *vs* Object-Level (OL)

Distinction between two levels $\rightarrow$ different *representational tasks*:

- Object-Level (OL): the level of the science itself [representational devices: mathematical tools, ... , used for scientists' purposes]
- Meta-Level (ML): the level of the philosophy of science [representational devices: meta-mathematical tools (e.g., set theory and category theory), ... , used for the purposes of the philosophical analysis)

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Example of a use of this distinction within the *Semantic Approach* → **French** (2015):

- OL: "The structure of the world is *presented* to us in the theoretical context under consideration by means of the relevant laws and symmetries, as informed group-theoretically."
- ML: "As philosophers of science, we then *represent* that structure by means of various meta-level resources, such as the Semantic Approach."

Structural SR in the Semantic Approach (SA)

How structures are used to represent in the SA $\rightarrow$ **French**, 2012:

> "It is philosophers of science .. who **use (partial) set-structures to represent** theories, their inter-relationships, both with each other and, heading downwards, with data structures etc., and moving up, with the families of mathematical structures into which theories can be embedded. [...]
>
> **Partial isomorphisms** and **homomorphisms** can then be considered two of the various tools that philosophers can use in this representational activity.
>
> Thus at the meta-level where philosophers of science operate, it is **(partial) set-structures** that are doing the (meta-level representational) work."

SA: Representational task $\longrightarrow$ at the ML

French and Ladyman (2003):

> "It is important to recall that ... **such set-theoretical relationships hold only between the mathematical structures** and not between such structures and 'the world' itself."

> "The realist representation of the relationship between theories and the world must be sought elsewhere ..."

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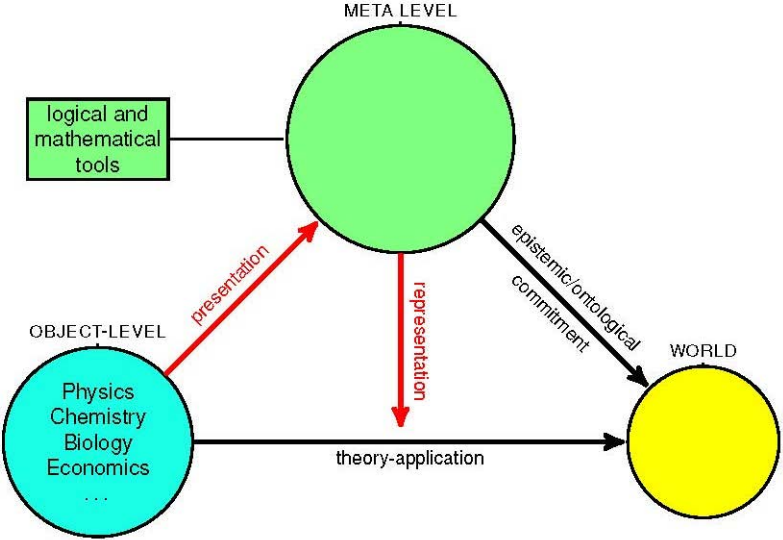
French (2017):

> “The idea then is that when we, philosophers talk about **theories representing** some target system, we have in mind some way of **‘representing’ theories** themselves and these systems”.
>
> “However, there is nothing for either the logico-linguistic set of propositions [syntactic approach] or set theoretical structure [semantic approach] to actually represent.”
>
> “Instead, these devices should be understood as **constructions that we philosophers of science use** to do our jobs.”


META LEVEL
logical and mathematical tools
presentation
representation
epistemic/ontological commitment
OBJECT-LEVEL
Physics
Chemistry
Biology
Economics
...
theory-application
WORLD

BACK TO THE OBJECT-LEVEL ...

Structuralist *vs* Pragmatist Accounts: 1) Suárez (2004 -)

Two kind of questions about SR $\Leftrightarrow$ Two **opposed** accounts of SR:

- The constitutional question ($\Leftrightarrow$ The *substantive/structuralist* account):

  "What is the relation *R* that constitutes the representation?"

  $\longrightarrow$ Focus on CONSTITUENTS (the nature of the representational relations)

- The pragmatic question ($\Leftrightarrow$ The *deflationary/pragmatist* account):

  "What are the effective means that scientists employ to get representations to deliver the required 'goods'?"

  $\longrightarrow$ Focus on MEANS (used by scientists to get representations of...)

Structuralist *vs* Pragmatist Accounts: 2) Chakravartty (2010)

▷ **Apparent dichotomy**: *Informational* vs *Functional* Accounts

- Informational (→ *structuralist*):
  - Based on objective, “mind-independent” relations (similarity, isomorphism, homomorphism).
  - Focus: what scientific representations are
- Functional (→ *pragmatist*):
  - Based on the use of SR
  - Focus: what scientists do when engaged in representing (e.g. interpretation and inference)

▷ **Chakravartty’s answer** to the pragmatist challenge: Complementarity (different aspects of the same process), **no dichotomy** (as in Suárez)

Structuralist *and* Pragmatist Accounts: 1) Bueno-Colyvan (2011)

• Context: the debate on the usefulness of mathematics (especially in physics)

• B-C's account: An "Inferential Conception of Applied Mathematics", *moving beyond the "mapping account" by allowing for pragmatic and context-dependent features* → a **3-stage adaptation** of Hughes' DDI account of SR (denotation, demonstration, and interpretation), patching together Chakravartty's "informational" and "functional" approaches.

- **First stage** ["informational"]: Immersion, by which a mapping is established between the empirical set-up and the representational structure.
- **Second stage** ["functional"]: Derivation, consequences are drawn using the representational structure.
- **Third stage** [again "informational"]: Interpretation, taking the results of the derivation stage back to the target system via another mapping (which may be different from the first).

Structuralist *and* Pragmatist Accounts: 2) van Fraassen (2008) / Frisch (2014)

- Starting point $\rightarrow$ van Fraassen's pragmatic and structuralist account:
  a) Representation is an essentially **pragmatic** notion: "there is no representation except in the sense that some things are used, made, or taken to represent things as thus and so".
  b) Representation, at least in physics, is **structural** representation.

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- Frisch's pragmatic structuralist account: also the *representation's target* is structured by a context of use (not only the link between a representation and its target, as in van Fraassen's account).

  → Thus, the **user** enters the account of scientific representation at two places:

  1) In the depiction of a phenomenon as structured in a certain way.
  2) In taking a model to represent the phenomenon, depicted as thus structured, as having such and such features.

→ Back to our questions

▷ What is the task of philosophers with respect to SR?

- **French**: Meta-level analysis, theoretical re-construction for philosophical purposes: e.g. doing away with objects
- **Pragmatists**, and **Chakravartty**, **Bueno-Colyvan**, **Frisch**: Philosophical analysis of scientific representation taking place at the object level of scientific practice

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- ▷ What are the vehicles of SR?
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- ▷ What are the vehicles of SR?
  - **Structuralists**: Set-theoretical models, morphisms, ...
  - **Pragmatists**: Actual representational objects, such as models (in the sense of model_2)
- ▷ What are the appropriate questions concerning SR?
  - **Object-level structuralists**: How to reconcile pragmatic aspects of representation with the structural approach
  - **Pragmatists**: Questions concerning actual representational practices in their heterogeneity

User-Model-Target (UMT): the multifaceted role of structures

- **Models**: Variety of model types $\rightarrow$ variety in the uses of structures
- **Targets**: structured targets targets without a structure (need to ascribe a structure to it), no real targets (unknown system's details, the target is another model. ..)

$\Rightarrow$ **Different representational roles**: for more direct to very indirect relations

- *Direct proportional relation* (e.g., $\vec{f} = m\vec{a}$, $PV = KT$, ...)
- *Harmonic oscillator* structure: e.g., oscillating physical systems (e.g., strings)
- *Ising model* structure (applied to describe, e.g., condensed matter systems, neural networks, socio-economic systems, ...)
- *Classification schemes*: e.g., symmetry-based (octet model, crystallographic classifications, ..)
- ...

$\Rightarrow$ Need for a multifaceted approach to the use of **structures** in accounting for the UMT relationship

FOCUS: symmetry based structures and physical objects

The context: structural approaches to the question of physical objects

⇒ role of *symmetry principles* and their *group-theoretical* exploitation

Related debates:

- *Structuralism* in science (physics)

  In particular:

  - *Structural realism*

    In particular:
    Ontic structural realism (OSR)

  - *Structural representation*

Structures – Objects

Structural representation: relation between structures and physical objects ($\rightarrow$ the targets)

- Structures:
  - Commonly: *structures* $\Rightarrow$ *relations*

    Examples in physics: physical equations/laws (i.e. relations among physical magnitudes), ...
  - *General definition*: $S = < U, R >$, where U is a set of elements (the domain of S) and R is a set of relations on U.
    - Ex. of a relation between structures: *isomorphism*
    - Ex. of an abstract structure: a (algebric) *group*
    - Ex. of a 'concrete' structure: the group of the symmetry transformations (the *symmetry group*) of a space, a geometrical figure, a physical law....

      Note: the elements (*relata*) – related through the *relation* characterizing the structure (the group product law) – are the group transformations
- Targets? $\rightarrow$ The question of *physical objects*

Objects and structures: the role of symmetries

The role of symmetry (*invariance with respect to a group of transformations*) in modern physics, for a *structural approach* to the question of (physical) objects.

Objects and invariance. The idea:

(1) *permanence* (invariance in time)$\rightarrow$ a classical requirement for defining the identity of an object in the philosophical tradition.

(2) *invariance with respect to change in space and time*, (i.e. under change of reference frames or observers) $\rightarrow$ as an *objectivity condition* (what counts in defining an object should not depend upon the particular perspective under which the object is taken into consideration).

Historically:

H. Weyl (1952): "Objectivity means invariance with respect to the group of automorphisms [of space-time]".

Objects: group-theoretic approach

History: F. Klein (1872), E. Cassirer (1944), M. Born (1953), G. Toraldo di Francia (1978), P. Mittelstaedt (1994), ...

Ground idea: the possibility of speaking in terms of **objects** in a given context is related to the possibility of individuating **invariants** (under the *symmetry group*) of that context.

- First introduced by **Felix Klein** with regard to *geometrical objects*, as a corollary of his **new conception of geometry** proposed in his famous Erlanger Programm (1872)
- With the subsequent application of **group theory** to other domains of science and in particular to physics $\rightarrow$ extention of this view to other sort of objects, in particular to *physical objects* (the objects of physical theories as well as the objects of our common perception)

Resulting view: objects characterized in terms of sets of invariants, i.e., quantities which are invariant with respect to the relevant transformation groups.

The case of **particle physics**:

- **Invariants** $\rightarrow$ quantities like mass (rest mass), spin, charge, i.e. . the so-called *intrinsic properties*, characterizing the **kind of particle** considered (for ex: the class of all electrons).
- The application of *group-theory methods* to exploit the physical **symmetry principles** provide us with a general procedure for 'constructing' the objects of physical theories as sets of such invariants (ref.: **Wigner, 1939**).

  NOTE: The invariant properties ascribed to a particle in this way are *necessary* (or *essential*), in the sense that the given *particle-object* couldn't be determined as such without them (an electron couldn't be an *electron* without given properties of mass and spin) .

Particles and group representations

An elementary particle $\rightarrow$ a physical system whose states transform under the operations of the symmetry group according to a definite *irreducible representation* of the group (Wigner, 1939).

In general:

If G is a **symmetry group of a theory** describing a *physical system* (i.e., the fundamental *equations* of the theory are invariant under the transformations of group G),

$\Rightarrow$ the group operations are *represented* in the states space by *operations/operators* relating the states one to each other, and

$\Rightarrow$ this implies, in particular, that the system (particle) has a given number of *invariant properties*, which are exactly the properties which characterize the *kind* of system (particle) in question.

Conclusion

Mathematical structures used in theory building:

(Symmetry groups [e.g., the Poincar/'e group), Lie algebras associated, the state space structure, the evolution law, ..

The issue (structural representation): What makes a structure 'physical'?

French-Ladyman (2003): "that it can be related - **via partial isomorphisms** - to physical 'phenomena'. This is how physical content enters"

$\Rightarrow$ *Mapping account* of structural representation

But: no direct **mapping** between the *group structures* and the physical objects characterized in group-theoretical terms!

Moral: the variety of cases suggest a multifaceted approach to the question of structural representation