C.R.AIPS 3

Proceedings of *the Académie Internationale de Philosophie des Sciences*

Comptes Rendus de l'Académie Internationale de Philosophie des Sciences

Tome III

Models and Representations in Science

Éditeur

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The structural view of representation: a defence

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Abstract. After having presented the objectifying attitude typical of science, this paper discusses various—scientific and non-scientific—examples of representation and shows that representation is an action that involves a user, a context, a target and a transfer of structure from the target to the representing artefact. It is argued that a transfer of structure from the target to the representing artefact by means of a representational isomorphism or homomorphism is a necessary (*albeit* not sufficient) condition for the success, and *a fortiori* the correctness, of a representation.

1 The objectifying attitude

To construct theories which predict and explain observations and measurements, scientists must adopt a particular attitude or stance towards the world. When looking at concrete entities given in perception, i.e., phenomena[1], they must see them as *systems.* A system is a set of parts or elements organised by means of relations. When I look at the *Madeleine à la veilleuse* by Georges de la Tour in the Louvre, I am immediately overwhelmed by its beauty. Yet I am also able to detach myself from this state of wonder to direct my attention to specific components of the painting such as the flame of the candle, the table, the left arm of Madeleine as well as the spatial relations between them. In doing so, I look at the painting as a system, namely an ensemble of selected parts or elements that stand in spatial relations.

To perceive phenomena as systems, I have to distance myself from immediate perception and to refrain from any feeling or emotion, whether aesthetic or otherwise, that I might experience. This distancing permits to select some properties of interest while disregarding many others. An astronomer interested in celestial phenomena might focus on the planetary orbital revolutions rather than their brightness or colour. In the same way, a chemist studying a gas could select its properties of pressure, volume and temperature, instead of its colour or smell.

In doing so, scientists adopt a selective *démarche.* First, they separate a concrete thing, such as a gas, within the thickness of phenomena. As a

[1]The term "phenomenon" can mean either something purely subjective such as a sensation or a perceived external thing. When I use the word "phenomenon", I mean something perceived or observed, which is external to us. Phenomena are not *sense data.*

Models and Representations in Science, edited by Hans-Peter Grosshans.
Comptes Rendus de l'Académie Internationale de Philosophie des Sciences 3 (2025).
M. Ghins, The structural view of representation: a defence, pp. 91–116.

second step, they will pick out particular characteristics or properties, such as pressure, volume and temperature, and organize them into a structure by means of specific relations. As a consequence, a perceived entity, such as a gas, is reduced to a system the elements of which are the properties of pressure, volume and temperature, organised into a structure. Within such approach, scientists identify properties in the phenomena which they consider to be cognitively interesting, and structure them with relations.

By proceeding in this way, scientists construct a scientific *object*, which is nothing else than a system of properties structured by relationships between them. A system is a structure of properties.[2] For instance, in the case of a gas at constant temperature, the domain of values of pressure, volume, temperature, can be organized using an equality relation, such as "the product of the values of pressure and volume divided by the temperature is equal to a constant".[3]

Thus, within the objectifying attitude, an entity is reduced to a system or object that is constructed by taking into account a limited number of properties and relations between them and neglecting many others. For science, an empirical object is nothing else than a system of properties chosen among the properties instantiated in the observed entity.[4]

In his book *The Empirical Stance*, Bas van Fraassen (2002) portrays the scientific attitude as "objective distancing". To construct a scientific object, scientists must in the first place adopt a distancing attitude regarding to the entities chosen as targets of investigation. Such attitude is very different from spatial distancing. To see phenomena as systems, scientists are compelled to establish a separation between themselves as human subjects on the one hand, and the entity from which they construct an object-system on the other. In most cases, a scientific object has the same status it had in seventeenth and eighteenth centuries experimental sciences, that is to say, "an object that is collected, labelled, put in a museum, that is sliced, dissected, solidified, dyed, and put under a microscope." (Wilson 1997, p. 37)[5] When looked at in this way, a thing or entity[6] is reduced to a scientific object that is completely deprived of intrinsic value. As reduced to an object, an entity

[2]The notions of system and structure are closely related. Systems are mostly taken to be real worldly objects which exemplify a structure. In this case, "structure" refers primarily to the organisation of elements. But in mathematics sets of related elements are regularly referred to as "structures". I will often use the words "structure" and "system" interchangeably since there is no structure without elements—whether elements are mathematical or not—in relation. For a general definition of system, based on Da Costa's notion of partial structure, see Bresciani Filho & D'Ottaviano (2018).

[3]Pressure $\times$ volume / temperature = constant. This is the Boyle-Charles formula.

[4]Of course, scientists do not always start from experience but also devise theoretical hypotheses and construct possible objects, as it will be seen later.

[5]Quoted by van Fraassen (2002, p. 157).

[6]By "thing" or "entity" I mean any kind of existent, be it a substance, a process etc. I favour an ontology of instantiated properties. An entity is a set of spatiotemporally

becomes available for cognitive purposes without any constraints or limits. Being devoid of any intrinsic value, a scientific object can be manipulated, altered and even destroyed to serve merely scientific purposes.

The objectifying approach is a defining feature of scientific practice. But it can be adopted in other fields as well. I can decide to see the *Madeleine à la veilleuse* as composed of parts, study the relations between them, and attempt to understand the arrangement between shapes, colours, proportions ... Embracing an objectifying attitude requires a reversal of our spontaneous attitude towards the world. When we look at entities around us, whether human or not, we immediately grasp them not as systems but as *singular totalities*. If we pause to reflect on this, we realise that the entities we immediately see are undivided totalities implicitly endowed with intrinsic value, whether positive or negative. A child spontaneously attributes some value to the entities he perceives, typically in terms of their intrinsic powers to cause pleasure or pain. The same is true for the people—undeservedly called "primitive"—who envision the world as populated by things inhabited by ancestors or spirits. Some entities, like some trees in New Caledonia, are directly grasped as undivided units with which it is possible to enter into a personal relationship. Such singular and unique entities have an intrinsic value which commands respect. Far from assigning negative connotations to such an attitude, we must see it as fundamentally positive, capable of revealing important aspects of the entities which make the natural world.

As we saw, the objectifying attitude typical of science consists in seeing phenomena as systems. It requires a detachment, a bracketing, a suspension of our personal, immediate and spontaneous grasp of the entities given in perception.[7] I call such a suspension of our natural relationship to things the *primary, primordial* or *original abstraction.* Primordial abstraction consists in seeing any entity as an object, that is, as a system of *properties.* I call it "abstraction" because it requires *neglecting* or *omitting* most of the properties of a concrete thing given in perception. Even though an object is constructed by abstraction, it is real if its properties and relations are. In science, the elements in relation are often (but not always[8]) quantifiable properties, such as the pressure and volume of a gas. These elements are not things in the usual sense of the term, but properties. It is these properties and the relations among them that are studied within the objectifying approach. The choice

instantiated properties or relations. Thus, an entity is not quite a "bundle" of properties since these properties generally stand in some relations.

[7]It seems to me that we are unable to simultaneously take both an objectifying attitude and what I call below a holistic (emotional, aesthetic, religious etc.) attitude. We certainly can move very quickly from one kind of attitude to the other. The scientist, *qua* scientist, must strive to avoid holistic influences.

[8]There are scientific domains, typically in social sciences, in which the properties put in relation are not quantifiable.

of the properties of interest is constrained by the requirement for scientists to introduce a distance, to control their emotions and to refrain from attributing intrinsic values to objects. In adopting some form of asceticism, scientists must strive to curb any personal—subjective or emotional—involvement with the object of study. Although this ideal is only partially attainable in practice, it is consciously and deliberately pursued by scientists. This is one of the most important aspects of the search for the highest possible degree of objectivity, which would be achieved by the complete elimination of any influence linked to a particular scientist, whether experimenter or theorist.[9] In fact, the scientific object-system cannot be a singular and unique thing but must be indefinitely reproducible and repeatable. Such a system could in principle be constructed or reconstructed by any scientist, regardless of personality and context of research.

The second step typical of the scientific *démarche*—although most often simultaneous with original abstraction—consists in *selecting* in a given phenomenal entity (or set of phenomenal entities) some properties, quantities or magnitudes taken to be relevant from the perspective of a given discipline: chemistry, sociology, psychology etc. In such a way, the field of research is circumscribed in a precise and restrictive way. Such process of selecting specific properties or quantities is what I call *secondary abstraction.* Within this second step, scientists take a particular point of view or *perspective* with respect to the targeted phenomena. This leads them to neglect or make abstraction of a vast quantity of objective properties.

Although many properties and structures can be selected in the same phenomenon depending on one's interest or point of view, this does not in any way prevents possible justified belief in their reality. The term "abstraction" can be misleading since in some contexts abstract objects are deemed to be in principle inaccessible to perception, such as in mathematics. Here, the term "abstraction" means that some properties, including relational properties, of the phenomenon are disregarded or omitted. Admittedly, the selection of certain properties and relations implies neglecting other ones, but sometimes the properties called "abstract" are the properties on which scientists focus their attention within their modelling process, especially when these properties are mathematical properties. According to the terminology used here, these abstract properties are *extracted*[10]*f*rom the phenomenal thing. From now on, I will understand by secondary abstraction (or simply abstraction when there is no risk of confusion with the primary abstraction) the operation that consists in selecting or extracting from a phenomenal entity some properties and relations while disregarding many others. By

[9]For an in-depth discussion of objectivity, see Agazzi (2014).
[10]See Portides (2018).

this process we construct an object of enquiry, which is real provided its properties and relations are instantiated.[11]

Idiosyncratic preferences, personal feelings, circumstances etc., play a decisive role in motivating scientists to engage in scientific disciplines rather than others. Some prefer physics to chemistry, others psychology to demography or economics. Nevertheless, the extracted *properties* themselves can belong to the entities that are the targets of investigation. They can exist independently of individual scientists and the way they are selected or observed. Therein lies the most common meaning of "objectivity". It is imperative in science that the relevant properties be observed or measured by any observer or experimenter, that is to say, by anyone who uses the appropriate observational or measuring instruments.

For example, a planet is a concrete thing which has an indefinite number of properties, objective or not. Yet in celestial mechanics a planet is reduced to a very restricted set of properties such as position, velocity, orbital period ... These properties are in principle observable, directly or indirectly, by anyone, anywhere and at any time. The scientific object is not a unique, singular entity, but a system that can be multiplied and replicated indefinitely. An electron is just a system of instantiated properties: charge, mass etc. with a precise value and always present simultaneously. These properties form a system: their organisation consists at least in their simultaneous presence or instantiation. Nothing resembles an electron more than another electron: they all share identical properties. As John Earman once said, there is nothing more boring than an electron: once you have seen one, you have seen them all ... This holds true for any scientific system-object. Yet this does not prevent scientific activity from being exciting. Every day new properties are discovered, new objects constructed, and novel theories developed.

Far away from the city lights, looking at the sky on a cloudless night, some verses of the *Chanson du mal-aimé* may come to your mind:

Voie lactée ô sœur lumineuse
Des blancs ruisseaux de Chanaan
Et des corps blancs des amoureuses
Nageurs morts suivrons-nous d'ahan
Ton cours vers d'autres nébuleuses[12]

Poets and scientists adopt strikingly different attitudes towards the sky. Instead of dissecting the Milky Way into a system, the poet sees it as a totality in which we immerse without making any distinction between us as

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[11] On this, see Agazzi (2014, p. 104).

[12] *Milky Way, O bright sister / Of the white streams of Canaan / And white bodies of lovers / Shall we, dead swimmers, follow with ahan / Your course towards other nebulae* (My literal translation).

subjects and the sky as an object. More generally, in the aesthetic attitude, natural entities as well as works of art such as paintings, sculptures etc. are perceived as unique, singular totalities with which, instead of maintaining a distance, we try to achieve closeness, even fusion, by entering into the work of art itself to the point of forgetting that we are looking at it. This is the right way of seeing when we look at the *Madeleine à la veilleuse*. Otherwise, we would fail to sense its beauty. I call this attitude *holistic, sapiential* or *contemplative*. We spontaneously adopt such attitude in our friendly and loving relationships with persons. Such contemplative attitude should be embraced in relation to natural entities in order to be able to value and respect it.

Do not be mistaken however in believing that I value the objectifying attitude more than the sapiential attitude, or the other way around. Both play important roles in human life and knowledge. Yet we must carefully distinguish them. We surely want to avoid falling into a pervasive materialism that would make the scientific approach exclusively and universally cognitively valid, or into a romantic holism that would unduly value the sapiential attitude to the point of despising the scientific attitude.

2 Modelling and representing

How do scientists proceed to construct models that could represent something?[13] Representing is an action that can succeed or fail. According to the *structural view* of representation which I favour, a representation is successful *only if* it involves a transfer of structure from its target (the represented entity) to the representing artefact.[14] This requirement of *structural similarity*—distinct from resemblance—is a *necessary* condition of success. However, as we shall see, it is far from being sufficient.

2.1 What models are

Take a very simple and familiar empirical example drawn from astronomy.[15] In order to construct a model, the initial step consists in isolating and identifying from the bulk of celestial phenomena concrete entities such as immobile bright spots called "stars" and moving ones baptised "planets". Individual planets can be identified by means of their colour and brightness. They receive names such as "Mercury", "Venus" or "Mars". Like all concrete things, they have many objective as well as holistic properties. Within the

[13]Here I propose a philosophical approach to modelling and theory building. I do not claim that scientists actually work in the way I describe.

[14]A structural conception of representation is defended, with variations, by Suppes (1967, 2002), Da Costa and French (2003), Bartels (2005, 2006) and Chakravartty (2010), among others. It is criticized by Suárez (2003), Contessa (2007), Frigg (2010), Pero & Suárez (2016), and others.

[15]Old fashioned examples have the advantage of being well-known and understood by all ...

primary abstractive *démarche*, scientists first view the ensemble of planets as an object-system. Then, by secondary abstraction, they select some monadic and relational properties in order to construct specific object-systems, i.e., sets of specific properties. For example, an astronomer can decide to focus on the observed orbital periods, namely the times planets take to return to the same position with respect to the stars. (Positions are attested by observing properties of brightness and distances to the stars). In proceeding thus, the astronomer omits mentioning most of the other properties of planets. Model construction is always *incomplete*.

When observed from the earth the planetary return periods are not constant. This is due to the motion of the earth around the sun. But these return periods are *on average* equal to what we mean today by orbital period, which is the return period of the planet to the same position with respect to the stars, *as seen from the sun*. The duration of a complete revolution of the planet earth around the sun is approximately 365.25 days.

The next step is to construct a scientific object-system. In the present example, the object is a *perceptual* or *phenomenal system* or *structure*, whose elements are some selected observed properties of the various planets, namely the *average* orbital periods observed directly with the naked eye from the earth. Orbital periods are evaluated by observing the positions of the planets relative to the stars over long periods of time. The values of the planetary orbital periods are then structured by a "smaller than" relation, which is an order relation.

Notice, and this is an important point, that the elements of the perceptual structure are not concrete things but properties. Periods of revolution are properties instantiated in concrete things, namely planets. A specific planet, say Mars, is a concrete thing with respect to which we can adopt a holistic attitude (for example aesthetic or religious) or a scientific attitude. The planets themselves are not components of the constructed perceptual system. Only some of their properties are. A perceptual system is a system of perceived properties and relations selected among those instantiated in the concrete things which have been selected for research.

By constructing an object—which in this case is a specific perceptual system—a scientist performs the first step of the *modelling process*. A *model can be first characterised as a system of properties, that satisfies, that is, makes true, some propositions*. In the empirical example discussed above, the perceptual system makes true the propositions that describe the relations between orbital periods. For example, the perceptual system satisfies the following proposition: ⟨the orbital period of Venus is smaller than that of Mars⟩. The constructed scientific object is thus a model in the sense just defined, which may be called the "veridical sense" or "alethic sense".[16] Obviously, models in this sense are not propositions.

Of course, scientists are not satisfied with the construction of perceptual systems. By direct observation we often get rough values that must be made precise by using instruments or measuring devices. In our planetary example, the measurement results are also structured by the relation "smaller than". In this manner, we obtain what is usually called a *data model.* Such data models satisfy the propositions that describe relations between the data, namely measurement results. Like the perceptual structure, the data model makes true propositions such as ⟨the orbital period of Venus, equal to 224.7 days, is smaller than that of Mars, equal to 686.98 days⟩.

In addition to making some propositions true, models can play another important role. Models are used by scientists to *represent.* In the above example, the data model represents part of the sky (the set of planets) *as* a system of orbital properties. The dual role of models is reminiscent of the Roman double-faced god Janus, with one face looking to the past and the other looking to the future.[17] Similarly, models in science have a dual function: they make propositions true and can represent at the same time. But, how and what can models represent?

2.2 Photos and maps

When we talk of representation, mundane examples such as photos or maps that may represent a person or a landscape immediately come to mind. In the context of our present culture (but not in the context of other cultures, such as precontact tribes in Amazonia), things like photos or figurative paintings are immediately seen as artefacts that represent. When I look at someone's photo, I implicitly establish a correspondence between properties I select in the photographed person and some parts of the photo. A given coloured area on the photo corresponds to the face, while another area corresponds to the hair of the person who is represented. This kind of correspondence is called a "function" in mathematics. When I look at a coloured piece of paper which I recognise as a photo of someone, I associate properties of the person who is represented with elements of the picture, mostly unconsciously. But I can also consciously construct a function that *codifies* a correspondence between what the photo represents and the photo itself. If each selected property of the person who is represented corresponds to one and only one element of the photo, and vice versa, I have constructed what is called a "bijective function" or "bijection". In this case, the properties selected in the photographed target and in the photo are equal in number.

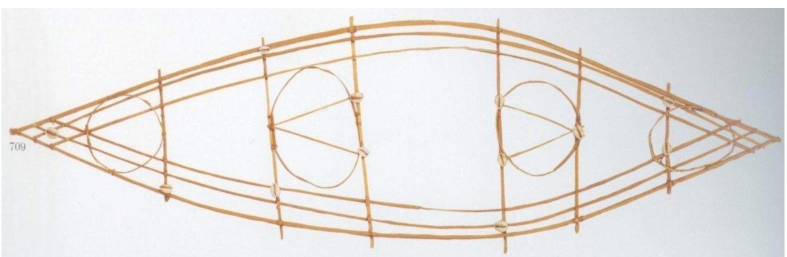
[16] This sense corresponds to what Alfred Tarski and Patrick Suppes understood by model in mathematical logic, namely a set-theoretical structure satisfying or making true the sentences of a theory (see Suppes 2002, p. 21).

[17] Da Costa and French insist on the dual role played by models (2003, p. 67).

Moreover, I choose a function that preserves specific relations of a certain kind, such as spatial relationships. What in the photo corresponds to the mouth is located below what corresponds to the nose etc. A bijective function that preserves relations is called an "isomorphism". The relations organise the elements into a structure, a form, as hinted by the Greek etymology of the word "isomorphism":[18] the person who is represented and her photo share the same structure or form, but only with respect to the construction of a specific correspondence, which is always based on selected elements and relations. Such construction—implicitly taken for granted in some cultural context—disregards some aspects of the photographed person, like three-dimensionality. The photo is a partial and thus incomplete representation of its target.

A function that maps some properties of a person into properties of her photo while preserving selected relations is called a *representative* or *representational function*. The representational function performs a *transfer of structure* and thus establishes a *structural similarity* between the person and the photograph. According to the structural view, some structural similarity between the representing artefact and what is represented is a necessary—but quite insufficient—condition for a representation to be successful.

Let us now look at an unfamiliar quite exotic example shown in the figure below.



The above artefact is easily recognised as representing a specific target in some cultural contexts only. Most people are unaware that it was used as a sea chart by Micronesians living in the Marshall Islands.[19] In constructing this artefact, the cartographer intended to convey useful information to a navigator. How did the Marshall Islands navigators manage to extract

[18]"Μορφή" in Greek translates as "form" and "ἴσος" as "same". Homomorphisms (many-to-one functions) are more general than isomorphisms. For the sake of simplicity, I will limit the discussion to isomorphisms. Homomorphisms, just as isomorphisms do, can ground structural similarity.

[19]This sea chart is in the Linden Museum in Stuttgart. I am grateful to Anthony Meyer (1995, p. 616, figure 709) and Ulrich Menter, curator of the Oceanic art collection of the Linden Museum, for permission to publish this reproduction.

interesting information from this map? In order to obtain correct, and therefore useful, information, I need to know the code. This code is not included in the map: it is *external* to it. Taken by itself, this artefact does not represent anything at all. Yet it is obviously true that it has internal properties. It is made of wooden sticks tied by knots, contains shells placed at some intersections and exhibits other features. When told that it is a maritime chart, I realize that the Micronesians mapped some elements and relations relevant to steering a canoe into elements and relations of the artefact, but I do not know which ones. In order to be able to see and use this artefact as a map, and not look at it as a work of art, I must know the code, that is, the function—more precisely the isomorphism—that connects selected relevant properties and relations of the maritime environment—which is the intended target—to selected properties of the map and selected relations among them.

In order to be able to use this artefact as a helpful instrument for navigation, I must know that the maker of the map intended to establish a correspondence between islands and shells. In addition, to detect the presence of a distant island, the Micronesians relied (besides the bearings of stars and other clues) on observing interference patterns of swells. Swells are quasi-permanent waves produced by persistent and strong winds, especially the trade-winds near the equator which blow from the east, called "easterlies". When an island is present, it reflects and refracts parts of those swells (refraction here means the bending of the inshore ends of swells by friction with the island coast). To put it briefly, the presence of an island distorts the swell interference pattern of the open ocean. Such distortion can be observed (by seeing but mostly by the body feeling the waves under the boat) by experimented navigators up to about a 100 km distance to an island. Swell interference patterns were rarely taken to be relevant to navigation by Western explorers ... However, what is represented by the arrangement of sticks and shells is the distortion of the ocean swell interference pattern by the presence of one or more islands. The map is used to partially represent the maritime environment—the concrete target—*as* a system of swells.

Yet such a map was not used during navigation. In fact, it is a pedagogical and mnemonic tool.[20] Only oral tradition in a specific context could initially reveal what and how it represents. What is more, the information encoded in this map is quite insufficient to serve as a guide for navigators in Micronesia. Such sea charts are far from being complete since no information from the bearings (azimuths) of stars, among other relevant guiding information, could be acquired from them.

[20] For a detailed explanation of how these maps were used, see David H. Lewis (1994, pp. 224–252) and Ascher (1995).

Suppose now that I am on a beach on the Ailinglaplap Atoll (where the above stick chart comes from) in the Marshall Islands. To be able to use such a map, I must first locate myself on it, *i.e.* I must know which shell the Ailinglaplap Atoll corresponds to, according to the intention of the maker of the map. I also need to correctly orient the map in relation to my surroundings. This information is not contained in the map! The map is "impersonal" in the sense that it can be used by different people at different locations. Location involves both position and orientation. If I locate myself at the wrong place on the map, I will be unable to make correct statements such as: if I sail in this direction, I will reach that particular island. Thus, proper use of the map presupposes the truth of the statement: I am here on the map. Such statement contains indexical terms. "I" and "here" have different denotations depending on who is making the assertion and where the map user is located. Again, just as the code was, the referents or denotations of these indexical terms are determined by information *external* to the representing artefact.

The examples of the photo and the Micronesian sea chart teach us valuable lessons. Firstly, something never functions by itself as an artefact representing something else. As van Fraassen insists "*There is no representation except in the sense that some things are used, made, or taken, to represent some things as thus or so.*" (2008, p. 23) From the outset, a photo or a map must be *appropriated* by a user for some practical purpose or aim with reference to a particular target. My grandmother's photo is not in itself the photo of my grandmother. It only becomes the photo of my grandmother because I *decide* to take such piece of coloured paper as a photo of someone and also specifically the photo of my grandmother. The decision to take the piece of paper as a photo is of course strongly suggested by familiar implicit conventions that permeate our cultural context and our knowledge of the production of photos by cameras, but it is not compulsory.

The example of the Micronesian artefact makes it clear that something does not immediately and obviously present itself as having a particular representing role, except for users in a specific cultural context. In order to represent, something must in the first place be appropriated by a user who determines its target. In themselves, a photograph or an arrangement of sticks, knots and shells do not provide any identification of a possible target. Such identification is achieved by a user who takes some artefact as a picture of a person or as a map that represents a swell pattern. The *intention* of the user is paramount: the decision to employ something to represent a chosen target belongs to the user. Different users could use the same artefact to represent different targets. The identification of the target is the result of the intentional act of the user which may or may not correspond to the intention of the maker of the artefact. Of course, this intentional act is also external to the target and the representing artefact. As van Fraassen says:

> Given this intentionality, it is perhaps not surprising that, in the case of a representation, the relations can change with context of use. The very same object (...) can be used to represent different things in different contexts, and in other contexts do not represent at all. (van Fraassen 2008, p. 27)

The direction or asymmetry of the representation also depends on the intention of the user: a photo or a map represents its target and not the other way around. Since the user's intention and the context play a crucial role in the success of a representation, the relation between a representing artefact R and its target T cannot be reduced to a two-place relation. The representational relationship is a four-place relation: a user U represents T as such and such by means of R in some context C. Given that the intention of the user and the context are external to the representing artefact and what is represented, the established structural similarity between R and T is far from being sufficient, although according to the structural view of representation it is necessary.

2.3 Truth and correctness

To identify a target, we could simply point to something which is immediately perceptually present. In other situations, we must formulate a description that mentions some properties actually possessed by the target. Identifying the target of a representation is similar to identifying the referent of a word. Referential success can be achieved either in accordance with Kripke's causal theory of reference or (at least partially) true descriptions. In the latter case, the (partial) truth of some propositions is necessary for the identification of the target.

The main point is that identifying the target of a representing artefact is arbitrary, just as a given word can be made to denote anything. Of course, conventions in place in some context determine in practice the denotations of linguistic signs, as a given context does for the targets of some representing artefacts. But such external facts do not eliminate the fundamental arbitrariness in attributing a target to a representing artefact. As a consequence, mistargeting understood by Suárez (2003) as applying a representing artefact or a model to "an object that it is not intended for" or to the "wrong target" (Pero & Suárez 2016, p. 74) cannot occur. Indeed, mistargeting is meaningless in the same way as misreferring for a word is, except in the external sense that a word may sometimes be used without complying with the conventions in place in some cultural linguistic context. For example, it could happen that someone who is not proficient in English uses the word "rat" to denote a mouse. Similarly, nothing intrinsic to a

Micronesian stick chart prevents it from being appropriated by a user as a map of Brussels. Then, its intended target would be Brussels. (I am insisting on this, because it helps to understand why a successful scientific model can be applied to a target which is very different from its initial target, when for example the liquid drop model is used to represent the atomic nucleus)[21]. Obviously, it could be the case that no intended target has been attributed to an entity or an object, as is the case for most entities in the world. Then, such entity does not qualify as a representing artefact in the first place and *a fortiori* cannot misrepresent.

Once a target has been identified, some selected properties, which are intrinsic to the target, are made to correspond to selected properties of the representing artefact, the photo or the map, in order to construct a representational function which preserves some selected relations. Such an operation, which is tantamount to specifying a code, is most often implicit in a given context. When performing a representation, the user always relies (often unconsciously) on a function which performs, as we have seen, a transfer of structure from the target *to* the representing artefact, be it a photo or a map.

It is crucial to realise that the construction of this function is based on the *assumed truth of some propositions* that attribute properties and relations to both the representing artefact (the photo, the sea chart) and its target (a person, a maritime environment) such as ⟨the stick chart contains shells⟩ and ⟨the maritime environment comprises islands⟩. This is the case even if the representation is incorrect, that is to say, misrepresents its target. However, such construction does not commit us to a constructivist antirealist position according to which our representations never provide cognitive access to external real things. It is certainly true that in this construction process a thing acquires the status of a representing artefact, but it is also true that it has intrinsic properties. If a photo is used to represent a person it is because people have properties which are put in correlation with properties actually possessed by the photo. This representational action is *successful* only if the target has been identified *and* a transfer of structure from the person to the photo has been carried out by the user, namely someone looking at the photo.

Suppose now that I decide to use the photo of a particular person as a representation of my grandmother. I might do that because at some place on the photo there is a black area above a light area, and my grandmother had black hair. Yet I could have used other identifying clues and other conventions. On the other hand, a photo of my grandmother is considered *correct* or "good" if propositions (which do not have to be uttered or written)

[21]The liquid drop model of the nucleus is carefully discussed by Da Costa & French (2003, pp. 50–51).

about relevant aspects of her physical appearance as well as propositions about some characteristics of the photo are true. The correctness of the photo decisively depends on the isomorphism, which has been established and which conveys to the user some information about my grandmother. If the photo is accurate (in some respects), it is because, among other things, the area and the photo corresponding to the nose is comparatively small and because my grandmother had a small nose, a fact that makes true the proposition ⟨my grandmother had a small nose⟩.

The very same photo may be intentionally appropriated by someone else to represent my great-aunt. In this case, the photo will *not* represent my great-aunt correctly, i.e., it will *misrepresent* her in some respects because, for example, my great-aunt's nose was larger than my grandmother's. However, it will be a photo of my great-aunt, a successful representation of her based on the truth of propositions (descriptions) identifying her as the intended target.

A representing artefact such as a photograph is neither true nor false. Only statements or propositions can be true or false, such as the proposition ⟨my grandmother's nose was small⟩. Artefacts and propositions belong to different categories that should not be mixed up.[22] If one speaks of the truth of a representation, it only can be in an indirect or derivative sense. The correctness of an artefact endowed with a representational use rests on facts on which we rely to construct representational functions. Those facts make some propositions true, but an artefact is neither an assertion nor a proposition. For this reason, I will not speak of true or false representations but of correct or incorrect representations.

In what sense can a representing artefact be incorrect or misrepresent? Since the choice of an artefact to represent a particular target is always intentional, the visual resemblance between an artefact and some entity does not determine that the artefact represents something specific, nor *a fortiori* that it represents it correctly in some respects. What is more, it is not true that an artefact must visually resemble its target to be a representation of it. This point is made clear by the example of the Micronesian sea chart. Is it plausible to claim that this chart resembles a maritime environment? If it did, it would immediately be recognised as a sea chart in most contexts. Does a sheet of paper with straight parallel lines and small elliptical patches immediately appear to anyone, in any cultural context, as a music score? Does the score look like the music it represents? Obviously not.

[22]According to my regimented construal of representation, true propositions do *not* represent their truthmakers. No representational function can be constructed from the truthmaker to the proposition it makes true. The failure of Wittgenstein's "picture theory of meaning" in the *Tractatus* is a case in point. (Wittgenstein 1971) Although I advocate a correspondence view of truth, the relation between a true proposition and its truthmaker is not representational in kind but rather referential. (Ghins 2024, pp. 51–52).

This is why Nelson Goodman could write:

> The most naive view of representation might perhaps be put something like this: "A represents B if and only if A appreciably resembles B". Vestiges of this view, with assorted refinements, persist in most writing on representation. Yet more error could hardly be compressed into so short a formula. (Goodman 1976, pp. 3–4; quoted by van Fraassen 2008, p. 11)

Visual resemblance can certainly play a representational role provided it is encoded in a (usually tacit) representational function that connects identical or nearly identical properties and relations. Obviously, this is implicit in the case of a photograph, which always resembles something or someone by virtue of the very process of its production by means of a particular technical device, such as a camera. Despite of this, a photo can misrepresent. It all depends on the target intentionally chosen by the user. As in the example discussed above, if I decide that the picture of my grandmother is the picture of her sister (who looks very much like her), then I certainly represent her sister. It is the intentional act that decides the target or referent of the representation, and thus its *asymmetry* (the photo represents my great-aunt and not the other way around).[23] However, I could claim that the photo *mis*represents my great-aunt by pointing out that, unlike my grandmother, her nose was large, as we saw. Again, the incorrectness of the photo depends on an actual physical property of my great-aunt.

2.4 Some objections

Let us now have a look at two standard objections to the structural view of representation I proposed. According to the first objection, the structural view fails to account for cases of *non*-representation, i.e., when no target has been identified and also when the intended target does not exist. According to the second objection, structural similarity is not a *necessary* condition for representational success in examples such as Stolz's caricature that represents the chancellor Bismarck as vainglorious, which is a case of what I will call "symbolic or metaphorical representations".

Firstly, if no target has been identified, there is no representation. As seen above, target identification is akin to denotation, since it is arbitrary (anything can represent anything ...) just as any entity can be made the referent of a given sign or word. Without target identification, it is obvious that no transfer of structure from a target to a representing artefact can be established by a user. Thus, objecting at this stage that isomorphisms (or, more generally, homomorphisms) have not been instituted or that they are unable to account for the identification of targets is irrelevant.

[23] On the asymmetry issue see also Bueno (2010).

Granted, in everyday language some objects are often called to represent other things even when no transfer of structure has been established. For example, in board games such as the Game of the goose, it is often said that coloured pieces *represent* the players. But in such instances, no representation takes place. Actually, it would be more appropriate to say that coloured pieces *stand for* or *denote* the various players.

It must also be emphasised that when an intended target has been properly identified, it need not to be real. Imaginary or ideal targets can be described and theoretically constructed, especially in scientific contexts. Mathematical models are routinely constructed, that may or may not match—approximately—selected properties of real targets. Such activity of model construction plays an important heuristic role in science. Mathematical models or ideal structures such as perfect gases or ideal pendulums are *necessarily* correct (or very nearly so) by construction, in the sense that they exactly (or very nearly so) satisfy the laws[24] of perfect gases and ideal pendulums.[25] Indeed, ideal structures are constructed in such a way that they satisfy some propositions. They are models in the alethic sense. Representation happens only when such models are claimed to partially represent real systems previously identified—independently of theoretical construction—as targets. If an ideal model does not correctly represent its target in some relevant respects, it can be called a misrepresentation of its target, as explained before.

A successful and partially correct model for specific targets, can be tentatively applied to very different targets in accordance with the claim that anything can represent anything. In science, such attempts are heuristically guided by analogies supposed to be present between the target (seen as a system) of the previous model and the intended target (seen as system) of the tentatively constructed model, as Mary Hesse (1970) famously contended.[26] In this paper I am more interested in the relation between scientific models and reality. Thus, I will not further delve into the (admittedly very important) heuristic role of models.

[24]More precisely, ideal structures satisfy nomological formulas such as $PV = kT$; more details on this in Ghins (2024, p. 27).

[25]It has often been pointed out that mathematical structures such as the ideal pendulum are contradictory. To get the law of isochronism of small oscillations ($T = 2\pi(\ell/g)^{\frac{1}{2}}$), where T is the period of oscillation, ℓ the length of the pendulum and g the gravitational acceleration), one supposes that the angle of oscillation is equal to 0 and thus that the pendulums does not move! Nevertheless, the ideal pendulum with small angles of oscillation nearly satisfies the law of isochronism. And observations of real pendulums approximately agree with the law when oscillations are small ...

[26]As Da Costa and French (2003) nicely showed, Hesse's notions of positive, negative, and neutral analogies can be precisely captured by the notions of partial structures and partial isomorphisms.

The issue of misrepresentation brings us to the second objection, namely when distortion is used to represent the target *as* having properties (or relations)—which I call "symbolic" or "metaphorical"—that are not mapped into properties (or relations) of the representing artefact by some isomorphism (or homomorphism).

Let us look more closely at this through one of van Fraassen's examples, namely Stolz's caricature of Bismarck (who was chancellor of Germany at the end of 19th century) as vainglorious.[27]

First, for the caricature to function as a representing artefact *of* Bismarck its target must be identified. In the present case, the referential intention is determined by propositions, which are implicitly supposed to be true by the user. These propositions attribute to Bismarck's visage specific properties that resemble some features of the face pictured in the caricature. Thus, the identification of the target relies on facts: Bismarck was bald, wore a moustache etc. These facts make the relevant propositions true. Moreover, a significant part of the structure of Bismarck's visage is mapped (by a user in some context) into the structure of part of the caricature. Thus, the target of Stolz's caricature is Bismarck.

Yet in the drawing Bismarck's head, chest and feet substitute the head, neck and legs of a peacock which displays his tail feathers. Evidently, the drawing was not intended by Stolz to be taken to be a resembling portrait of Bismarck but as a caricature that represents him *as* vainglorious. How is

[27]This caricature is in the public domain (Wikimedia Commons). It is discussed by van Fraassen (2008, p. 14).

Stolz's aim achieved? As van Fraassen stresses, success in achieving such aim relies on some *distortion* of Bismarck's physical features. Bismarck's arms are replaced by wings, his chest looks like a long neck etc. If implausibly believed to be a resembling portrait of Bismarck, such representation is obviously incorrect and is thus a misrepresentation of him in some respects. However, the drawing contains properties and relations—notably the displayed tail feathers—which are typical of peacocks. In our cultural context, peacocks are metaphorically or symbolically associated with vanity. Hence, appropriated by a user in a Western culture, Stolz's drawing successfully represents Bismarck as vainglorious, whether he was actually vainglorious or not.[28] Here again, representational success is grounded on an isomorphism between parts of Bismarck's body as well as properties of peacocks on the one hand and properties of the drawing on the other hand.

Although metaphorical or symbolic representations are not usually used in scientific contexts, distortions are. The representation of a planet-star system as a structure of two mass points is a clear and frequently cited example of distortion. Clearly, planets and stars are voluminous entities ...

2.5 Scientific modelling

Today, many philosophers of science rightly emphasise the prominent role of models within scientific practice. For the proponents of the "semantic view of theories",[29] theories are primarily sets or classes of models. Such a conception, defended by Patrick Suppes (1967, 2002), Bas van Fraassen (1980, 2008) and Ronald Giere (1988), among others, gradually became prevalent in reaction to the "syntactic conception" according to which theories are just sets of statements or propositions. This syntactic view was embraced by the logical positivists of the Vienna Circle in the early 20th century, such as Rudolf Carnap, Moritz Schlick and Otto Neurath, to mention only a few. The syntactic conception dominated philosophy of science until the late 1960s.[30]

In the *Scientific Image*, Bas van Fraassen endorses the semantic view and claims that "models take centre stage" (1980, p. 44). He of course acknowledges that theories also contain propositions. Nevertheless, a theory is primarily a set of models that fulfil the dual role of representing phenomena as well as making propositions true. Yet theories are not maps or photographs. Models in science can be systems of real properties (like the DNA double

[28]The caricature could have been appropriated to represent a peacock as Bismarckian. Given the context, this would have been somewhat far-fetched ...

[29]The name "semantic" is justified because the semantic conception of theories is primarily interested in models and these, as we saw, can make true some statements and propositions.

[30]Look at Frederick Suppe's (1974) classic work for a presentation of the reasons that led to the abandonment of the syntactic conception in favour of the semantic conception of theories.

helix modelled as a system of spheres and rods), but also mathematical structures whose mode of reality is controversial and which I qualify as *ideal*.

In the example of the orbital periods of the planets presented above, the aim of representing a perceptual structure by a data model is reached by establishing a correspondence between two distinct sets of properties, one which contains directly observed quantities while the other contains measurement results. If the domains of the perceptual structure and the data model contain the same number of elements, a one-to-one correspondence between them can be constructed by means of a bijective function F. Such function maps an element of the domain of the perceptual structure to an element of the domain of the data model, in such a way that there are no unpaired elements. In the example above, the orbital period of planets observed by the naked eye are mapped to their measured orbital periods.

In addition, we can arrange things in such a way that the correspondence preserves selected relations between the elements of the domains. Two elements a and b connected by a relation R in the perceptual domain are mapped by F to data that stand in a relation R^*. In the example we are discussing, R and R^* are the same relation "smaller than". Let us call two observed orbital periods "a" and "b". $F(a)$ and $F(b)$ are the corresponding elements (images) in the data model of a and b. If a is smaller than b, then $F(a)$ is smaller than $F(b)$: if aRb, then $F(a)R^*F(b)$. The representative function F is an isomorphism. Thus, this set of data can be appropriated by scientists as a model to represent the perceptual or phenomenal structure of orbital periods.

For a data model to represent a perceptual structure, a representational function operating a transfer of structure must have been constructed beforehand by a user. This is the central point of the *structural* conception of representation in science which I favour. Granted, a mathematical model, such as a data model, does not appear to have the material solidity of a photograph or a map. Although models are not propositions, they can be conveyed by means of symbols like written signs on a piece of paper, just as propositions also can. It seems to me that the relation between a mathematical model and those signs is analogous to the relation between a proposition and a corresponding sentence or propositional sign. In the same way as a proposition can be expressed by various sentences in different languages according to distinct conventions, a model can be conveyed by various material symbols.[31]

We saw above that the *context* can play a crucial role in indicating some representational function when some artefact is seen as a photograph or a map. A given cultural milieu includes a wealth of conventions which deter-

[31] Let me recall that the relation between sentences and propositions is not representational.

mine, most often implicitly, the code assumed by a user in appropriating an artefact as a map, a photo ... I also emphasized that the representational relation is complex since it involves four ingredients: the representing artefact, the represented target, the user and the context. However, once the representative function between two structures has been explicitly and clearly specified, as is often the case in science, one can limit the representational relationship to a two-place relation between two structures, while remaining silent about the other ingredients, which are taken for granted. I also insisted that I use the word "representation" in a precise, regimented, technical sense, which does not correspond to its usual meaning in some contexts, such as when we say that some piece on a board game represents a player. Besides, in attributing a property P to an entity S, we commonly say that we *represent* S as instantiating property P. However, in this case we are not establishing a representational relationship (in the structural sense) between a property P on the one hand and an entity S on the other, let alone a relationship between an "image", an "idea" or a "representation" in our mind and an external entity.

A successful action of representation—in the technical structural sense—requires constructing an isomorphism (or homomorphism) between two structures. A scientist can succeed in representing a targeted phenomenon only by selectively extracting a perceptual structure from it. Then, a data structure and an isomorphism between them is constructed in order to finally get a representing data model. Proceeding in this fashion within the objectifying approach seems to lead to the following counter-intuitive consequence: the data model does *not* represent the targeted phenomenon, but only the system of perceived properties which is extracted from it, that is, a scientific object. At first sight, the representing process seems to imply the unwelcome consequence that scientists loose contact with concrete real things. This is not so! Success and correctness of a representation are grounded on instantiated properties, that is, on facts, described by true propositions as we saw earlier.

For sure, the elaboration of a scientific theory cannot remain limited to the construction of a data model, if only because a data model has no explanatory power. The data model only represents the perceptual structure and does not explain *why* the durations of orbital periods increase with the distance to the sun. In order to explain the measurement results, scientists immerge or "embed" the data models into larger, more encompassing structures, called "theoretical structures". What does such *embedding* consist in?

Embedding a data model in a theoretical structure amounts to constructing an isomorphism between a substructure of the theoretical structure and the data model. By extension, we can speak of the embedding of perceptual structures (and even of phenomena themselves according to van

Fraassen, 1980) in theoretical structures, which make true (or nearly so) the laws of the theory. In this broad sense, phenomena are embedded in theoretical structures although phenomena are not systems. Theoretical structures are mathematical structures. They often are set-theoretical structures capable of representing structures of properties instantiated in an intended target. Furthermore, theories contain structures that cannot be instantiated in reality. The world does not contain completely isolated systems of two massive bodies which exactly match the mathematical models of Newtonian mechanics. Real systems are represented by mathematical models only in an approximately correct way.

In celestial mechanics, the structure of orbital periods can be embedded in the set of models of Newtonian mechanics that deal with two masses in gravitational interaction. As a first approximation, when looking at the orbital motion of a planet such as Mars we focus on Mars and the sun only and disregard the gravitational influence of other planets. Since the mass of the sun represents more than 99% of the total mass of the solar system, such omission is justified when a high degree of precision is not required. Moreover, we take planets and the sun to be point masses. When simplifying assumptions disregard properties which are known to be relevant (such as the presence of more than two gravitationally interacting bodies), this is a well-known feature of the abstracting process. However, the simplifying assumptions may not conform to some relevant properties of the target. In such cases, some relevant properties are modified or distorted. In situations like these, we should speak of *idealisation* as Portides recommends. (Portides 2018) As a consequence of omissions and idealisations, a proposed model can be incorrect in several relevant respects. Scientists are aware of this. This is why they strive to construct less incomplete and more accurate models by taking into account relevant factors that have first been omitted by abstraction and also by modifying or cancelling idealisations. In practice, simpler or more sophisticated models are used in different contexts in function of the demanded degree of precision.

Newtonian theory contains a theoretical substructure isomorphic to the data model of orbital periods. But the availability of an isomorphism does not imply that the theoretically calculated values of orbital periods conform the data. In addition, we want the theoretical values to be sufficiently close or *adequate* to the measured values. Otherwise, the two-mass-point model would be useless for delivering correct predictions. A theoretical substructure susceptible to be isomorphic and also adequate to the data model is called an *empirical substructure* (van Fraassen 1980, p. 64). It is empirical because the properties of its domain, such as the orbital period values, are measurable. Yet an empirical substructure is also theoretical since it is obtained by calculation within the framework of a theory. Given that its adequacy can be tested empirically, there is no contradiction for an empirical substructure to be both empirical and theoretical. When for any data model belonging to the domain of investigation of a theory, the theory always contains an empirical substructure that adequately, i.e., correctly (at least approximately), represents the data model, the theory is said to be “empirically adequate”.

Obviously, an empirically adequate theory must also permit calculating and predicting *novel* measurement results. This is a challenging requirement. Empirical adequacy is not limited to available data but must encompass *all* possible future measurements. A theory is empirically adequate if and only if it contains empirical substructures that are isomorphic (or homomorphic) to the set of data models that can be constructed for the set of perceptual structures that fall within its domain of investigation. It may happen that new data do not conform to the predictions of the theory. A scientific theory always runs the risk of being falsified: there is no guarantee that future data will always match the predictions of the theory. This typically occurs when more accurate measuring instruments are developed. If the predictions of the theory deviate too much from new measurement results, then it can no longer be taken to be empirically adequate.

The process described above can be summarised in the scheme given in Figure 1.

It should be clear that this scheme is not supposed to reflect the actual manner in which scientists proceed, let alone the way classical mechanics has been elaborated. Rather, it is meant to be a conceptual epistemological analysis of the connection between theoretical models and observed things. Once the laws of classical mechanics are known, structures that make true those laws—or rather solutions of them in disciplines like physics—can be constructed and studied independently of experience. Such purely theoretical models could then be applied to some real systems, including systems that do not pertain to the domain for which a theory was originally designed. In other words, a theoretical model can play a heuristic role as mentioned earlier.

I acknowledge that the presentation above offers a very simplified view of the complex process of model construction in science, as the abundant current literature on models testifies. However, the value of simplification lies in its ability to facilitate generalisation. I submit that the proposed framework generally applies to successful modelling in science.

3 Conclusion

To conclude let me first recall that representing is an activity or an action, as van Fraassen stresses. It involves a user appropriating an artefact to represent an intended target as such and such by stipulating a code and

Phenomenon (sky)

@

Perceptual structure (perceived orbital periods)

$\downarrow$ isomorphism

Data model (measured orbital periods)

$\downarrow$ isomorphism

Empirical (*and* theoretical) substructure (calculated orbital periods)

$\cap$

Set of theoretical models (two-mass models)

$\cap$

Class of models (theory) of classical point mechanics

FIGURE 1. The symbol @ stands for abstraction, i.e., selection and omission of properties and relations, and $\cap$ stands above for strict set-theoretic inclusion.

adopting conventions in a certain context. An action is neither true nor false; it can succeed or fail, insofar as the user succeeds or fails to achieve some intended aim. To successfully represent a target, two conditions must be met. First, the user must identify the target. This identification is achieved by an intentional action in the first person: I decide to represent a particular thing (or class of things), recognisable by some of its specific properties, whether it exists or not. This is the reason that mistargeting cannot occur, but non-representation only, in the same way that a word sign can lack denotation. As a next step, the user must establish, consciously or unconsciously, a transfer of structure from the target to the artefact used to represent it. This requires extracting from the target some properties and relations that are mapped, by an isomorphism (or homomorphism), to selected properties and relations of the artefact. For example, if I decide to use the liquid drop model to represent an atomic nucleus, I must establish a mapping between some properties of the nucleus into some properties of the liquid drop model as seen earlier. The success of these two actions (target identification and transfer of structure) presupposes the truth of some propositions about the properties of the target and the representing artefact. I can also successfully represent a person, *albeit* incorrectly in some respects, when using my grandmother's photograph to represent my great-aunt. Since a representing artefact is never true or false, its correctness or incorrectness depends on the code determined by the representative function and—crucially—on some facts which make certain propositions true or false. The code as well as the facts are external to the representing artefact.

When I represent a given target using some artefact, I always adopt a particular perspective with respect to certain properties and relations. By appropriating a piece of coloured paper as a photograph, I represent the chosen target according to some of its visible aspects; in other words, I represent its target *as* a visual system. By appropriating a Micronesian artefact *as* a sea chart, I represent an environment as a system of properties relevant to navigation. In other words, I adopt a particular point of view on a target by representing it as such and such, that is, according to some highlighted respects. Of course, many other respects are disregarded: my representation is never complete. It is even hugely incomplete because my representation disregards the vast majority of the properties and relations instantiated by the target.

Discussing some mundane examples of representation helped us to better understand how model construction works in science. Starting from some phenomena, the first step is to extract from them a perceptual structure, that is, a set of perceived properties organised by specific relations. The next step is to construct a data model to which the perceptual structure is connected by a representative (isomorphic or homomorphic) function. The data are measurement results often smoothed out to produce a continuous structure. Then, an empirical structure is constructed to represent the data model. Such empirical structure is then embedded in a theoretical structure, such as a two point masses model as illustrated above. Obviously, scientists do not usually proceed in the way just described in their actual practice. More often than not, phenomena are not directly observable, and no perceptual structure can be constructed by extracting properties from them. Scientists often work within the theory to produce empirical substructures susceptible to guide them towards collecting new measurements and data. Be it as it may, I submit that the relationships between data models, empirical substructures and theoretical models generally obtain as presented above.

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