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ORDER: GOD'S, MAN'S AND NATURE'S

Analysis of Theories and Synthesis of Models'

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ABSTRACT

We treat an old problem appearing in a new context, namely the Duhemian problem of testing holism, in the context of modeling. We explore modeling in terms of analytic and synthetic strategies, and under this rubric we investigate a recent proposal for how models, used in their analytic role, work as a solution to the Duhemian problem. We show that this solution fails, but in failure it suggests a new approach to the problem based on the distinction between the two kinds of modeling strategies. It would be a mistake to think of the Duhemian problem as a methodological tragedy. We would make the same mistake if we thought that the failure of the analytic use of models to eliminate holism exhausted the options. Instead, we want to conclude by pointing to the synthetic dimension of modeling. The Duhemian problem is an expression of the synthetic dimension of modeling and hypothesis formation in scientific experimentation. Development in applied and unapplied science has relied increasingly on fruitful projects of local syntheses. For scientific testing, the synthetic dimension of modeling is fundamental. From this point of view, neither scientific practice nor representations of science should be held hostage to what is a particular logical image of scientific methodology. The challenge posed by the Duhemian problem is to understand the different interpretations and uses of experiments in connection with modeling practices. It may be a logical tragedy, but it is not a scientific problem. It shouldn't be a problem for Philosophy either.

Introduction

The properties of scientific models are the subject of much debate. Modeling is generally thought to be the useful application of theories. Since theories are formal complexes of hypotheses, their application and testing often prove intractable. Modeling provides a possible solution to this problem. Scientists can apply abstract theories to concrete situations through the use of models. In this sense modeling can reduce the complexity of theories for application purposes (e.g. prediction, exploration, explanation and representation). This is the analytic role of models. Models in this role reduce theoretical complexity. complexity in this context is a general characteristic involving a multiplicity of elements possibly organized by relations forming a structure (we will not be concerned here with how the elements are fixed that was Russell's problem).[1] However, to think of models strictly in their analytic role, simply as a tool to reduce theoretical complexity, would be to miss the significance of the complexity of their synthesis. That is, models are, in the theoretical context, *constructions* of theoretical and testing hypotheses. In that context, models represent testing situations which cannot be created from information provided by a theory alone; modeling requires the synthesis of auxiliary theoretical hypotheses and data concerning background conditions. Thus, modeling features the integration of many theoretical and testing hypotheses along with an element of creativity on the part of scientists.[2] Although models may simplify the application of complex theoretical hypotheses , models are themselves complexes of theories and background conditions. In this way, models play an important role in the analysis of theories, but as we wish to make clear only as a consequence of their own synthetic complexity.

The complexity of scientific modeling raises a number of issues for the testing of hypotheses. Although modeling is useful in the application of theories, their complexity of construction prevents them from avoiding the traditional problems of holism in testing situations. Duhem famously argued that holism in testing situations precluded the testing of isolated hypotheses. In addition to the theoretical hypothesis that scientists wish to test, there are a multitude of testing or auxiliary hypotheses that are imbedded in

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[1] We are using a general notion that is closer to Russell's view of logical construction in logical atomism than to the more specific formal and material notion such as computational complexity and descriptive and interactional complexity for spatially localized material systems (for a discussion of this see chapter 9 in Wimsatt (2007) for a discussion of computational complexity see Papadimitriou (1994)).

[2] For a treatment of the creative strategies employed in modeling see Bailer-Jones (1999)

the testing apparatus and conditions. Since experimental testing always includes more than a single hypothesis in this way, it is impossible to know whether the target theoretical hypothesis or one of the auxiliary testing hypotheses is confirmed or disconfirmed. This apparent problem of complexity based holism in testing situations is what we call the Duhemian problematic.[3]

Yet, one need not be pessimistic about the Duhemian problematic. When framed as a problem, the Duhemian problem is a logical problem concerning the indeterminacy of analytic logical strategies of hypothesis testing. When theories are thought of as deductively closed systems, the underdetermination of hypotheses by experimental data presents a particularly damning problem, especially for Duhem who thought that “agreement with experiment was the sole criterion of truth for a physical theory” (Duhem Aim and Structure).   Thus, if one were to hold onto this kind of logical image of science, then analytic strategies, even in modeling, are manifestly inadequate given the sheer complexity presented in testing situations.

However, testing holism is not a problem to be solved; rather testing holism is only *apparently* a problem. Viewed as a problematic, or something to be clarified and properly understood, alternatives appear: there are non-analytic, non-logical, and non-pessimistic ‘solutions’ to the apparent testing problem. Neurath, for example, suggested that in order to engage with the apparent problem of underdetermination and to capture the actual practice of scientists, one needs to appeal to pragmatic considerations. Furthermore, recent work describing the use of modeling in describing, capturing, and explaining phenomena has shown that scientists are not bothered by this apparent problem (Bailer-Jones 2000). Pragmatic decisions must be made in testing situations concerning the use of data and the background conditions in the experimental or testing apparatus (Cat 1995). Other authors such as Duhem, Poincaré and Quine also offer solutions.

In this paper we explore modeling as involving analytic and synthetic strategies. We explore under this rubric a recent proposal by Barberousse and Ludwig for how models used in their analytic role work - from their perspective - as a solution to the ‘Duhemian problem’. We show that this solution fails, but in failure it suggests a new

[3] This is different in important ways from the Duhem-Quine Thesis, which contends in addition that any proposition could be held 'come what may' (Quine 1951). That is, it is always possible to revise parts of a theory to preserve a proposition in light of apparently conflicting observations. The Duhemian problematic is merely concerned with the ambiguity of falsification or confirmation inherent in a complex of testing hypotheses (For details see Ariew (1984)).

approach to the problematic based on the distinction between the two kinds of strategies to modeling. Thus, it would be a mistake to think of the Duhemian problematic as a methodological tragedy. We would make the same mistake if we thought in the same way of the failure of the analytic use of models to eliminate holism.

Instead, we want to conclude by pointing to the synthetic dimension of modeling. The Duhemian problem is not a problem, but is merely problematic. It is an expression of the synthetic dimension of modeling and hypothesis formation in scientific experimentation. Development in applied and unapplied science has relied increasingly on fruitful projects of local syntheses, synthesis OF models and synthesis BETWEEN models. The issue speaks to the last two decades of debates about pluralism and unification, and attempts to synthesize ideas from both (Cat 2007). For scientific testing, the synthetic dimension of modeling is fundamental. From this point of view, neither scientific practice nor representations of science should be held hostage to what is a particular logical image of scientific methodology. The challenge posed by the Duhemian problematic is to understand the different interpretations and uses of experiments in connection with modeling practices. It may be a logical tragedy, but it is not a scientific problem. It shouldn't be a problem for philosophy either.

1. From theories to models

When modeling is discussed in connection with scientific theories, their understanding and application, the driving questions are: what is the relation between models and theories? What are models? How and why are they used? How and why do they work?

During the last four decades, the discussion of the relevant units of scientific knowledge has been dominated by one particular answer to the first question, namely, the semantic view of theories. This view replaced the syntactic view, which had dominated the literature of the first half of the 20th century. The syntactic view placed an emphasis on formal and linguistic structures. A theory was considered typically a set of sentences and symbolic or mathematical equations. Their interpretation and truth was assumed to be either an internal –implicit-, a conventional, or an empirical matter. The view was heir to the logicism and linguistic turn dating from early in the century. By contrast, the semantic view asserts *inter alia* that theories are or are best thought of as collections of models (Suppes 1967, Suppe 1974, Van Fraassen 1980, Suppe 1989, Thomson-Jones 2006). Specific theoretical hypotheses, including laws, have been

assumed to be elements in either the construction of the models or their application (Giere 1999). The different versions of the semantic view, according to its proponents, is preferable to the syntactic view, since semantic views are more successful in engaging actual scientific practice and philosophical concerns about methodology.

But what are models? This question is tied to the other driving questions listed above. In the semantic view, models have been presented as having a dual property and purpose of providing truth, or interpretation, and representation. Models in science are thus closely related to the models of model theory in mathematical logic. The logical perspective associated with Tarski and others characterizes models in terms of truth and interpretation. In particular, from an extensional, set-theoretic perspective, models are semantic entities, that is, truth-makers for axioms or sentences in theories. As representations, models are formal, especially mathematical structures. For instance, the physics concept of phase-space regions was adopted by Van Fraassen and others (Van Fraassen 1980, Suppe 1989) and intended to represent phenomena and systems in a target domain of inquiry –as theoretical models-, or to represent data –as models of data (Suppes 1962). Recent arguments have defended the emphasis on representation rather than semantics, considering the label 'semantic view' a misnomer (Thomson-Jones 2006). However, other accounts of models such as Cartwright's defend the relation between models and theories as one of mediation between theory and phenomena or systems, much like a version of the dual-purpose view (Cartwright 1999a and 1999b, Cat 2001). On this view, models are concrete representations that, in turn, make more abstract representations –laws, principles- in a theory true of, or at least applicable to, some representation of intended phenomena or systems. Going back to Maxwell, the view asserts that specific models of force, potential energy or Hamiltonian allow the application of general force laws, and energy principles or equations, to specific phenomena such as planets, gases or electromagnetic fields.[4]

[4] The emphasis on specific representations has been used to circumvent the dilemma introduced by Cartwright that universal laws of nature are either universally false or applicable only restrictedly (Cartwright 1983 and 1989). The restrictions, under a causal interpretation, are to be specified formally by *ceteris paribus*, or *ceteris absentibus*, conditions, and are realized materially in experimental settings (Cartwright 1989).

In general, as representations, the restricted application of laws or theories to, say, ideal gases, can be understood in terms of two relations to their intended target in empirical reality: idealization and abstraction (see Jones 2005 for a recent discussion; also Cat 2005). Idealization, also known as Galilean idealization, involves some misrepresentation of a feature considered relevant and attributed to the target system. An approximation is a formal, mathematical, sort of idealization. Abstraction, also known as Aristotelian idealization, involves omission of irrelevant features without misrepresentation of relevant ones. It is clear from broadly cognitive and actual scientific practices, that idealization and abstraction are context-dependent, namely, their relevance conditions and other resources and constraints show them to be, broadly speaking, value-laden, perspectival, heuristic, or pragmatic.[5]

In this paper we are concerned with the role of holism and synthesis in the application of models. Models as mediators are constructed idealizations for the application of theories. Since models are constructions, their application involves employing a complex of theoretical and background components, which can only be tested holistically.

2. Barberousse &Ludwig's account

Barberousse and Ludwig (2009) argue that models at their most basic level of description are representations that have "useful content." Since models have the ability to stand in for something else and have intentional content, models are useful for the generation of new scientific knowledge. More specifically, they say that models represent fictional situations. These are situations that cannot be instantiated in the world. They are literally false, but possess the "power to convey new usable scientific knowledge." (Barberousse and Ludwig 2009, 57) Fictions direct their interpreter to imagine a particular context which conveys new intentional content. In allowing scientists to imagine the world within another context, models succeed in aiding in the generation of new usable scientific knowledge.

What makes Barberousse and Ludwig's account interesting is that they claim that models as fictions are particularly useful in generating new scientific knowledge because

[5] It is not surprising that we can speak of models more generally to include properties and purposes that involve theoretical autonomy –from specific theories- (Morgan and Morrison 1999) and material autonomy –whether in the form of model systems such as Kuhn's exemplars or material toy models or scale models (Sang 1841, Tomlinson 1862, vol 2; see also articles in Hopwood and De Chadarevian 2004).

of their ability to break the “Duhem-Quine cement” (Ibid., 66). Models as fictions provide situations in which hypotheses do not need to be interdependent. Barberousse and Ludwig claim that the Ehrenfest Model of thermalization in gases illustrates this function of models (Ibid., 66) since the Ehrenfest Model enables scientists through idealization to consider the probabilistic component of the statistical mechanical representation apart from the causal-dynamical component. Thus, because models are able to separate particular theoretical hypotheses, they have an analytic role relative to the complex of theoretical hypotheses.

Barberousse and Ludwig further claim that models as applications of theories have the ability to ‘*bracket*’ individual theoretical hypotheses for testing. This analytic function, our term, of models akin to Aristotelian idealization allows them to include particular hypotheses while excluding others based on their relevancy to the available data. Bracketing also involves a semantic subsethood relation between the model and the theory that is indeterminate or imprecise. The authors address the relation, and hence the difference between models and background theories which provide conceptual resources as one of potential contradiction. But they explain the relation as follows: The generalizations in the theory and the meanings of terms they fix become constrained and distorted in the context fixed by the constitution and application of the model. In classical models of gases, the meaning of the term molecule and the generalizations the concept obeys distort and even contradict the generalizations from quantum mechanics that the model brackets (Ibid, 63).[6] Thus, by focusing the ‘imaginative game’ of modeling on a small set of constituent principles and components of a theory, scientists are able to investigate hypotheses one by one.

In this way, scientific models appear to be anti-Duhemian. The bracketing function of models seems to allow for the isolation of a particular hypothesis thereby breaking through the holistic interdependence of hypotheses. Moreover, in the Ehrenfest model, the probabilistic component can be evaluated independently of other theoretical hypotheses through an idealization; “In fictional situations, hypotheses need

[6] The authors use this situation to accommodate the use of metaphorical terms and meanings in scientific language and modeling, as pointed out by Max Black: “Using theoretical models consists in introducing a new language or dialect” (1962, p. 229). See also James Clerk Maxwell’s account of this aspect of modeling (Cat 2001). Not surprisingly, Max Black led Lotfi Zadeh to introduce fuzzy sets as the proper semantics for natural languages and reasoning with vague terms (see Zadeh 1965 and 1975; also Cat 2006).

not be interdependent." (Ibid., 66) However, it is our contention that they over-generalize in making this claim since the case they lay out is about a particular subclass, testing models.

Barberousse and Ludwig make two claims that can be formulated as follows: (D1) models can be parts (subsets, Ibid., 71) of theoretical representations. They bear a formal relation, in that sense, to independent hypotheses of a theoretical complex that realizes the bracketing function of *analytic representations* (our term). And (D2) models for the application of theories are testing models, which test independent theoretical hypotheses. These *analytic models* (our term) serve an anti-holistic function and are, thus, anti-Duhemian.

Barberousse and Ludwig admit that a problem remains for D2: (D2 Qualification) testing models may still present Duhem-type, "technical" difficulties. These difficulties result from residual analytic models with more than one, interdependent, theoretical hypothesis. They suggest that this difficulty might be resolved with simulations. A simulation is a model of an experimental test based on a model of the theory (in their example, properties of a new plane) and a model of the data (analytic model of the data, in their case of the pilot's perception of the environment, which are imagined to be facts). Simulations apply the models of theory and data together in a fictional experimental situation. Since the useful theory and data have been bracketed in the application of their models within the simulation, a hypothesis (in their example: any hypothesis about the behavior of the pilot) may be tested in isolation in the same manner as analytic models. Thus, simulations may provide a means of breaking through the 'Duhemian cement' when analytic models alone cannot.

Models represent fictional situations that enable the generation of new scientific knowledge. However, we believe that the analytic power of models is overstated by Barberousse and Ludwig. While they make the case for the analytic power of models in relation to theoretical complexes of hypotheses, models do not in fact break through the holism present in testing situations. Duhemian holism in testing situations involves auxiliary hypotheses concerning the conditions and apparatus of experimentation. The construction or synthesis of these models is inherently complex, and simulations only further add to this complexity. We will discuss this in further detail in the following section.

3. Discussion

So far we have made clear that models are constructions. They are the products of many acts of synthesis: theories are conjoined with background conditions, auxiliary hypotheses, and assumptions in their construction. Models applied in testing situations are thus complex. We have also made clear that models have an analytic role, i.e. there are *analytic models*. These models reduce theoretical complexity in testing situations. However, this reduction is of relative merit. In the following discussion section, we will discuss the analytic, or Anti-Duhemian power, of models as proposed by Barbarousse and Ludwig and outlined in the previous section. We will show that models in this analytic role fail to solve the Duhemian problem, and are thus not anti-Duhemian. The upshot is the need for a greater appreciation for the relative a priori facts of model construction.

Barberousse and Ludwig's operative notion of Duhemian in their notion of anti-Duhemian is not the notion that establishes what we have called the Duhemian problematic (Barberousse and Ludwig 2009). We call it their notion Duhemian*. Duhemian holism is distinctively a property of a testing application where the empirical implications require the theoretical hypotheses to be glued to auxiliaries, in particular regarding the testing conditions. This problem clearly arises also in the case of a single hypothesis. Duhemian*, by contrast, captures the fact that a number of theoretical hypotheses 'are glued together' in applications of a theory (Ibid., 66). As a historical point, both notions can be found in Duhem's *Aim and Structure of Physical Theory* (Duhem 1906).

If we assume the notion of Duhemian, as distinguished earlier and corresponding to the Duhemian problematic, to be in place in Barberousse's and Ludwig's account, then D1 is manifestly inadequate. All modeling is constructing, and testing models are constructions, therefore forms of synthesis. The outcome of synthesis by construction is complex representation. The complexity of the testing model is introduced with the auxiliary hypotheses –alongside any issue of tacit knowledge, expertise, etc- about experimental testing setups and conditions. But this is the interdependence or complexity that characterizes the Duhemian problematic and holism. Thus, models cannot represent parts of theoretical complexes, or a single hypothesis, alone, and appealing to analytic theoretical *models* cannot be the ultimate solution, i.e. sufficient in all cases.

If one assumes with Barberousse and Ludwig the Duhemian* notion, as it seems implicit in D2 Qualification, then D2 Qualification is inadequate as well. The notion of Duhemian* captures the theoretical complexity of the residual testing models. Their example of the flight simulation for the purpose of testing a complex of hypotheses about a new plane during flight does not address the problem it is meant to solve: how the simulation has analytic power in the testing of any of the individual hypotheses in the complex. It is worth noting that this is now a situation in which the analytic strategy of isolating hypotheses takes the form of a relation between models. This topic has been addressed to some extent in Bailer-Jones (2000). Bailer-Jones points to features of modeling like “splitting up” and “embedding” as strategies for capturing different aspects of a phenomenon for explanation. Scientists might ‘split up’ models into sub-models in order simplify or focus on particular aspects of a phenomenon. ‘Embedding’ then, is the process of placing these sub-models back into an ‘overall-model’ (Ibid, 51). While these strategies are for capturing and explaining phenomena, it is easy to see how such strategies might be employed in testing situations. The role of one model is to be analytic relative to the other, in order to further analyze the original complex of hypotheses into isolated units for testing purposes. However, as in the relation between the theory and analytic model, the strategy is bound to remain logically inconclusive. The testing model underdetermines the others. Insofar as relations between models are concerned, alternatives such as robustness might prove more satisfactory from a methodological standpoint, provided the priority is given to internal constraints and criteria (see below).

More importantly, under either Duhemian interpretation, if that is the basis for the logical form of the difficulty, simulations can provide no help in their account, since they are not analytic models of the testing model. Rather, as complex modeling constructions themselves, in actual science, simulations are far from simple kinds of models or fictions. Simulations are constructed from components, which may be models themselves, of phenomena that are well understood, i.e. there are established laws that govern their behavior. Simulations help scientists understand the interactions between these components where no analytic solution is available (Winsberg 2001). In simulations, theories “guide rather than determine the construction of models” (Ibid. S442). By construction, they add complexity of representation of the data, and therefore can solve neither the Duhemian* nor address the Duhemian problematic. This point has been made clear in a recent paper by Lenhard and Winsberg (2010), where they demonstrate

that climate models are “analytically impenetrable” since “successes and failures” cannot be “attributed… to particular modeling assumptions.”[7]

The anti-Duhemian character of analytic modeling is successful only relative to the original degree of complexity of the theoretical hypotheses or the theory. It is a relative merit, not absolute. Different sorts of strategies, external (example, Duhem, Neurath and Poincaré’s forms of conventionalism and pragmatism) and internal (Bayesianism, Glymour’s bootstrapping, Wimsatt’s robustness, Darrigol’s modularity)[8] remain the possible ways to address with the Duhemian logical problem in evaluating theories, hypotheses and models.Even if a hypothesis is presented in a single, simple formulation, it can typically be decomposed to generate a Duhemian* scenario. There are elements in the model and the simulation that carry with them implicitly or explicitly analyzed hypotheses that are relatively non-empirical conventions and assumptions –for instance, meaning-constitutive. They contribute to the interpretation of hypotheses prior to their empirical testing and are thus relatively a priori (they are fixed by more general principles or by convention but they are not themselves purely conceptual, i.e. absolutely a priori, constraints). They could be functionally a priori: they could be empirical assumptions that need to be taken for granted in the construction, interpretation, and testing of the hypothesis. In that context therefore, there will always be a part of any analytical model that cannot be analyzed away further for testing purposes. Since the original accounts of models were relegated to semantic, truth-theoretical extensional interpretation of theories and subsequently of data with Suppes and Suppe, this notion of relative(ly) a priori has never been incorporated in model talk (Schlick and Reichenbach introduced the role of conventions as part of axiom systems, (Friedman, 1999; Cat 2006)). The nature of these resources should be understood broadly, logically and naturalistically, cognitively and materially, individually and socially, and multi-disciplinarily.[9] These relatively a priori kinds of elements in the construction of models include elements that fit Putnam’s notion of law-cluster concepts or else what one of us has called anomic elements (Cat 2005 and 2006): notions of causality, organism or particle, or, like the spandrels of San Marco, idealizing assumptions such as a thermodynamic limit, and more venal kinds of elements.

[7] They argue that this fact is due to their “entrenchment” (Lenhard & Winsberg, 2010).
[8] Glymour 1980, Wimsatt 1981 and Darrigol 2007.
[9] Giere’s assigned role for laws in the construction of models as predicates, analogous to an extensional version in Suppes’ early account, is one potential example (Giere 1999, but note the limitations, see Cat 2005).

We are facing here a Duhemian* scenario. Take for example recent research in the evolution of selective attention (for instance, Kruschke and Hullinger 2010). There is an internal complexity to an initial theory such that it can be decomposed into a complex of theoretical hypothesis that constitute a Duhemian* scenario. It is hypothesized that evolution converges on an architecture that incorporates attentional learning (Kruschke and Hullinger 2010). This theory contains the theoretical hypotheses that people and some animals use attentional learning and selective attention is part of learning, evolution is the process by which this ability emerged, architecture is the appropriate theoretical structure in the cognitive system for describing this phenomenon, the mechanism of learning quickly is of evolutionary value.

Kruschke and Hullinger's hypothesis can only be investigated by simulation because evolution does not lend itself to empirical experimental testing. Thus, Kruschke and Hullinger simulate a population of individuals that exhibit varying speeds of learning over a number of generations. The outcome of the simulation will indicate whether or not there is convergence on quick selective attention. Their simulation relies on the formal structure i.e. the calculus of matrices and algorithms of evolutionary models developed by Todd and Miller (1991) as well as assumptions concerning the structure of genetic makeup across a population, choice of mutation rates, reproduction algorithms, fitness-selection programs, and of learning optimization models. In addition, highlighting, the shift of attention to a particular cue that is the perfect predictor of the relevant outcome, is used as the operational criterion for attentional learning. While their simulation seems to test a single evolutionary hypothesis, the simulation actually exacerbates the Duhemian problem at the expense of any alleged analytic power or purpose of the modeling.

On recent and more sophisticated accounts and examples, simulations provide complex inferences from non-tractable existing theoretical knowledge through tractability-enhancing methods, namely, hierarchies of different kinds of modeling with complex computational techniques and assumptions (such as parametrization, boundary conditions, ad hoc assumptions, discretized coding and other approximations, reductions of parameters and degrees of freedom, imaging techniques, data analysis and interpretation, etc) to a phenomenological model as a form of approximate new knowledge about the system simulated (Winsberg 1999, 2009a and 2009b). Simulations in actual scientific practice yield simple phenomenological data modeling built on theoretical complexity, in Duhemian* sense, and an increased complexity of auxiliary

ingredients and operations. All of this modeling appears to be without analytic power or purpose.

One suggestion (Raaijmakers and Shiffrin 2002) is that simulations could be used to test background knowledge i.e. the apparatus and assumptions used to construct the simulation. Like experiments, simulations have many purposes: explanation, prediction, representation, policy decision, and extending the scope of models beyond their domain of validity (Grune-Yanoff 2010). However, if the simulation is testing background knowledge, then it cannot also serve the purpose of testing the empirical hypothesis. Moreover, this evaluation of the background hypothesis does not get around the Duhemian scenario.

4.0 Conclusion: Avoiding the problem and Addressing the Problematic

All sorts of non-analytic strategies and considerations, theoretical and heuristic, will and should play a role in establishing and assessing theoretical models. Some ways to address the Duhemian problematic present themselves as conceptual, epistemological 'solutions' to the logical problem of confirmational holism such as robustness-based strategies (Wimsatt 1981 and 2007, Weisberg 2006).[10] Others have long fallen under the pragmatic rubric. The construction and assessment of models is embedded, not just entrenched, in diverse kinds of practices, materials, skills, expertise, values, institutions, and other sorts of resources and constraints (see for instance, Longino 1989 and 2002, Collins and Evans 2006 and Biagioli 1993 and 2006). An underlying issue here is the relation between the value of a model, or purpose of modeling, and the ways of acceptance or adoption of the product. We have reached the view over a broader and multidimensional landscape of concrete a priori conditions for modeling. Modeling may equally serve many purposes.

Part and parcel of the Duhemian holistic predicament is the attempt to reconcile two assumptions: (1) a logical internal strategy involving the relation between hypotheses and experimental data, and maybe also inferred worldly 'phenomena' (Woodward and Bogen 1989); and (2) the representational external value involving a putative relation between the hypotheses or models and the worldly phenomena and their real entities. Non-analytic internalist strategist such as robustness want to aim at (2)

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[10] Robustness analysis aims at identifying the scientifically relevant representational -descriptive or predictive- parts of models and at separating them from 'accidental' artifacts of the modes of representation. It is heir to the tradition of invariant theory and its structural identification of objective elements in theories and their counterpart in reality, and its the method examines different models for a related 'robust' structure that corresponds to a robust property, behavior or causal structure.

without having the internal methodological constraints be fixed by the inferences linking hypotheses and data. An alternative to the internalist inferential approach is the acceptance of pragmatic, conventional and other external standards and resources to fix the choice an adoption of a model or hypotheses while still somehow retaining an aim at (2). This strategy appears, among other contexts, in the certain kinds of inferences to the best explanation in actual practice and historical contexts that fixed what counted as best. Then, if a community of practitioners has adopted an aim of inquiry different from (2), the non-inferential logical strategies will easily, although only within that community, reconcile (1) and the alternative to (2). The first without the second will yield models of data, not realistic models of worldly phenomena, bearing different values and subject to different uses. Reconstructing how these become the *ways* of acceptance or adoption of models and hypotheses may be a solution to or strictly a way around the Duhem problematic is the important task.

In fact, simulations, models and the role of scientific fictions in them have been explained and extolled in terms of their synthetic rather than analytic power: that is, their value in weaving together different, often incompatible models or model-building frameworks, as in certain treatments of nanosystems (Winsberg 2006). This is the key to explaining and expanding the application of theories as well as new hybrid models between theories, models without theories, and especially between broader disciplinary approaches (Cat 2007). Research projects and even whole disciplines in isolation exhaust their internal cognitive resources. Models as pluralist modes of interaction and cooperation through their construction and application open new doors for scientific understanding and progress. To characterize the synthesis of models in order to gain better understanding, predictive power and other heuristic purposes remains a key and worthy challenge in philosophy and the sciences.

Development in applied and unapplied science has relied increasingly on fruitful projects of local syntheses (Galison 1997 and 2000, Cat 1998 and 2007; Cartwright 1999b). New trends in engineering, nano and macro, involve the coordination of different kinds of expertise and interest in hybrid technologies. Paramount among then are models that take the particularly synthetic form of models of mechanisms (Glennan 1996, Cat 2005, Craver 2009). Whether in the engineering of treatments or the explanation of diseases and their co-morbidity, models from anthropology, geography, meteorology, anatomy and microbiology need to be contributed. Thermodynamics, quantum mechanics and gravitational cosmology join resources to model the behavior of

black holes. A similar situation arises in matters of social policy. Again, the challenge consists in how to represent the different actual and possible situations, from different domains of phenomena and from the same, from different conceptual domains and from the same, not to mention material, institutional, practical and other aspects we think to be aspects of science.

Surely, synthesis of models and synthesis between models requires attention to the inconsistencies assumed (Cat 2005). Elsewhere, one of us, has focused on how local integration, as the constructive dimension of pluralism, requires attention to conflicts standing in the way of potential cooperation or in the way of its development, and compromises (sacrifices, not consensus) need be made and reflected upon as a link from conflict to cooperation, in the tradition of political and moral philosophy (Cat 2010).

For scientific testing, the synthetic dimension of modeling is fundamental. Experiments and observations, microscopic and telescopic, electronic and ecological, require the assembly of different models and hypotheses, conceptually and materially, epistemically and culturally (Galison 1997, on high-energy physics; Cat and Boyle (forthcoming), on radiocarbon dating). The Duhemian problematic is an expression of this fact, that experimentation really is one of many virtuous instances of the synthetic dimension of modeling and hypothesis formation in science. This dimension is a precondition of experimental testing. Even approaches such as robustness-based ones may be said to illustrate synthetic strategies. From this point of view, neither scientific practice nor representations of science should be held hostage to what is a particular logical image of scientific methodology. The challenge posed by the Duhemian problematic is to understand the different interpretations and uses of experiments in connection with modeling practices.

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