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RESPONSE TO VIOLA SCHIAFFONATI

Her comments on my work cover a rich variety of topics. I won't try to comment on everything she has to say, but she has focused on a number of issues that I have also thought about and think are important. Broadly speaking we do agree, I believe, about the role of models in the philosophy of science and also in various parts of science as well. I have several comments, so I will highlight each topic as I move from one to another.

Models of data. Schiaffonati mentions early in her discussion of models, the special topic of models of data a subject dear to my heart as reflected in my early publication on this topic (Suppes [1962]). I did not say as much about models of data as much as I would have liked in my recent book [2002], *Representation and Invariance of Scientific Structures*, even though this was part of my original plan. But what I have to say about models of data would have added too much. I say this to emphasize that my conviction about the importance of the explicit consideration of models of data has not waned. As I have remarked on several occasions in the past, those parts of mathematical statistics concerned with the consideration of data provide a rich assortment of models, for the language of modern mathematical statistics is entirely set theoretical in nature but statisticians do not really emphasize this, and philosophers of

science have neglected it more than they should. Of the most significance are the large steps of abstraction in going from the intricate details of experiments, or even of observational collection of data, to the restricted and formal representation of data used for testing scientific hypotheses in statistical form or estimating important physical parameters. It is a fact, not sufficiently emphasized in many quarters, that experimental methods in physics did not change in basic conception in the move, for example, from classical physics to the modifications required by special relativity. The methods of observation and measurement are essentially untouched. In fact, to be quite explicit about the matter, I do not know of a single axiom of measurement as such that was changed by the introduction of special relativity, or even for that matter, general relativity. This does not mean that new instruments of measurements were not introduced throughout the twentieth century, but rather that the fundamental theories of measurement of physical quantities and the detailed experimental methods of measuring those quantities were not changed.

In Chapter 10 of Krantz, Luce, Suppes, and Tversky [1971] a table that runs over six pages lists a great variety of physical quantities that are measured in experimental physics. The dimensional analysis and units of each of these quantities are given. In terms of their experimental measurements relative to a given frame of reference, I believe that not a single one has been changed by the theoretical introduction of relativistic ideas or quantum mechanics. There will, of course, be some change in invariance properties, for example, for the velocity of light, but the specific procedures of measurement relative to a fixed frame of reference have not. I linger on this point only to stress how the detailed consideration of experiments and the enormous carry over of methods of experimentation from one theoretical framework to another in physics is a way of challenging too radical a set of ideas concerning theory change. Again, this is not a topic I really discussed in my book [2002] but something that is a natural extension of the ideas developed there.

Isomorphism and similarity. Schiaffonati mentions the recent literature that suggests the notion of isomorphism that is used extensively in my book [2002] for relations between models of a theory be replaced by the weaker notion of similarity. This is a familiar move in Euclidean geometry. Two triangles of different size that are not congruent can still be similar because their angles are congruent. More generally in psychology a notion of similarity is widely used that violates in a strict sense transitivity, so familiar in standard notions of isomorphism or of congruence in geometry. Even with this violation, the intuitive idea of similarity as being a generalization of isomorphism still works well. I find no difficulties with this approach, in fact it is quite clear that it has been important to be more realistic about the finite precision of human or instrumental judgement to leave room for such non-transitivity. I scarcely discuss such a concept of similarity in the book [2002], but in the treatise on the foundations of measurement I co-authored, in volume 2 (Suppes, Krantz, Luce, and Tversky [1989], chapters 16 and 17) such ideas are explored in some detail and a very large number of references to the earlier and extensive literature are given.

Computational models. In many ways the most important concept that Schiaffonati introduces is that of a computational model. Again I find myself in agreement with what she has to say about such models and from my own standpoint I look at computational models as being not in opposition to set-theoretical ones, but a distinguished subset important in many parts of mathematics and science. Like her, I don't think it is important to try to give an explicit formal definition of computational models but the intuitive idea is clear. We have in mind for such models that the resources are available in principle from a formal standpoint to compute functional values of a variety of sort. The standard computations that are made in statistics on data meant to test stochastic-process ideas constitute in many standard forms good examples of computational models. From a formal standpoint we could insist that in a computational model everything be computable in the standard mathematical sense but I don't think this is going to take us very far, because what one

has in mind is not theoretical computations that might in fact not be possible to make, but actual models that are in a practical sense computational, is demanded in models that are simulations of some empirical phenomenon. I also like her emphasize that computational models are not just a kind of mirroring of phenomena but also a kind of rendering. This corresponds to classical ideas in geometry and perception of perspective from many viewpoints, which is often a feature of discussions of rendering.

It is also important to recognize that there are important problems that cannot be well simulated. A good example is given in chapter 7 of my book [2002], the example of a restricted form of the three-body problem in classical mechanics, which reduces to the motion of a single particle for study. This single particle, moving through the center of mass, and perpendicular to the plane of motion of the two other bodies, whose trajectories are closed ellipses, can have for selected values of the parameters, determinateness or uniqueness, in the mathematical sense of being a unique solution of the reduced ordinary differential equation, but can at the same time not be simulated well by any standard computational procedure, because of the rapid approach to randomness in the motion of this particle.

Multiagent systems. As a final concept introduced by Schiaffonati I consider her discussion of multiagent systems. This is an important topic in both contemporary computer science and also in several parts of the social sciences. In fact, markets with large numbers of agents operating in them are often studied as if there were a non-denumerable continuum of such agents, an abstraction that has no empirical justification whatsoever, but that is useful for computational purposes. For this kind of situation I find no natural extension needed of the concepts concerning models and theories introduced in my book [2002]. The consideration of multiagent activities is a natural one, and is natural already in physics in considering systems of many particles. When we want to have more complicated agents, I agree with her emphasis on agents interacting and coming to cooperative agreement about, for example, what actions are to be

taken. But again I find no problems with this and in fact many years ago I coauthored a book full of interactive models in primitive game settings but studied from a standpoint of stochastic models of learning (Suppes and Atkinson [1960]).

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