Erik Weber and Helena De Preester

MICRO-EXPLANATIONS OF LAWS

ABSTRACT. After a brief introduction to Kuipers' views on explanations of laws we argue that micro-explanations of laws can have two formats: they work either by aggregation and transformation (as Kuipers suggests) or by means of function ascriptions (Kuipers neglects this possibility). We compare both types from an epistemic point of view (which information is needed to construct the explanation?) and from a means-end perspective (do both types serve the same purposes? are they equally good?).

1. Introduction

1.1. *Kuipers on Micro-Explanations*

Theo Kuipers (SiS/2001, pp. 82-104) claims that explanations of laws have different forms, but contain only steps of five types: application steps, aggregation steps, identification steps, correlation steps, and approximation steps. As a rule, these steps occur in this order, but exceptions are possible. Not all explanations contain steps of all types, and some types may occur more than once.

Kuipers defines reductions as a subclass of explanations of laws: reductions contain at least one aggregation, identification or approximation step. So explanations of laws that contain only an application and a correlation step (Kuipers gives explanations of interbreeding laws in classical Mendelian genetics as examples) are not reductions.

Kuipers defines micro-reductions as explanations that contain at least one aggregation step. Let us look at one of Kuipers' examples, the ideal gas law (IGL). The IGL tells us that for one mole of gas in a container, the product of volume V and (macroscopic) pressure P is proportional to the empirical absolute temperature T, such that the proportionality constant is the same for all gases (viz. R):

$$PV = RT$$

According to the kinetic theory of gases an isolated quantity of gas consists of molecules which move and collide with each other and with the container wall

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in accordance with Newton's laws of motion. In the application step these laws are applied to one molecule colliding with the container wall. In this step we use the auxiliary hypothesis that the collision is elastic. The result is the "individual law" which states that the momentum exchange q equals $2mv_w$ (where m is the mass and v_w the velocity in the wall direction). The second step, the aggregation step, leads, by means of some auxiliary statistical hypotheses, to the "aggregated law" that the product of the kinetic pressure on the container wall p and the volume V is equal to $(2/3)N\bar{u}$ (where N is Avogadro's standard number of molecules in a mole of gas, and $\bar{u}$ the mean kinetic energy of the molecules). In the third and last step, two identity hypotheses ($p = P$ and $\bar{u} = (3/2)(R/N)T$) are used to derive the IGL.

It is important to notice that explaining the macroscopic law requires both the aggregation and the identification step: the aggregation step alone allows us only to explain the intermediate law about the collective behavior of the molecules ($pV = (2/3)N\bar{u}$). In Kuipers' view, a micro-reduction of a macroscopic law (as opposed to a law about the collective behavior of the micro-level objects) requires an aggregation step and a *transformation* step (a general term introduced to denote both identification and correlation steps). In the explanation of the IGL, the transformation step is an identification step. In Kuipers' other example of micro-reduction (the explanation of Olson's law about collective goods) the transformation step is a correlation step.

1.2. *Aims and Structure of this Article*

The first aim of this article is to show that, contrary to what Kuipers claims, not all micro-explanations of laws contain an aggregation and transformation step. In Section 2 we give an elaborate example of what we call an AT explanation (micro-explanation of a law by means of aggregation and transformation). In Section 3 we show that laws can be micro-explained in a completely different way, viz. by means of function ascriptions. Explanations that use function ascriptions will be called FN explanations (the meaning of the N will become clear in that section).

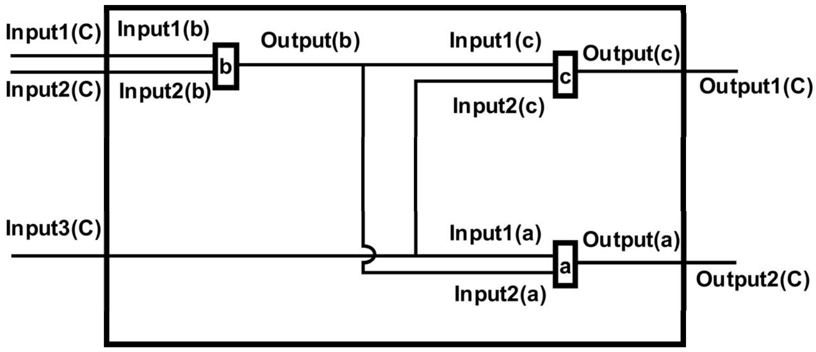
Our second aim is to show that, from an epistemic point of view, FN explanations are superior: they require less information and are therefore easier to construct than AT explanations. The argument for this epistemic advantage will be given in Section 4.

The last aim of this contribution is to investigate the uses of AT and FN explanations. Micro-explanations are sometimes sought for practical reasons (prediction, manipulation) and sometimes for theoretical reasons (the desire to understand how the law fits into our worldview and how it relates to other laws). In Section 5 we argue that, if the motivation is practical, FN explanations are complementary to AT explanations. If the motivation is theoretical, FN explanations are useless.

2. AT Explanations of Laws

2.1. *Example*

Consider the following electrical circuit, which we call *C*:



Assume that everything inside the large rectangle is contained in an opaque box, so that only the three input wires and two output wires are visible. Assume also that we can somehow measure whether these wires are charged or not. Then an experiment can be performed to see whether there is a law connecting the states of the input wires with the states of the output wires. Suppose that such an experiment yields the following law:

L: If $input_1(C)=1$, $input_2(C)=0$ and $input_3(C)=1$, then $output_1(C)=0$ and $output_2(C)=1$.

'$Input_1(C)=1$' is shorthand for 'The first input wire of *C* is charged', '$input_2(C)=0$' for 'The second input wire of *C* is not charged', etc.

One way to explain this law is to derive it from an explanatory model by means of an aggregation and a transformation step. Performing those steps presupposes that the explanatory model from which we start consists of ontological claims, fundamental laws, interaction principles and bridge principles. In 2.2 we take a closer look at the content of the explanatory model, while in 2.3 we discuss the structure of the derivation. In section 3 we will present an FN explanation of the same law *L*.

2.2. *The Content of the Explanatory Model*

The *ontological claims* specify which micro-elements are contained in the macro-system (in this case: the circuit). In order to explain L in our example, we have to open the box. If the box is open, we can observe that the following ontological claim holds:

O_1: Circuit C contains three binary gates (a, b and c).

Each of the gates can be taken out of the circuit, so we can investigate their individual behavior. Assume that such test gives the following results:

F_1: a is an AND gate.
F_2: b is an XOR gate.
F_3: c is an XOR gate.

An AND gate has output 1 if and only if both inputs are 1. And XOR gate (exclusive OR) has output 1 if and only if the values of the inputs are different. We call F_1-F_3 *fundamental laws* because they describe the individual capacities of the elements of which the macro-system is composed: they are laws at a lower, more fundamental level than the law we want to explain.

Interaction principles provide information on the *relations* between the components of the system (unlike the fundamental laws, which give information about isolated components). In our example the interaction principles are:

I_1: The circuit is wired such that output(b) = $\text{input}_2(a)$.
I_2: The circuit is wired such that output(b) = $\text{input}_1(c)$.

Finally, there are the *bridge principles*. When the box is opened, we can observe the relations between properties of the circuit as a whole (the states of its input and output wires) and properties of components of the system (the states of the input and output wires of the three gates). More specifically, we can observe that:

B_1: $\text{Input}_1(C) = \text{input}_1(b)$.
B_2: $\text{Input}_2(C) = \text{input}_2(b)$.
B_3: $\text{Input}_3(C) = \text{input}_1(a) = \text{input}_2(c)$.
B_4: $\text{Output}_1(C) = \text{output}(c)$.
B_5: $\text{Output}_2(C) = \text{output}(a)$.

We call B_1-B_5 bridge principles because they connect properties of the system as a whole with properties of its components.

2.3. *The Structure of the Derivation*

An AT explanation for *L* is obtained by deriving it from the explanatory model in two steps: first we derive an intermediate result *R* from the fundamental laws and the interaction principles (the aggregation step); then we use the bridge principles to derive *L* from *R* (the transformation step). Note that the ontological claims are not explicitly used in the derivation: they are conditions that must be fulfilled to make the claims of the other types meaningful. For instance, it does not make sense to claim that *a* is an AND gate if *a* does not exist.

In our example, the intermediate result obtained in the aggregation step is:

R: If $\text{input}_1(b)=1$, $\text{input}_2(b)=0$, $\text{input}_1(a)=1$ and $\text{input}_2(c)=1$, then output(*c*)=0 and output(*a*)=1.

This intermediate result differs from *L* in that it is *not* a regularity about *C*, and from the fundamental laws and interaction principles in that it is a *collective* law about *all* the components of the system. In this respect, *R* is analogous to the intermediate law obtained in the explanation of the IGL.

The aggregation step goes like this:

(1)	If $\text{input}_1(b)=1$ and $\text{input}_2(b)=0$, then output(*b*)=1	[F_2]
(2)	Output(*b*) = $\text{input}_2(a)$	[I_1]
(3)	If $\text{input}_1(b)=1$ and $\text{input}_2(b)=0$, then $\text{input}_2(a)=1$	[1,2]
(4)	If $\text{input}_1(a)= 1$ and $\text{input}_2\ (a)=1$, then output(*a*)=1	[F_1]
(5)	If $\text{input}_1(a)=1$, $\text{input}_1(b)=1$ and $\text{input}_2(b)=0$, then output(*a*)=1	[3,4]
(6)	Output(*b*) = $\text{input}_1(c)$	[I_2]
(7)	If $\text{input}_1(b)=1$ and $\text{input}_2(b)=0$, then $\text{input}_1(c)=1$	[1,6]
(8)	If $\text{input}_1(c)=1$ and $\text{input}_2(c)=1$, then output(*c*)=0	[F_3]
(9)	If $\text{input}_2(c)=1$, $\text{input}_1(b)=1$ and $\text{input}_2(b)=0$, then output(*c*)=0	[7,8]
(10)	If $\text{input}_1(b)=1$, $\text{input}_2(b)=0$, $\text{input}_1(a)=1$ and $\text{input}_2(c)=1$, then output(*c*)=0 and output(*a*)=1	[5,9]

Since (10) is identical to *R*, the aggregation step is completed. In the transformation step we transform the antecedent and consequent conditions of *R* by means of bridge principles:

(1)	If $\text{input}_1(b)=1$, $\text{input}_2(b)=0$, $\text{input}_1(a)=1$ and $\text{input}_2(c)=1$, then output(*c*)=0 and output(*a*)=1.	[R]
(2)	$\text{Input}_1(C) = \text{input}_1(b)$.	[B_1]
(3)	If $\text{input}_1(C)=1$, $\text{input}_2(b)=0$, $\text{input}_1(a)=1$ and $\text{input}_2(c)=1$, then output(*c*)=0 and output(*a*)=1.	[1,2]
(4)	$\text{Input}_2(C) = \text{input}_2(b)$.	[B_2]

(5)	If $input_1(C)=1$, $input_2(C)=0$ and $input_1(a)=1$ and $input_2(c)=1$, then $output(c)=0$ and $output(a)=1$.	[3,4]
(6)	$Input_3(C) = input_1(a) = input_2(c)$	[B_3]
(7)	If $input_1(C)=1$, $input_2(C)=0$ and $input_3(C)=1$, then $output(c)=0$ and $output(a)=1$.	[5,6]
(8)	$Output_1(C) = output(c)$	[B_4]
(9)	If $input_1(C)=1$, $input_2(C)=0$ and $input_3(C)=1$, then $output_1(C)=0$ and $output(a)=1$.	[7,8]
(10)	$Output_2(C) = output(a)$.	[B_5]
(11)	If $input_1(C)=1$, $input_2(C)=0$ and $input_3(C)=1$, then $output_1(C)=0$ and $output_2(C)=1$.	[9,10]

Step (11) is the law *L*, so the derivation is complete.

3. FN Explanations of Laws

The derivation given in 2.3 is not the only way to explain *L*. There is an alternative, in which the explanatory model contains the ontological claim that the circuit contains three binary gates (O_1), three function ascriptions, and three claims about well-functioning. The function ascriptions are:

F_a: The function of gate *a* is to ensure that $output_2(C)=1$ if and only if $input_3(C)=1$ and $output(b)=1$.

F_b: The function of gate *b* is to ensure that its output is 1 if and only if $input_1(C) \neq input_2(C)$.

F_c: The function of gate *c* is to ensure that $output_1(C)=1$ if and only if $output(b) \neq input_3(C)$.

L does not follow from these three function ascriptions alone. We need three claims which state that the gates function well:

N_a: Gate *a* functions normally.
N_b: Gate *b* functions normally.
N_c: Gate *c* functions normally.

In general, the explanatory model of an FN explanation contains ontological claims (which, as in AT explanations, serve as background knowledge in the derivation), function ascriptions (hence the F) and claims about normal functioning (hence the N).

It is important to note that FN explanations require an interested explainer, who has an ideal about how the system and its components must work. Without such an ideal, function ascriptions are impossible. The ideal of the explainer may differ from the ideal of the designer of the system (if there is one). AT explanations do not require such an ideal: the explainer can remain neutral.

4. FN Explanations Require Less Information

The functional explanation in section 3 is compatible with the AT explanation in 2.3. As already mentioned, the ontological presuppositions are identical. Furthermore, N_a is logically entailed by F_a together with F_1, I_1, B_3 and B_5. From these four last statements we can derive:

R Output$_2$ (*C*)=1 if and only if input$_3$(*C*)=1 and output(*b*)=1.

F_a says that the function of gate *a* is to ensure that *R* holds. This means that, if F_a is part of the explainer's ideal of how the system must work, he/she must conclude that *a* functions normally if he/she is convinced that F_1, I_1, B_3 and B_5 are true. Analogously, N_b is entailed by F_b together with F_2, B_1 and B_2; and N_c by F_c together with F_3, I_2, B_3 and B_4.

However, each of the gates would also function normally if the structure of the circuit were to differ slightly from its actual structure. So all the functions have multiple material realizations. For instance, N_a would also be true if F_1 and B_5 hold, input$_3$(*C*)=input$_2$(*a*) (instead of B_3) and output(*b*)=input$_1$(*a*) (instead of I_1). Similarly, *b* will still perform the function ascribed to it in F_b if it is an XOR gate with input$_1$(*C*) = input$_2$(*b*) and input$_2$(*C*) = input$_1$(*b*). For *c* the alternative material realisation is input$_3$(*C*)=input$_1$(*c*) and output(*b*)=input$_2$(*c*) (F_3 and B_4 remaining identical).

In our circuit example the FN explanation is easier to arrive at than the AT explanation: the functions can have multiple realizations, so the information we need about the system is less detailed. For instance, the AT explanation requires that we know that input$_3$(*C*) = input$_1$(*a*). The FN explanation only requires that we know that input$_3$(*C*) = input$_1$(*a*) *or* input$_3$(*C*) = input$_2$(*a*): this is sufficient to claim that *a* functions normally. This is the epistemic advantage of FN explanations: if the functions have multiple realizations, they require less knowledge than the AT explanations that are compatible with them. This epistemic advantage increases with the number of possible realisations of the function.

5. The Uses of AT and FN Explanations

5.1. *The Pragmatic Perspective*

Micro-explanations can be used to *change* the observed macro-level relation and to *predict* whether this relation (assuming that we do not intervene) will still hold at a later time. We discuss the cases in this order.

Suppose we want our circuit *C* to behave as follows:

L : If $\text{input}_1(C)=1$, $\text{input}_2(C)=0$ and $\text{input}_3(C)=1$, then $\text{output}_1(C)=1$ and $\text{output}_2(C)=0$.

The AT explanation in section 2 suggests a number of possible changes: we can change the wires so that one of the bridge principles or interaction principles changes, or we can replace one of the gates by a gate of a different type. By means of aggregation and transformation steps similar to the ones in the explanation we can calculate which (set of) change(s) is sufficient to obtain the desired result. The FN explanation, if available, shortens the calculations: by showing that some changes do not affect the normal functioning of any of the elements, we can show that no change at the macro-level will occur (and thus that the desired result will not be obtained). For instance, we can calculate that changing the circuit such that $\text{input}_1(C) = \text{input}_2(b)$ and $\text{input}_2(C) = \text{input}_1(b)$ (other things remaining the same) will not affect the normal functioning of *b*, nor of any of the other gates. So we can eliminate this set of changes without going through the complete aggregation and transformation procedure.

This example shows that, from the point of view of manipulation, the FN explanations are useful complements to AT explanations. However, FN explanations are not "autonomous": they become useful only if an AT explanation is available too.

In the case of prediction, FN explanations provide a similar shortcut. The AT explanation tells us where to look for changes at the micro-level. The significance of these changes (do they imply a different law at the macro-level?) can be evaluated by means of a calculation involving an aggregation and transformation procedure. If an FN explanation is available, a simpler calculation is possible by showing that the change(s) do or do not affect the normal functioning of one of the components.

5.2. *The Theoretical Perspective*

If the motivation for explaining a law is purely theoretical (i.e. if the aim is to understand how the law fits into our worldview and how it relates to other laws), FN explanations are useless. The IGL example shows that in some cases the fundamental laws and interaction principles that are used in an AT explanation are obtained be specifying a general theory. This specification procedure, which Kuipers calls the application step, consists in adding appropriate auxiliary hypotheses to the theory. The theory and the auxiliary hypotheses together entail the fundamental laws and interaction principles. An AT explanation which is constructed in this way has unificatory power: it shows how the explained law fits into our general world view, and (together with explanations of other laws that start from the same theory) how the law relates to other laws. FN explanations cannot have a similar unificatory power, because function ascriptions do not follow from any general theory.

6. Conclusion

We have shown that Kuipers' analysis of micro-explanations wrongly neglects functional explanations. Our contribution is not only a reaction to Kuipers, but also to authors who make the opposite mistake. An example of the latter category is Robert Cummins. In Cummins 1975 he argues that capacities (e.g. the circuit's capacity to produce certain outputs given certain inputs) can be explained by following the subsumption strategy or the analytical strategy. The *subsumption strategy* consists in showing that the capacity is a manifestation of one or more general laws, i.e. laws governing the behaviour of things generally, not just things having the specific capacity to be explained. For instance, we can explain why an object *a* has the capacity to rise in water of its own accord by invoking Archimedes' principle. This principle is applicable to all objects and all fluids, not just the object *a* and water. So the specific case (object *a*, capacity to rise in water) is explained by showing that it can be expected on the basis of a general principle. The *analytical strategy* proceeds by analyzing a capacity of *a* into a number of other capacities of *a* or components of *a*. As examples, Cummins mentions assembly-line production, schematic diagrams in electronics, and explanations of biological capacities:

> The biologically significant capacities of an entire organism are explained by analyzing the organism into a number of "systems" – the circulatory system, the digestive system, the nervous system, etc., – each of which has its characteristic capacities. These capacities are in turn analyzed into capacities of component organs and structures. (1975, pp. 760-761).

Obviously, micro-explanations are a subclass of what Cummins calls analytical explanations. Since Cummins regards function ascriptions as indispensable ingredients of *all* analytical explanations, this entails that for Cummins all micro-explanations must use function ascriptions. In other words: for Cummins all micro-explanations are FN explanations. We have shown that this position is wrong: FN explanations do not have unificatory power, and their pragmatic function presupposes AT explanations.

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Theo A. F. Kuipers

KINDS OF MICRO-EXPLANATION

REPLY TO ERIK WEBER AND HELENA DE PREESTER

The paper by Erik Weber and Helena De Preester is in at least two respects very stimulating. First, it nicely illustrates how my five-steps model of explanation can be adapted to what I would like to call structural explanations of system laws. Second, it provides a clear sight of a (compatible) kind of functional explanation of such laws that is not touched upon in SiS.

Structural Explanation of System Laws

The explanation elaborated by Weber and De Preester in Section 2 for a circuit law on the basis of my five-steps model of explanation (SiS, Ch. 3) is an excellent and totally unexpected kind of use of that model. More specifically, they convincingly show that an input-output law (L) characterizing the observable behavior of the circuit can be deduced from three "fundamental (individual) laws," two "interaction principles" and five "bridge principles." The deduction comprises an aggregation (A) step, followed by a transformation (T) step, hence their speaking of an AT explanation. I have nothing to add to this lucid analysis, just some additional remarks that may further exploit the example.

(1) The aggregation step is a nice example of what was intended with the second (italicized below) half of my elucidation (SiS, p. 87): "the total effect of the individual law for many objects is calculated by a suitable addition, *or composition* (*or synthesis*) *if more than one type of individual law is involved*," since the three individual laws, characterizing the gates, concern two types: AND and XOR gates. Moreover, only in the case of uniformly sequential or parallel grouping of a number of gates of the same type would it be adequate to speak of (straightforward) aggregation.

(2) As a matter of fact, the authors show that the five-steps model, which was primarily intended for the explanation of a law by a theory (indicated in Weber and De Preester's Section 5.2), can easily be adapted to a model for the

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explanation of a "system law" starting with, instead of a "(theory-) application step," an "observation step," as I would like to call it, for it amounts to the establishment of observational laws regarding components of the system. Their fundamental laws amount essentially to thus established laws for the gates in the circuit.

(3) The interaction and bridge principles are essentially identity claims. The first ones claim that certain gate outputs are identical to certain gate inputs. The bridge (or transformation) principles claim that certain gate inputs and outputs are identical to certain circuit inputs and outputs, respectively.

(4) The fundamental laws (or individual gate laws) and the bridge principles (gate identities) constitute together the internal or micro-principles used by the micro-explanation.

(5) The resulting explanation may not only be called a case of micro-reduction due to the (complex) aggregation step, but also a case of identificatory reduction, due to the identity nature of all transformation principles. Hence, apart from the different nature of the (hidden) first step, the example is essentially similar to the reduction of the ideal gas law.

(6) It seems plausible to call the present type of explanation of circuit laws and, more generally, system laws, structural (reductive) explanations, in particular when they are opposed to what Weber and De Preester call functional explanations of such laws, to be discussed now.

Functional Explanation of System Laws

Inspired by Cummins (1975), Weber and De Preester also give a kind of functional explanation of the same system law, viz. an explanation in terms of function ascriptions to the three gates in the circuit and the assumption that these gates function normally. Again I would just like to make a couple of remarks.

(1) Talking about functions should not hide the fact that the normal functioning of a gate can be described by hybrid behavioral laws, e.g. F_a and N_a together imply the law (NF_a): "$output_2(C)$ = 1 iff $input_3(C)$ = 1 and $output(b)$ = 1," and the resulting three laws together imply the system law to be explained.

(2) Such hybrid laws can easily be redescribed as bridge principles, from gates to the system or vice versa. For example, NF_a is equivalent to "if $output(b)$ = 1, then $output_2(C)$ = 1 iff $input_3(C)$ = 1, and if $output(b)$ = 0, then $output_2(C)$ = 0." Hence, the resulting explanation fits into the five-steps model in the sense that these laws are in fact transformation principles of the causal correlation type such that the explanation amounts to a number of correlation

steps, with the peculiar fact that they do not start from individual laws of a substantial nature but of a (context-relative) tautological nature, such as "*output*(*b*) = 1 or *output* (*b*) = 0." In view of the fact that neither Weber and De Preester's version nor the indicated nonfunctional version use individual laws, let alone micro-principles giving rise to such laws, it seems less appropriate to talk in this case about micro-explanations, as Weber and De Preester in fact do.

(3) The foregoing remarks are not intended to play down the practical usefulness of normal function talk. As in the case of biological functions, following Ruth Millikan (see SiS, Sections 4.2 and 6.2), if adapted, function talk makes also perfect sense in the case of artificial functions. As a matter of fact, whereas ascriptions of biological functions are essentially based on at least two causal components, one of a proximate and one of an ultimate nature, artificial function ascriptions may be based on merely one type of causal laws, as NF_a illustrates. Weber and De Preester's contribution strongly suggests that a further general analysis of functional explanations related to artificial systems along the lines of "explanation by specification" as developed in Chapter 4 of SiS would be very interesting.

(4) Very illuminating is the "multiple realizability" that Weber and De Preester discuss in Section 4. The same functions that are played by the gates can be realized in other ways than the particular "material realizations" in the sample circuit. I would like to add that the reductive explanation of the circuit law in Section 2 provides a perfect "artificial" illustration of the compatibility of multiple realizability and reductive explanations. As suggested in SiS (e.g. pp. 154-5) with some examples from natural science, the popular claim in functionalist philosophy of mind by Fodor and Putnam that multiple realizability is a blockade for reduction, is due to a lack of understanding of successful reductive arguments in the natural sciences.

(5) Finally, Weber and De Preester go as far as to claim that a functional explanation of the circuit law is not theoretically interesting and only practically useful, i.e. useful for manipulation of the circuit and, I would like to add, diagnostic reasoning about it, if the relevant structural explanation is available as well. This agrees with my claim (SiS, p. 126): "Explanation by a certain type of specification [intentional, functional, causal] automatically leads to a corresponding type of description, in particular classification." In other words, (isolated) functional explanations are in a sense merely a kind of description. However, as indicated in the contribution of Grobler and Wiśniewski and my reply to them, in special cases, they may play an important role in the evaluation of theories.

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