The Manipulability Account of Causation applied to Physical Systems.

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Abstract. In the following we will apply the manipulability theory of causation of Woodward 2003 to physical systems, and show that, in the latter context, the theory can be simplified. Elaborating on an argument by Cartwright, we will argue that the notions of 'modularity' and 'intervention' of the cited work should be adapted for typical physical systems, in order to take *coupling* of system equations into account. We will show that this allows to reduce all cause types discussed in Woodward 2003 to only one, namely that of 'total cause'.

1. Introduction.

In the present article we will examine an influential theory of causation, namely the 'manipulability' account advanced by James Woodward. We will focus our attention on Woodward's well-known textbook (Woodward 2003). Woodward has authored or co-authored other texts on the topic, such as Hausman and Woodward 2004 (the latter as a reaction to Cartwright 2002); but these articles can be seen as corroborating the full-blown theory of Woodward 2003. As is well known, the manipulability account was developed to apply to a wide spectrum of systems, from sociology, economy, physics etc. to everyday life. In the present article we will focus on systems studied in physics, and argue that the theory should be adapted in that case, in order to be fully compatible with the particular mathematics of these systems. The singularity of the systems studied in physics is that they are describable by complete sets of equations involving all system variables - which is rarely possible in other contexts. More precisely, we will argue that the notions of 'modularity' and 'intervention', as they are defined in Woodward 2003, are incompatible with a feature of system equations termed 'coupling'. Coupling, a property of most if not all realistic physical systems, will be explained in Section 2. Its incompatibility with modularity and intervention, in Section 3. We will in particular be led to conclude that typical system equations from physics are not modular, but coupled.

Allowing for coupling has an unexpected effect for the manipulability theory of Woodward 2003: it allows to greatly simplify it. Indeed, we will show (Section 4) that, for physical systems, of all the causal notions that are defined in Woodward 2003, only that of 'total cause' remains. 'Total cause' would therefore be, for such systems, nothing else than cause *simpliciter*.

Nancy Cartwright has extensively criticized the manipulability account of causation, and in particular modularity, using a series of arguments (see her 2006 and references therein). In one of the articles, namely in Cartwright 2004, she has identified the point we will investigate here in detail. She discusses a model of a carburetor, and mentions (Cartwright 2004, 810): "By design the different causal laws are harnessed together and cannot be changed simply. So modularity fails." As will be detailed in the following, this 'harnessing of laws' corresponds to what will be termed here 'coupling of system equations'. Our aim is to study in detail all the consequences of the latter central concept, not only for modularity, but also for the definitions of cause proposed in Woodward 2003. Such a task is made possible thanks to the formal detail and logical coherence of the cited book by Woodward, just two of the merits of this text.

Above we said that we will restrict our analysis to physical systems. We could be more precise in stating that we will focus on systems described by coupled system equations. Physics doubtlessly provides the paradigmatic case, but there exist countless examples of coupled systems in other fields that can be mathematized.

2. Physical Systems. Coupling of System Equations.

In the following we will use the term ‘physical systems’ to denote systems of ‘things’ (entities and their interactions) that are studied in physics. Let us start by making a few introductory observations linked to the notions of ‘variables’, ‘constants’ and ‘equations’.

Physical systems are described in the practice of physics by sets of mathematical equations that quantify the relations that exist between the different parameters or *variables* of the system. In other words, for our present purposes ‘systems’ can roughly be equated with ‘sets of (system) equations’; obviously, the latter equations are typical for the physical subfield or domain in question (e.g. relativistic mechanics, thermodynamics, quantum mechanics, etc.).

We will focus our attention in the following on physical systems that are realistic and therefore somewhat complex, namely systems that are described by several variables (not just one) *that intervene in general in several equations (not just one) describing the system*. The latter property, to be defined more precisely in the following, is called ‘coupling’ of the system equations. Let us note from the start that a majority, if not all, of physical systems are ‘coupled’. Indeed, if a system is characterized by N (dependent) variables, it is described by N equations; these equations are coupled, else mathematical solution of the system would be much easier than it is: every equation could then be handled ‘on its own’ to be solved for one variable (see e.g. Boyce and DiPrima 1997, Ch. 7). That seems hardly ever the case in physics[1].

To illustrate the notion of coupling, let us have a quick look at a particularly beautiful example, namely Maxwell’s equations of classical electromagnetism – particularly beautiful

[1] The only exception to the ubiquitous coupling of equations we are aware of are (artificial) systems of independent subsystems each described by only one dependent variable (say x), for instance a collection of N linear springs (evolving according to Hooke’s law). One could describe this system by N equations $\{m_i.d^2x_i/dt^2 = -k_ix_i, i = 1,\ldots,N\}$. This set of equations is ‘decoupled’: each dependent variable $x_1, x_2, \ldots x_N$ only intervenes in one equation. However, such a ‘system’ is not studied in physics: all the relevant information is already contained in the first equation involving x_1.

since describing a potentially infinite class of systems, belonging to such diverse subfields as electrostatics, magnetostatics, and electrodynamics. Maxwell's equations (Jackson 1999, Ch. 1) are a set of four 'coupled partial differential equations', expressing a relationship between the electric field ($\underline{E}$), the electric displacement field ($\underline{D}$), the magnetic field ($\underline{B}$), the magnetic field intensity ($\underline{H}$), and their so-called sources, namely the electric charge (ρ) and current density ($\underline{J}$):

$$\underline{\nabla} \times \underline{H} = (4\pi/c)\, \underline{J} + (1/c)\, \partial\underline{D}/\partial t$$

$$\underline{\nabla} \times \underline{E} = - (1/c)\, \partial\underline{B}/\partial t$$

$$\underline{\nabla} \,.\, \underline{B} = 0$$

$$\underline{\nabla} \,.\, \underline{D} = 4\pi\rho$$

(The operator '$\underline{\nabla}$' effectuates derivation in the space coordinates, but that is a detail of no importance in the following.) In above equations, 'c' is the speed of light. We explicitly exhibit the equations, because it allows us to illustrate an essential point for the rest of the article. One notices that the set contains variables ($\underline{D}$ and $\underline{B}$) that belong to different equations; more precisely, *all equations contain variables that also belong to at least one other equation* – i.e., the equations are *coupled* (this is the more precise definition). The coupling makes mathematical solution difficult: none of the equations can be mathematically manipulated 'on its own' to derive a solution for a variable; they have to be treated in parallel[2].

Another example refers to figure 1, which represents an electric circuit, involving currents I, I_1, I_2, I_3, an electric potential source V, and three constant resistors R_i (constants of the system). This system is fully described by following four relations: $I_1 = V/R_1$, $I_2 = V/R_2$, $I_3 = V/R_3$ and $I = I_1 + I_2 + I_3$. Here to, the representative equations are coupled: the system variables appear in general in more than one equation (this is the case for V, I_1, I_2, and I_3, not for I); more precisely, all equations contain at least one variable that also appears in at least one other equation.

[2] Let us note that the coupling is even more intricate than the Maxwell equations suggest, since in order to solve the set one needs additional equations, the so-called 'constitutive relations', depending on the properties of the environment, the media and materials involved in the particular system under study. One example of such an equation is $\underline{D} = \varepsilon.\underline{E}$, with ε the electric permittivity, a constant of the system. These auxiliary relations introduce additional coupling between the equations. But that only enhances our argument.

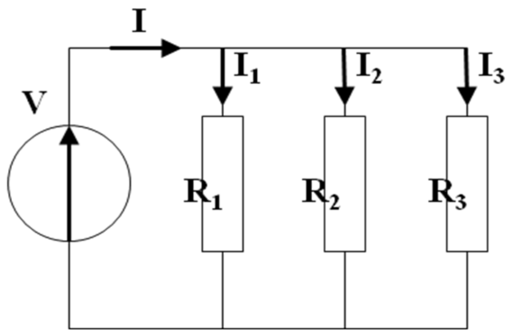

Figure 1.

Let us repeat that only the simplest systems, those that involve just one independent variable and that therefore can be described by one equation, do evidently not exhibit coupling. But such systems are a small minority of all physical systems studied (and indeed they are not treated by Woodward 2003). As already stated, the modification of Woodward's theory we undertake in the following concerns only coupled systems - but all of them, whether from physics or other fields. Indeed, many real world systems that can be mathematized via equations are coupled. Physical systems are the most telling case, but see Giordano and Weir 1988, Ch. 7 for a series of systems from economy, biology, population dynamics, etc., all described by coupled equations.

For the purpose of the article it is important to remember that the role of the 'variables' and 'constants' in the system equations is clearly distinct. For any given physical system, the constants are fixed, i.e. they keep the same numerical value independent of the values of the variables. In above examples, 'c' and the 'R_i' are such system constants: their value is assumed to be given. 'Variables' obviously play a very different role: within one system with fixed constants, the variables may assume different values; the system equations numerically describe how a variation in one variable is linked (coupled) to the variations of the other variables. For examples, let us go back to the two systems we presented. If in electrodynamical systems, described by the Maxwell equations we exhibited, the source (or independent) variables $\underline{J}$ and ρ change (for instance due to human intervention, or due to changes in the natural environment), the other (dependent) variables will also change (always for fixed constants). Similarly, if in Figure 1 the potential source doubles its output voltage V, all currents will double their value (while the R_i remain constant), as immediately follows from the mathematics of the equations.

Let us now study in some detail the relevant parts of Woodward's theory of manipulability.

3. Coupling versus Modularity.

Woodward 2003 heavily relies on the notions of ‘modularity’ and ‘intervention’ in constructing his theory of causation and explanation[3]. Our aim is to show that, in the case of physical systems, the definition of ‘intervention’ should be modified, and that ‘modularity’ does not hold for coupled systems. In Woodward 2003 modularity is defined as follows (quote 1):

> “More generally, a system of equations will be modular if it is possible to disrupt or replace (the relationships represented by) any one of the equations in the system by means of an intervention on (the magnitude corresponding to) the dependent variable in that equation, without disrupting any of the other equations.” (Woodward 2003, 48)

A similar definition is offered in Woodward 2003, 329. Observe that, a priori, the expression ‘to disrupt an equation’, intervening twice in above definition, could have different meanings. It could be interpreted as I1) ‘to change the form of an equation’, or as I2) ‘to determine the numerical values of the variables of an equation’ - or there may be other meanings. Under interpretation I1) modularity seems not a property of equations describing physical systems, because interventions, in the sense defined below (and in the sense in which the word is used in physics, for that matter) do *not* change the form of an equation, they set a variable in the equations to a given value (more on this below). Under interpretation I2) to, modularity is not a property of sets of equations, as soon as they are coupled, as will be explicitly shown below. But maybe we overlook valuable interpretations; let us see how the concept is used. To that end we need the definition of ‘intervention’[4], involving the variables X and Y (quote 2):

> “More generally and slightly more precisely, we may think of an intervention on X with respect to Y as an exogenous causal process that changes X in such a way and under conditions such that if any change occurs in Y, it occurs in virtue of Y’s relationship to X and not in any other way.” (Woodward 2003, 47)

The many examples offered in the text allow to draw a clear picture of the precise meanings of above concepts. Let us study the most revealing one in detail. In Woodward (2003, 330) following system of equations is discussed (we keep the original equation indices):

(7.4.3) $Y = aX + U$

(7.4.4) $Z = bX + cY + V$.

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[3] These notions have been discussed (and defined differently) by other philosophers, e.g. Spirtes et al. 2000 (see Woodward 2003, 46-48 for a complete list of references).

[4] The more detailed definition on p. 98 leads to exactly the same analysis as is presented here.

The equations – which are manifestly coupled - are rewritten as follows by algebraic rearrangement:

(7.4.3) Y = aX + U

(7.4.5) Z = dX + W, where d = b+ac and W = cU + V.

The author states (quote 3):

> "Despite their observational equivalence, if (7.4.3) – (7.4.4) is modular, then (7.4.3) – (7.4.5) cannot be (and vice versa). To see this, consider an intervention on the variable Y in (7.4.3) that replaces (7.4.3) with the new equation (7.4.3*) Y = y. In effect, what this intervention does is to set the coefficient a in (7.4.3) equal to 0." (Woodward 2003, 330)

(The argument is that, if a = 0, d becomes equal to b, and thus (7.4.5) 'changes' (or is 'disrupted'), so that (7.4.3) – (7.4.5) is not 'modular', according to the definition of quote 1 we displayed above. It would seem here that Woodward avows himself to the questionable interpretation I1) above.) Our point is that the phrases in quote 3 do not correspond to a legitimate interpretation of the mathematical apparatus used to model coupled physical systems. First, as highlighted in Section 2, a coefficient as 'a' is, in such contexts, a constant of the system: its value cannot change, and can in particular not become 0. What is possible, is that one indeed sets by intervention Y to a certain value, y, so that y = aX + U according to (7.4.3). The point to observe is that this intervention on Y will influence X *and* Z, whichever set of equivalent equations one starts from, *due to the fact that the equations are coupled*. Indeed, if the equations were not coupled (if they had no common variables), they could be mathematically handled in a fully separate manner, as if, so to speak, the other equation did not exist. This 'parallel' influence of Y on X *and* Z may be obvious if one considers (7.4.3) – (7.4.4) since Y intervenes in both equations; but it also follows from (7.4.3) – (7.4.5). Let us prove it. Whatever value Y takes, whether these values are set by intervention or not, according to (7.4.3) X can be rewritten as (Y – U) / a, so that (7.4.4) becomes, by substitution of X: Z = (c + b/a) Y + V – b U/a (7.4.4#). By inspection of equations (7.4.3) and the simultaneously valid (7.4.4#), one directly sees that by intervening on Y (by causing it to assume the value y), one *necessarily* changes or influences the value of X *and* of Z. Again, the reason lies in the coupling of the equations. This result holds independently of the representation one chooses for the system. Indeed, one can easily verify that (7.4.3) – (7.4.5) lead (of course) to the same equation (7.4.4#) (one could say, based on (7.4.3) – (7.4.5), that Y influences Z through its link with X; *X 'couples' Y and Z*). This is a mathematically necessary property of sets of equations that only differ by algebraic rearrangements, such as sets (7.4.3) – (7.4.4) and (7.4.3) – (7.4.5). There is no mathematical nor physical information that can differ in both representations. We arrive here at a conclusion that differs from Woodward's, since he claims (quote 4):

> "By contrast, according to (7.4.3) – (7.4.5), Y does not cause Z and hence there are no interventions on Y that will change Z. (Recall that an intervention on Y should be uncorrelated with other causes of Y such as X.)" (Woodward 2003, 331)

The phrase between brackets points out what is the central issue. The author stipulates that under 'interventions' one variable (Y) can be set in such a manner that another variable (Z) is determined in a fully unrelated, *'decoupled'* manner. That may be an appropriate characterization for systems from economy, sociology etc., but such interventions do not exist in systems as soon as coupling between the equations occurs. We have explicitly proven this fact via our derivation of equation (7.4.4#) from (7.4.3) – (7.4.5): Y does cause Z, and this fact holds irrespectively of the equation set one starts from. For the system discussed, *all variables are linked to each other via coupled system equations*. Clearly, this property can be generalized to all coupled systems (for those who prefer an explicit argument, see footnote 7).

Thus it appears that in coupled systems 'modularity' does not apply, and that the unwarranted use of the concept traces back to an 'unphysical' use of 'intervention' – more precisely a usage that does not apply to coupled systems, and in particular not the example just discussed. Note that this particular interpretation of the mathematical representation of intervention is not yet obvious in the definition of the concept as reproduced in quote 2. There is however a shift in the meaning of 'intervention' throughout the text, as was already noticed by Cartwright (2002, 414-15)[5]. Careful inspection of the text shows that the same use of 'intervention', violating coupling, appears in other passages[6], and, most importantly, in the definitions of cause, as we will show in the next Section. Therefore, and for reasons that will become clear in the following, we will arrive at the conclusion it is this element of the manipulability account of causation that should be modified to make it generally applicable to physical systems.

An important corollary of above findings is the following. Our analysis points to the idea that systems represented by coupled equations should not be conceived of as being made up of variables that are directly linked to only a subset of the other variables, but to *all* of the other variables. Indeed, from the definition of coupling of system equations, it follows that no variable can be solved for by using just one equation: one needs all equations. But that means that a change (e.g. under an intervention) in one variable 'propagates' itself to all other

[5] In the detailed definition of intervention (Woodward 2003, 98), the incompatibility with coupling *is* manifestly built-in.
[6] See e.g. Woodward 2003 p. 52, p. 100.

variables[7]. In other words, *all variables are linked to all other variables*; their values cannot change without influencing the values of all other variables. This would seem to have essential implications for the 'graph' representation that is extensively used in Woodward 2003 to depict and characterize causal networks – i.e. networks representing 'which variable influences which other variable'. Indeed, it would seem that, for physical (in general coupled) systems, *the correct representation is one in which each vertex is connected to each other vertex*. Note that the graph representation of Woodward 2003 is *only* based on the equations connecting the variables X, Y, Z,…, *not* on any time-relation between those variables (at least in examples such as Woodward 2003 p. 49, p. 51, p. 328 and others). But as we have argued, due to the coupling of the equations there is no privileged connection nor direction in the graph, at least not when only taking the equations into account: all variables are symmetrically (and therefore maximally) connected. (As briefly argued below, we believe a causal directionality can be recovered by taking time into account.) We will not elaborate here on this idea, but this conclusion of a maximally interconnected network of system variables seems inescapable in the case of coupled equations. Since we have not presented a detailed proof of the latter thesis (it is not essential for our argumentation), let us introduce it as a conjecture, in the following termed the 'dense grid conjecture'.

Notice that the graphs of Woodward 2003 are defined in a different manner than in e.g., Spirtes, Glymour, and Scheines 2000, or in Pearl 2009. In the latter works graphs are attached to *probabilistic* systems, *and are not directly derived from deterministic and coupled system equations*. There seems to be no reason why such graphs could not be 'directed'. (But we believe that even such graphs for probabilistic systems will be dense as soon as they represent coupled system equations, for the reasons indicated above.)

In conclusion, following Cartwright 2002, 2006, we believe modularity as defined in Woodward 2003 is not a property of (most) physical systems. We have argued in some detail that the concept of 'intervention' as employed in the notion of modularity is incompatible with the coupling that exists between the equations of the systems studied in physics. This conclusion may be seen as an elaboration of a claim of Cartwright (2004, 810, where the 'harnessing of laws' is discussed). We believe it is therefore safe to stick to the meaning of 'intervention' as understood in many passages in Woodward 2003, and in physics, as based

[7] Suppose one changes variable x_1 in equation e_1; in a coupled system e_1 will also contain, by definition, at least one other variable, say x_2 (if not, x_1 will intervene in a second equation containing a second variable x_2); therefore a change in x_1 will change x_2. If there are three variables, x_3 necessarily intervenes in an equation that contains, due to coupling, at least one other variable, i.e. x_1 or x_2; so a change in x_1 causes a change in x_2 *and* x_3; and so on if there are more variables. This can easily be seen in the system equations we exhibited as examples in the former Section.

on the idea that an intervention sets the value of a variable to a given value. *We cannot ask more of an intervention, if we do not want to violate the property of coupling.* Also, with this interpretation of intervention, the only case in which equations can be called 'modular' is that of 'decoupled' equations in the usual mathematical sense. Only if two equations are decoupled, if they share no common variables, an intervention can set the value of a variable in one equation without changing the value of a different variable appearing in the other equation.

4. Implications for the Manipulationist Concept of Cause.

In the present Section we will investigate in detail the consequences of abandoning modularity for the theory of causation that is proposed in Woodward 2003. As is well known, the theory strongly links modularity to the different notions of 'cause' it defines. One reads:

> "(…) I will assume that when causal relationships are correctly and fully represented by systems of equations, each equation will correspond to a distinct causal mechanism and that the equation system will be modular. As we will see, the notion of direct causation and the related notion of causal route is closely bound up with these ideas." (Woodward 2003, 49)

Closer inspection of the text reveals that, according to the author, a set of equations that allows to identify 'direct' causes is a 'modular' set, representing 'distinct causal mechanisms'. But we have just argued that 'modularity' is not an appropriate description of most or all physical systems. As we will develop in the following, it is then intuitively compelling that *abandoning the concept of modularity, leads to abandoning of the distinction between the different types of causes that are introduced in Woodward 2003, namely 'direct', 'contributing', and 'total' causes.* If that would be the case, our investigation would lead, for physical and coupled systems in general, to a substantial simplification of the theory. Indeed, especially in Chapter 2 of the book each of above cause types is given a separate definition, which strikes by its logical detail (see especially Woodward 2003, 51 – 61). In view of the importance of above conclusion, let us proceed carefully to prove it, by two different (and independent) routes.

The concept of 'direct cause' (DC) is defined as follows (our italics):

> "(DC) A necessary and sufficient condition for X to be a direct cause of Y with respect to some variable set V is that there be a possible intervention on X that will change Y (or the

probability distribution of Y) *when all other variables in V besides X and Y are held fixed at some value by interventions*." (Woodward 2003, 55)

The italicized part shows that the definition of direct cause directly relies on the concept of intervention in its 'decoupled' form, i.e. conflicting with the mathematics of coupled equations. Such a definition may be logically consistent 'on its own'; it is however not synthetically applicable to real world systems – it does not describe such systems. As we have studied in detail in the preceding Section, a real intervention on a coupled system will influence all variables, so that 'all other variables besides X and Y' *cannot* 'be held fixed at some value'. Therefore 'direct cause' cannot be a legitimate concept for coupled systems. Since 'contributing cause' is introduced as the complement of 'direct cause' (any cause is either a direct or a contributing cause)[8], the former is likely to be not a good concept either, in the considered context. And indeed, the definition of 'contributing cause' in Woodward 2003, 57[9] explicitly uses the concept of 'direct cause' (and therefore intervention), of which we just showed it is problematic. Therefore, for coupled systems 'contributing causes' do not exist either (as defined).

This argument suffices as proof, but in view of the importance of the conclusion, let us give a second, independent argument for the idea that the distinction between direct and contributing causes is inadequate for coupled systems[10]. Since this argument is based on the 'dense grid conjecture' of former Section, it may be found less compelling by some than our first argument. The definition of contributing cause (Woodward 2003, 57) explicitly relies, besides on the concept of direct cause, on the notions of 'causal path' and of 'causal chain'. A rough restatement of the definition could be as follows: either a cause is 'direct', either 'contributing' if it is part of a causal chain (see the last phrase of the definition). However intuitive this may be[11], we have succinctly argued in Section 3 that *the image of causal chain,*

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[8] See the last sentence in the definition (NC*) in Woodward 2003, 57.

[9] Here is the first part of the definition of contributing cause (Woodward 2003, 57, our italics): "(NC*) If X is a contributing type-level cause of Y with respect to the variable set V, then there is a directed path from X to Y such that each link in this path is a *direct causal relationship*; that is, there are intermediate variables along this path, Z1…Zn, such that X is a *direct cause* of Z1, which is…" (This is the necessary condition reappearing in the full definition on p. 59.)

[10] A third argument is the following: we believe that the original intuition of the author (see p. 50) to introduce the notion of 'contributing cause' is questionable in the case of physical systems. On p. 50 an example of a system is discussed, for which the constants (a, b, and c) assume values such that a = -bc, implying that one of the variables (Y) becomes 0, so that X would not have a direct influence on Y. We cannot elaborate our arguments, but we believe one cannot infer causal relations by giving ad-hoc values to the constants (see also the discussion following quote 3). In contrast to variables, system constants have fixed numerical values. Even if for a very peculiar system (a real situation is not provided) they would be such that a = -bc, then the original equations still hold, and allow to infer the causes without accounting for the information a = -bc. (Also observe that in real systems a will never be *exactly* equal to –bc.)

[11] The idea of causal chain is indeed intuitive – think of the paradigmatic example of colliding billiard balls. Here it seems one could easily introduce the notion of 'direct' and 'indirect' cause (some balls directly cause a given

as represented in the author's graphs, is not *appropriate for coupled systems*. Indeed, we have argued that the adequate graphs, as derived from the system equations only, are maximally dense grids – maximally interconnected networks, connecting all vertices to all vertices. In this sense, before considering time, i.e. only considering the equations, there are no chains: all variables play geometrically a perfectly symmetric role. If that is true, our point follows immediately; the distinction between types of causes, as defined, vanishes. Since we have not elaborated the latter ideas in detail, we submit them here as a conjecture; but it seems an inescapable one – due to coupling. Let us also emphasize that a concept as 'direct cause', as it is defined for *probabilistic* systems in works like Suppes 1970, Spirtes et al. 2000, and Pearl 2009, may very well be legitimate, *as soon as the considered systems are decoupled*. That implies that these systems should not be the systems studied in physics; they could however be the much more complex systems from economy, sociology, or everyday life. As is well known, such systems are almost never described by full sets of coupled equations; they may however be governed by probabilistic interdependencies.

If the notions of direct and contributing cause do not apply, as defined, to coupled systems, the only remaining cause type for such systems in the manipulability theory of James Woodward is that of 'total cause'. It is defined as follows:

> "(TC) X is a total cause of Y if and only if there is a possible intervention on X that will change Y or the probability distribution of Y." (Woodward 2003, 51)

It is essential to observe that the definition of total cause is the only one that accepts the (classical) meaning of 'intervention on X', as an operation that sets the numerical value of X. As we have shown, the other definitions of cause types are based on a conception of intervention that is illegitimate for most physical systems, and at any rate for all coupled systems. We are thus lead to the conclusion that the above definition of 'total cause' is the only remaining, valid definition of cause for physical systems. We believe it therefore captures the essence of the notion of causation in Woodward 2003 for such systems.

5. Conclusion.

We started this paper with a study of Woodward's notions of modularity and intervention (in his 2003), playing an essential role in the manipulability theory of causation and explanation. We corroborated an earlier argument of Cartwright (2004, 810), and showed

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ball to move, others indirectly). That could indeed be done, if one introduces *time* into the picture. But not, we believe, by means of the definition of 'contributing cause' provided in Woodward 2003, essentially because it relies on the definition of 'direct cause', and thus on a problematic use of the concept of intervention.

that these concepts are conflicting with a ubiquitous property of physical systems, namely the coupling between system equations, and thus between system variables. Next, we showed that modifying the manipulability account of causation in order to take coupling into account has drastic consequences: it substantially simplifies the theory, leaving one generally applicable notion of cause, namely that of 'total cause'. Throughout the text we emphasized that our conclusions hold for physical systems, more generally for systems characterized by coupled equations.

In conclusion, we believe the manipulability account of causation, which has a broader scope than only physics, remains a rich and interesting theory of causation, applicable to a wide range of systems. It appears however that in the case of coupled systems, such as physical systems, the theory can be simplified.

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References

Boyce, William, and Richard DiPrima. 1997. *Elementary Differential Equations*. New York: John Wiley.

Cartwright, Nancy. 2002. 'Against Modularity, the Causal Markov Condition and any Link between the Two.' *British Journal for the Philosophy of Science* 53:411 - 453.

Cartwright, Nancy. 2004. 'Causation: One Word, Many Things.' *Philosophy of Science* 71:805 - 819.

Cartwright, Nancy. 2006. 'From Metaphysics to Method: Comments on Manipulability and the Causal Markov Condition.' *British Journal for the Philosophy of Science* 57:197 - 218.

Giordano, Frank and Maurice Weir. 1988. *Differential Equations. A Modeling Approach*. Reading: Addison-Wesley Publishing Company.

Hausman, Daniel and James Woodward. 2004. ‘Modularity and the Causal Markov Condition: A Restatement.’ *British Journal for the Philosophy of Science* 55:147 – 161.

Jackson, John. 1999. *Classical Electrodynamics*. New York: John Wiley.

Pearl, Judea. 2009. *Causality. Models, Reasoning, and Inference*, 2nd Ed. New York: Cambridge University Press.

Spirtes, Peter, Clark Glymour, and Richard Scheines. 2000. *Causation, Prediction, and Search*, 2nd Ed. Cambridge, MA: MIT Press.

Suppes, Patrick. 1970. *A Probabilistic Theory of Causality*. Amsterdam: North-Holland Publishing Company.

Woodward, James. 2003. *Making Things Happen. A Theory of Causal Explanation*. Oxford: Oxford University Press.