The Metaphysics of Forces

Penultimate version, please quote the published version : Massin, O. (2009). The Metaphysics of Forces. *Dialectica*, *63*(4), 555-589.

Abstract. This paper defends the view that Newtonian forces are real symmetrical and non-causal relations. In the first part, I argue that Newtonian forces are *real*; in the second part, that they are *relations*; in the third part, that they are *symmetrical* relations; in the fourth part, that they *are not causal* relations, (but causal *relata*) by which I mean that they are not species of causation. The overall picture is anti-humean to the extent that it defends the existence of forces, irreducible to spatio-temporal relations, but is still compatible with humean approaches to causation (and others) since it denies that forces are species of causation.

I shall defend the view that Newtonian forces are real symmetrical and non-causal relations. I first defend the reality of forces, by arguing that a realist view of component forces is the best way to make sense of the cases in which bodies change their disposition to move without changing their actual kinematical behaviours. It is then argued that those real forces cannot be monadic properties for there is no way for a monadic property to have a direction akin to the direction commonly ascribed to forces. In the third part, I claim that force-relations have to be symmetrical relations, on the ground that it is the best metaphysical reading of Newton's Third Law. The last part is devoted to distinguishing forces from causation: forces have causal powers, but are not instances of causal relations, one reason for that being that they are symmetrical.

1. Forces are real: a truthmaker argument

Are forces real? Following a long tradition, which has been recently revived by J. Wilson (2007), I want to argue that Newtonian forces are real, by which is meant that forces exist independently of our thinking about them and are irreducible to other same-level properties (such as mass or acceleration for instance). Before deciding whether Newtonian forces are real or not, we need first to make clear why the ontology of Newtonian Mechanics still matters today, and second to spell out what kind of ontological candidates forces are.

1.1. The ontology of Newtonian mechanics

Newtonian Mechanics (NM) may seem to be of little interest for contemporary metaphysics since it has been superseded by better physical theories (quantum mechanics, the theory of general relativity). Is the ontology of NM of more than historical importance? J. Wilson (2007) has argued for a positive answer. According to her, Newtonian mechanics should be treated in the same way as the special sciences. The ontologies of thermodynamics, biology, psychology, botany or geology are still of some metaphysical importance, despite their inapplicability to the quantum world. According to Wilson, the fact that certain structurally complex entities or aggregates exhibit enough stability, independent of the details of the behaviour of their constituents, constitutes one important *rationale* for special sciences. The same may be true of Newtonian mechanics: though it cannot handle quantum indeterminacy, it is still close to the truth concerning the behaviour of the medium-sized world. This may be understood in two different ways: first, one may think that microphysicalism is false, and that the world is irreducibly layered. If so, Newtonian mechanics could be seen as describing and explaining *sui generis* emergent properties or episodes. Second, one may think that microphysicalism is true and that all the entities assumed by special sciences are reducible to microphysical ones. Even so, it is still true that the ontologies of special sciences matter: they give us *candidates for reduction*. If we are going to carry out a reduction of a special science, or to evaluate whether this reduction has been achieved, we need to understand its ontology. Microphysical reductionism is not eliminativism: though both agree on the ontology, reductionism holds the reduction of the entities posited by the special sciences to be an important task to achieve, contrary to eliminativism. I shall only assume that eliminativism about Newtonian mechanics is wrong. I will not decide between anti-reductionism and reductionism concerning Newtonian entities. In both cases, the ontology of Newtonian mechanics matters for contemporary metaphysics.

1.2. What do forces purport to be?

I shall focus on the question of the ontology of Newtonian forces as they are referred to in the three fundamental laws of NM (Newton, 1999):

> *First law*: "Every body perseveres in its state of being at rest or of moving uniformly straight forward, except insofar as it is compelled to change its state by forces impressed."
> *Second Law*: "A change in motion is proportional to the motive force impressed and takes place along the straight line in which that force is impressed."
> *Third Law*: "To any action there is always an opposite and equal reaction; in other words, the actions of two bodies upon each other are always equal and always opposite in direction."

Before deciding whether forces are real or not it is worth spelling out what kind of ontological candidates they are. One suggestion is that the definition of forces is to be found in the Second Law. This sounds odd since *prima facie* Newton's formulation does not look like a definition. Nevertheless, such a proposal is more easily understood when one considers not Newton's own formulation of the law, but its usual mathematical translation, which states that the force exerted on a body equals the product of the mass of the body and the acceleration induced in that body:

$$\mathbf{F}=m\mathbf{a}$$

(Bold letters represent vectors). Once written this way, one may propose to read the "=" as definitional. Since mass and acceleration are admittedly more clearly defined than forces, forces are taken to be the *definiendum*, and the product of mass by acceleration the *definiens*. The suggestion is then that the alleged second "law" is indeed a nominal definition of forces in terms of changes in the motion of bodies. The term "force", in NM, would just be an abbreviation for "accelerating mass".

There are I think two reasons to reject such a proposal. First, it cannot be a definition of *all* forces that are appealed to in NM. An important distinction in NM is the one between *component* forces and *resultant* ones. Force-vectors can be added together, according to vector calculus. The addition of two forces $\boldsymbol{F}$ and $\boldsymbol{G}$ having the same direction and the same magnitude gives a resultant force $\boldsymbol{H}$ of twice the magnitude and of the same direction as each component force. Component forces are the forces that are added together. Resultant forces are the results of these vectorial compositions.

Now, the Second Law holds for resultant forces and its exact mathematical formulation is rather:

$$\mathbf{F} = m\mathbf{a}$$

The acceleration of a body equals the *sum* of the forces exerted on that body. Once written this way, it becomes clear that the Second Law cannot be a definition of *all* forces. It only states a connection between accelerations and *sums* of forces, that is, *resultant* forces. Nothing is said about the forces that are summed, that is, *component* forces. Indeed, according to NM, there are no such nomic connections between each component force that acts on a body and the acceleration of the body: very often NM claims that there are component forces without any actual acceleration of the body under consideration. The component forces exerted on a body must then be something else than the acceleration of that body. Newton's Second Law is of no direct help in the definition of component forces. This is not to claim yet that component forces are real, but only that prior to the question of their existence, the question of their essence cannot be settled by appealing to accelerating masses, i.e. changes of momentum. C.D. Broad was right to claim that Newton's Second Law is a genuine law (rather than a definition) "asserting a connexion between two independently measurable sets of facts in natures" (Broad: 1923: 165).

The second reason why the definitional reading of the Second Law should be rejected at this stage is that it undermines the very debate between realists and anti-realists about forces. The reality of accelerating bodies is clearly not what is at stake in that debate. If forces purport to be nothing else than accelerating masses, the realist about forces has simply no means to express his view (and the anti-realist about forces has nothing to disagree with). The term "force" turns out to be just a notational device in NM, with no new ontological commitment. There must be another concept of forces that underlies the substantial metaphysical disagreement between realists and anti-realists about forces.

It is often said that forces are "causes of motion or acceleration" (which is of course quite distinct from saying that they are accelerations). Although such a definition is on the right track, it has to be specified: not all causes of motion will do (for instance, accelerations could be caused by other accelerations). I therefore propose the following preliminary definition of force:

A force is a basic dynamic property that can be represented by a vector.

"*Dynamic*" is an ambiguous term that is opposed either to "static" or to "kinematic". Here it should be understood in opposition to "kinematic" (statics being crammed with dynamic entities, as we shall see). Dynamic properties include mass, force, energy, momentum, work and so on. Kinematic properties include distance, motion, velocity and acceleration. By extension, kinematic properties include distances and shapes and amount to spatial properties. Dynamics is often defined by means of forces: its aim is to explain (causally) the motion described by kinematics in terms of properties such as forces, mass, energy…. But since I intend to define forces by dynamicity, I need a definition of dynamics that does not make reference to forces. There are, I submit, two distinctive features of dynamic properties. First, though they may *have* spatial and temporal properties, they *are not* spatial and temporal properties, nor are they reducible to spatial and temporal properties. This distinguishes them from kinematical properties, such as shape velocity or acceleration. Dynamics explain motion in terms of non-spatial properties But this is not sufficient: phenomenal colours for instance are not spatio-temporally reducible, but they are clearly not dynamic entities. The second necessary feature of dynamic properties is that they necessarily possess *causal powers*, by which I mean that they can be causes (presumably, of kinematic episodes). This distinguishes them from secondary qualities such as colours for which epiphenomenalism is at least an option. Dynamic properties are thus spatio-temporally irreducible and causally empowered properties.

To say that forces are *represented by vectors* means that they are ascribed both a magnitude and a direction. This distinguishes them from other dynamic entities such as mass, work or energy, which are represented by scalars: a magnitude, but no direction is ascribed to them.

Forces are *basic* dynamic entities in the sense that they are not constituted by, or reducible to other kinds of dynamic entities. This distinguishes them from other dynamic entities that may also be described by vectors or combinations of vectors such as momentum, moment of forces or inertia tensors. Those entities are defined by reference to vector forces. But there is no need to refer to them in order to define vector forces. Forces are then irreducible both to kinematical entities and to other dynamical ones. Here again, "*irreducible"* means only irreducible to other medium-sized entities, be they kinematical or dynamical (=intra-level irreducibility). Microphysical reduction (inter-level reduction) of forces is not at stake here.

Finally, forces are *properties* in the generic sense that they are not substances. They cannot exist by themselves. They are dependent on at least one body. This is compatible with their being basic: forces are basic in the sense in which they are unanalysable or primitive entities. But they are non-basic or non-fundamental to the extent that there are existentially dependent entities. Whether forces are monadic or *n*-adic properties is left open at this stage. One important upshot is that since forces are dynamic (non spatio-temporally reducible) properties*, they cannot be relations without violating Humean Supervenience*, "the thesis that the whole truth about a world like ours supervenes on the spatiotemporal distribution of local qualities" (Lewis, 1994: 473). Humean supervenience implies that every external relation is spatio-temporal (Lewis, 1986: ix-x). But forces, if they are relations, are external relations that are dynamical.

Putting these remarks together, we can rephrase the definition of forces as follows:

> *Forces are spatio-temporally irreducible, causally empowered basic properties to which are ascribed both a magnitude and a direction.*

This definition, I hope, captures a minimal but fairly standard concept of physical forces that can be traced back to Newton and that is still adopted in most contemporary textbooks and discussions on this matter. The next question is to determine whether there is something in reality that corresponds to that definition.

1.3. The reality of forces

Many objections to the existence of forces have been advanced (unobservability, redundancy, overdetermination…). J. Wilson (2007) has I think addressed those objections successfully. My goal here will therefore not be to address them again, but rather to look for a new positive argument in favour of the reality of Newtonian forces.

One important, but insufficient rationale for forces lies in the central role that they play in NM. This is not sufficient because many upholders of NM, (including maybe Newton himself), have been reluctant to endorse a full-blooded realism about forces. Anti-realist about forces have to claim that the term "force", as it appears in NM, either is not referential or refers to something else than *sui generis* forces. One rather radical way of making sense of that claim, which we have just rejected, is to argue that the Second Law is a definition of force. But defining the forces that exerts on a body in terms of the acceleration and mass of *that* body is not the only option for the anti-realist about forces. A more moderate and common option is to claim that the Second Law is indeed a law (not a definition) that connects the acceleration of a body not to forces, but to the distribution, masses and motions of the *other* bodies surrounding it. The term "force" should be understood as referring not to forces proper but to all the bodies (possibly unknown) whose kinematical behaviour and mass determine the behaviour of the body under consideration. It is then possible to make sense of NM without appealing to forces as primitive dynamical entities. The reason to admit forces must lie elsewhere.

There is, I believe, a principled difficulty for those who want to get rid of forces in the explanation of the behaviour of medium-sized entities. (Whether this kind of argument can be extended to what is not medium-sized is an open question). This difficulty arises from the following type of examples:

Imagine two equally strong persons who are arm-wrestling. By hypothesis, at the time they begin their efforts, nothing moves: their respective endeavours neutralize each other. The friend of forces cannot help thinking that despite the absence of any motion of their arms, something important happened between them. The equilibrium of forces of their arms has been radically transformed. Their hands were only juxtaposed at the time each one was about to begin its effort. They are now strongly pressing against each other.

In a similar vein, suppose two magnets are in contact, attracting each other with equal force. Suppose also that their attractive powers decrease with time. From a kinematical point of view, nothing happens: the magnets do not move relatively to each other, nor relatively to anything else. Still, the friend of forces has the strong impression that the two magnets undergo some change. At the beginning of the process, the two magnets are attracting each other; at the very end, they are only juxtaposed.

As they stand, those examples will not scare the opponent of forces. He simply does not share the inclination to posit dynamical changes. It cannot be assumed that the arms or the magnets have undergone a non-spatial change because that is precisely what the kinematically-minded people would deny. According to them, the two cases are exactly the same at the beginning and at the end: no motion, no change. The only way the friend of force can make himself heard by his opponents is by telling them a story about motion.

So consider the *disposition* to move of these systems. Before the beginning of their contest, the arm of each wrestler is disposed to stand (roughly) in a vertical position if the arm of the opponent is removed. After the beginning of the game, the arm of each wrestler is disposed to quickly move toward the table if the other arm is suddenly removed. As for the magnets, at the beginning of the process, they are disposed to stay in contact when struck by some external body. But they are disposed to move away from each other in the very same circumstances at the end of the process. This means that the dispositions to move of these two static equilibria have changed. Surely, this is something that the friends of kinematics should be willing to explain. It is now true that the arms and the magnets are disposed to move in certain ways in certain circumstances. It was not true before. Transposing David Armstrong's truthmaker argument against the Rylean view of disposition, we can claim that *something must have changed in the arms and in the magnets that explains the changes of their dispositions to move*. If we grant that neither the masses, nor the shapes nor the positions of the arms and magnets have changed, some dynamic entity other than the masses must have changed. Then some dynamic entities are real. Forces are among the favourite candidates for this role. In short:

(i) In some cases, the disposition to move of a system changes without occurrence of any kinematic changes inside the system.
(ii) The proposition that the intrinsic disposition of a system has changed must have a truthmaker in the system (Armstrong's truthmaker argument).
Some dynamic changes do occur inside certain systems.
(iii) The best candidates for the changing dynamic properties are forces.
Some forces are real.

(i) Concerning the first premise, one may protest that some kinematic changes actually occurred in the arms and the magnets at a more microphysical level so that after all, the alleged macro-dynamic change is reducible to a multiplicity of micro-kinematic changes. But recall that the point here is not that forces are not microphysically reducible. It is only that they cannot be reduced to other *same-level* phenomena. The conclusion of the argument is only that there are some forces *at the macroscopic level*. Whether those medium-sized forces can be reduced to microphysical kinematic properties, processes or events is an issue that is left open.

Despite this focus on macroscopic phenomena, a possible upshot of this argument for microphysical levels is worth being noted. Suppose we can transpose the same argument all the way down, that is, suppose that at each level we can encounter changes in dispositions to move without changes in same-level kinematical behaviour. Then the argument may show that the only way to avoid dynamic entities is to engage in a microphysical regress. The true proposition "The disposition to move of the static system has changed." must have a truthmaker: if not a same-level dynamic change, it should be a level n-1 kinematic change. The only way to block such a regress is to admit dynamic entities in our ontology.

(ii) Concerning the second premise, it is worth pointing out that Armstrong's truthmaker argument is often used to kill two birds with one stone: it is first directed against the Rylean view of dispositions according to which dispositional talk is metaphysically free-floating, devoid of any ontological anchorage; and second against dispositionalism, the view that there are indeed dispositional properties without categorical basis (a view that Ryle would have rejected as well as its opposite, categoricalism). In the second premise, the truthmaker argument is only used to the first end: ascriptions of dispositional changes must be ontologically grounded. The only point here is the need for a truthmaker, not the nature of the truthmaker: it can be a categorical or a dispositional property.

(iii) The third premise is needed because the two first ones do not show that forces are the *relevant* dynamic entities: they only show that we should look for dynamic —non-kinematic— changes in each of the two systems. Having said that, it is quite tempting to take the plunge and to claim that the entities that have changed are forces. But this requires further justification because forces are not the only candidates here: one could also argue that the dynamic entities that have changed are the *potential energies* of the arms and of the magnets. Why prefer forces? Though energy-based mechanics has superseded forces-based mechanics, both remain equivalent (they are inter-translatable). Ontologically, we have still to choose between forces and energy. Briefly, one can mention two reasons to prefer forces in the explanation of our medium-sized world. (i) Energy-based mechanics holds the principle of least action to be primitive, but this principle has often been claimed to have undesirable teleological implications. (ii) Unlike energy, forces can be perceived (felt pressures on our skin, see note 51). I shall therefore admit that potential energy is not a *primitive* dynamic entity: in order to define it, we need to appeal to the notion of work (roughly, energy is defined as the capacity to do work), and in order to define work we need to appeal to forces (a work is done on a object when a force causes its displacement, that is, when the point of application of a force moves).

Finally, an important point about the scope of the above argument is that it shows that real forces must be *component* ones and not (only) *resultant* ones. Four options are open to the realist about forces relative to this distinction:

(1) Only resultant forces are real, *component* forces are only theoretical fictions.

(2) Only component forces are real.

(3) Both resultant and component forces are real. There are two versions here:

(3a) The resultant forces and the component forces that constitute them are real .

(3b) Resultant and component forces are never real *together*: when the component forces are real, then the resultant force is fictional; and when the resultant force is real, then the component forces are fictional. But both kinds of forces can occur alternatively.

According to Cartwright (1983) only resultant forces are real, component forces being theoretical fictions. The present argument, if correct, contradicts this: forces must have changed in the system of the two arms, and in the system of the two magnets. Following Newton's Second Law, the resultant force that acts on a body equals the mass of the body times its acceleration. Since by hypothesis neither the arms, nor the magnets have undergone any acceleration, the resultant force that exerts on them is null, and remains constant during the beginning of the efforts of the arms and the decrease of the attractive power of the magnets. So exclusive realism about resultant forces cannot account for the change that occurred in the systems. If I am right, (1) is no longer an option for realists about forces: they have to choose between the three other options. I shall quickly argue in favour of (2) in the third part. My main points however concern Newtonian *component* forces. It is of component forces that I want to claim that they are real symmetrical relations.

2. Forces are relations: the direction problem

I have argued that macroscopic component forces are real. The next step is to show that they are relations. Despite the relational character of the expression 'body *a* exerts a force on body *b*', some philosophers (Bolzano, 1972/1837; Armstrong, 1997; Molnar, 2003) deny that it stands for a relation. According to them, forces are *monadic properties* of physical entities. Let us call this a *monadistic view* about forces. Force monadism may be developed in two quite different ways. According to the first one, forces are monadic *categorical* properties. According to the second one, forces are monadic *dispositional* properties. I aim to show that both options fail. The argument I propose is that none of them can account for the *direction* of force vectors.

In examining these two monadistic views of force, I shall make two assumptions:

(i) As far as sparse or natural properties are concerned, the distinction between monadic properties and relations is exclusive: ontologically speaking, there are no *relational monadic properties* such as being a brother, or being ten meter from a tree. So-called relational properties are not sparse properties but abundant ones. They are just figures of speech, ways of describing true relations. As a consequence forces are either properties or relations.

(ii) Every natural monadic property is *intrinsic* to the particular that has it (and every natural relation is intrinsic to the particulars that have it). This implies that the monadic natural properties exemplified by a body do not depend on other bodies. Forces, as natural properties or relations, must be intrinsic to their bearers. If forces are monadic properties, they must be intrinsic to single bodies. If they are relations, they must be intrinsic to the set or sum of their *relata*.

2.1. Forces are not categorical monadic properties

According to the first kind of force monadism, advocated by D. M. Armstrong (1997: 76sqq.), forces are *categorical* monadic properties of force-exerting bodies. This view relies on a more general monadism about vectors, including forces but also motions, velocities or accelerations. Following Tooley (1988), Robinson (1989) and Bigelow & Pargetter (1989, 1990a), Armstrong claims that we have to take at face value the attribution of physical vectors to bodies at instants. Such vectors are not relations between bodies but monadic properties of single bodies. Unfortunately the arguments in favour of this view focus on motion and velocity vectors rather than on force vectors. If they were to succeed, some additional argument would be needed in order to extend this conclusion to forces vectors. I shall grant, for the sake of the argument, that such a generalisation from kinematic vectors to force vectors is possible. I first present vector monadism and then raise an objection to it: vector monadism cannot account for an essential feature of vectors, their direction.

The relational view of kinematic vectors (to which I subscribe) states that motion and velocity are a matter of spatiotemporal *relations* between the different positions that a body (or parts of a body) occupies at different times. Motion is a change of position. Velocity is the rate of this change. Acceleration is the rate of change of this rate of change. This relational view is the most standard one. Bigelow and Pargetter (1989, 1990a) attribute it to Ockham and its followers. It was adopted by Newton, and was clearly stated by Russell (1992/1903). By contrast, the monadist view of kinematic vectors denies that motion and velocity are essentially defined or constituted by facts concerning positions at times. According to it, velocity and motion are *intrinsic* or *monadic* characteristics that a body has at an instant, whatever its past or future positions. For the monadist, the notion of "instantaneous velocity" is to be understood literally: it is a velocity that a body has at a time, that is essentially independent of the position it has occupied or will occupied at other times, however near they are. Two confusions are to be avoided here.

First, it is important not to confuse this strong notion of instantaneous velocity, with the more usual one, used in kinematics, which refers to the limit of the average velocity when the variation of time tends towards zero. This weak notion of instantaneous velocity is compatible with the standard view of motion and velocity: it still defines velocity by reference to latter positions of the body, although very near ones. By contrast, what the upholders of intrinsic states of velocity have in mind is a strong and absolute notion of instantaneous velocity that does not make any reference to neighbouring times.

Second, the debate between relationists and monadists concerning kinematic properties is quite distinct from the debate between relationists and absolutists concerning space. Indeed, Newton is a relationist about motion and an absolutist about space. He defines motion as the change of absolute position in space. True, the admission of absolute space introduces a distinction between apparent and absolute motion (that is, motion relative to other bodies, or motion relative to space). But we must distinguish between absolute motion and intrinsic one. Absolute motion is still a relation between a body and the absolute space. It is non-relative only in the sense of being natural, non-conventional or non-arbitrary: it does not depend on a free decision concerning the frame of reference. Intrinsic motion, on the other hand, is a property that an object can have even when it is not moving relatively to absolute space.

The monadist about kinematic vectors who does not deny relations altogether has a richer ontology than the relationist: he does not deny, of course, that they are actual changes of position, namely relational motions and accelerations. But he claims that there are *also* intrinsic motions that cannot be construed as relational motions. How then are intrinsic states of motion and/or velocity to be connected with actual changes of positions during time—extrinsic motions? The answer of the vector monadist is that the connection between changes of position on the one hand, and motion or velocity on the other, is not one of constitution or definition, but one of explanation. Vector velocity, far from being constituted by changes of position, *explains* them (Bigelow and Pargetter, 1990a: 65-66; Tooley, 1988: 238). If an object changes position, it is *because* it has instantaneous velocities at each time.

The burden of proof clearly lies with the vector monadist. First, because its ontology is richer than the relationist's one. Second, because the additional entities that monadists introduce (instantaneous motions, velocities, accelerations) are *prima facie* strange. Since intrinsic and extrinsic velocities stand in a relation of physical explanation, it is possible that the ones occur without the others. For instance, it ought to be possible that an entity can possess an intrinsic velocity at each instant of its existence without ever moving. This sounds strange. Vector monadists, who introduce new and strange entities, owe us some arguments.

Rather than reviewing these arguments, I shall raise a general difficulty for vector monadism: it cannot account for the direction of vectors.

Vectors have both a magnitude and a direction. Let us assume that the magnitude of vectors can be accounted for in a monadist framework. That is, let us assume that quantities are monadic properties. Can direction be a monadic property, intrinsic to single bodies? Here is first a simple form of the argument for a negative answer: nothing is directed *tout court*; direction is always a direction *toward* something else. When we think of a single arrow, the reason why it is directed is that it points towards some other entity (a region of absolute space, another body…) other than itself. The entity towards which the arrow is pointing is not a constituent of that arrow. Therefore direction is not intrinsic to the directed entity: it requires at least one other entity. This line of argument can be reinforced if we try to understand more precisely what the notion of direction of vectors amounts to.

At first sight, direction appears to be *one* single feature of vectors, beside their magnitude. Indeed, it can be represented by one number: the most straightforward way to represent a vector in a two-dimensionnal plane is to use a value for its magnitude, and another value for its direction. The numerical value that represents the direction of the vector is the value of its angle from the abscissa, anticlockwise. But this is misleading: embed in fact *two* distinct features of forces and other vectors, which can be called their *orientation* and their *sense*. When we draw a vector, the length of the line represents the scalar magnitude of the vector. The inclination of the line in space (its angle relatively to the abscissa) represents its orientation. The arrow on the line represents its sense. The important point is that once we have an oriented line (the line of action, for forces), we still need some information in order to know in what sense to put the arrowhead, which represent the sense of the vector. The very same oriented line can be travelled over in two ways. My argument against vector monadism is that none of these two features, orientation and sense, can be intrinsic to a single body.

Vectors		
Magnitude	Direction	
	Orientation	Sense

Concerning orientation, the monadist faces two problems. First, in order to draw a line, we need two points. How are we to draw the line of action of the force exerted by a body if we have only this single body? Orientation seems to be essentially a spatial *relation*. Note that orientation is not necessarily a spatial relation to other bodies. Orientation may also be a relation to a different part of the same body (the orientation of a line drawn on a single figure), to absolute space (the orientation of a single line), to another absolute space behind the absolute space we are considering (the orientation of the space itself, if there is one)... I suspect that the intuitions concerning “intrinsic orientation” fail to consider these other relations. Accordingly, nothing can change its orientation without changing its relation to anything: it is indeed hard to conceive of a body rotating without changing its spatial relations to anything else (be it another body, the absolute space, an observer, or whatever other background one is tempted to hold fixed in order make sense of the rotation).

Second, even if the notion of an intrinsic orientation were meaningful, a specific problem would arise for force vectors: one would still have to explain how these intrinsically oriented forces might reach other bodies: the line of action of a force has to extend spatially *beyond* the body that exerts the force. Otherwise, forces would flounder around, being incapable of any influence on other bodies. But it seems that something that is (partly) outside a body cannot be (fully) intrinsic to it. Then, how can a purely intrinsic force reach other bodies? (An intrinsic force could at best influence endogenously the motion of the single body that exemplifies it, but would not be able to influence directly the motion of any other body outside it).

Concerning sense, the main difficulty is that the notion of sense is closely tied to the notion of asymmetry. Saying that a force has a sense, amounts to saying that it is exerted by *a* on *b*, but not by *b* on *a*. But asymmetry is a property of *relations*. Claiming that a monadic property is asymmetric is meaningless. If the monadist about vectors is to maintain that forces exert in a sense but not in the opposite one, he has to give us a notion of sense that is independent from the notion of asymmetry. The only suggestions I can think of are (i) to equate monadic sense with dispositional or intentional directedness (I. Johansson, 2001; G. Molnar, 2003). I shall reject this suggestion latter, when discussing the hypothesis that forces are monadic dispositions. (ii) to equate monadic sense with some kind of chiral property such as handedness. But first, the intrinsicness of chiral properties is a matter of important controversy, and second it is not clear how chirality can capture the asymmetry essential to the concept of sense.

A second problem concerning the intrinsicality of sense is that in some cases the fact that a force has a given sense (say, that it is attractive and not repulsive) depends on other bodies. Think of the force that an electron exerts on other particles. Since its charge is negative, it will exert an attractive force on the positron coming into its vicinity. But it will exert a repulsive force on another electron entering its field. So apparently the force exerted by a particle depends on the nature of the other particles around. It is not intrinsic to one single particle.

Surprisingly, both Robinson (1989: 408) and Armstrong (1997: 79) recognise that the direction of vectors constitutes an important and unsolved problem for their monadist view. Since direction is essential to vectors, this seems to me to be a sufficient reason for rejecting vector monadism.

2.2. Forces are not dispositional monadic properties

So vectors cannot be categorical monadic properties. Could it be that they are dispositional monadic properties? According to the dispositionalist, (most or all) properties are actual powers essentially directed toward a possibly non-actual manifestation. Molnar calls this essential feature of monadic powers or dispositions their *directedness* (2003, 60sqq). *Prima facie*, the dispositionalist is in a far better position than the categoricalist: he can explain the *directionality* of vectors by resorting to the *directedness* of powers —the fact that powers essentially point to their manifestations. Dispositionalism seems to fit pretty well with the vectorial nature of forces.

Somewhat surprisingly however, many dispositionalists such as Molnar, Ellis or Cartwright, though they emphasize the role of forces in ontology, do not explicitly claim that forces are dispositions. Rather, they consider forces as *manifestations* of intrinsic powers. They do not seem to address the issue whether forces themselves are categorical or dispositional. Presumably, the hypothesis should be the following: forces are monadic powers whose manifestations are accelerations. They are dispositions to accelerate. Their vectorial directionality is explained by their dispositional directedness.

Despite its intuitive appeal, there are I think two difficulties for this suggestion. First, if we are to explain monadic direction with the help of power directedness, we have to be sure that directedness is less mysterious that monadic direction. We may doubt that this is the case. Thus, Armstrong claims that if powers are properties pointing to some non-existing entities, directedness leads to a Meinongian metaphysics, which is no less mysterious.

Nevertheless, we do not need to reject the whole of dispositionalism in order to show that forces cannot be monadic powers. Indeed, *the very analogy between vector's directionality and power's directedness is misleading*. We've seen that the direction of forces is in fact a complex property that includes their orientation and their sense. None of them fits with the directedness of powers.

Concerning orientation, we've seen that it requires a spatial relation between the body that exerts the force and some point outside it. Now, it is true that with the directedness we have two entities: the disposition itself and its possible manifestation. But these two entities clearly do not stand in a *spatial* relation to each other. First, when the manifestation is not actual, there is presumably not any genuine relation at all, since one of the terms of the putative relation does not exist. Second, even when the manifestation occurs, it makes no sense to ask about the distance between the breaking of the glass and its fragility. Likewise, it is vain to try to draw a line between a force-power and an acceleration, or to say that the acceleration is above or under the force-power. It follows that the orientation of a vector has nothing to do with the directedness of a power.

Concerning sense, the dispositionalist may think that, contrary to the categoricalist, he has here a card to play: he may propose to reduce the asymmetry of vectors to the asymmetry of the relation between a power and its manifestation: the acceleration is a manifestation of the force but the force is not the manifestation of the acceleration. But this would be obviously fallacious: we are looking for an asymmetry inside the force itself, that is, inside the force-power. More exactly, we want an asymmetry in the very exertion of the force, not in its relation to its kinematic manifestation (as the static examples given in the first part show, exertion and kinematic manifestation of a force are very different things). Clearly, the proposed asymmetry is not of the right kind: once you know that the manifestation of a force is acceleration, you still do not know in what sense to put the arrow on the force.

A better solution for the dispositionalist would be to argue that the asymmetry of a force-power is inherited from the asymmetry of its manifested acceleration. Once you know that the manifestation of a force is a determinate acceleration, you know in what sense to put the arrow on the force: namely, the sense in which the body would accelerate. But this would be to put the cart before the horse: powers are supposed to explain or ground their manifestation, not the contrary. If the force-power has no direction by itself, why should its motion- or acceleration-manifestation be of such and such direction? The direction of the kinematic manifestations of forces would be entirely unpredictable. (From an epistemological point of view though, it might still be true that the sense of forces is accessed through the sense of their kinematic manifestations). It follows that neither the orientation, nor the sense of forces can be explained by the directedness of powers.

In conclusion, the directionality of vectors cannot be accounted for in any monadist framework. Forces are not monadic properties, categorical or dispositional. They must be relations.

3. Forces are symmetrical relations: Newton's Third Law

3.1. The thesis defended

So far, it has been argued that forces are real dynamical relations. I shall now argue that they are *symmetrical* relations. Even if most relationalists about forces hold them to be non-symmetrical relations, some of them consider forces as symmetrical relations: J.C.

Maxwell (1877: 26), P. Foulkes (1951: 176, 1952), M. Bunge (1959: 153), C. Hellingman (1989), A. Newman (1992: 151) and R. Ingthorsson (2002). Physicists also appear to assume that forces are symmetrical relations when they use the terms 'forces' and 'interaction' interchangeably.

The argument I shall present in favour of the view that forces are symmetrical relations relies on Newton's Third Law (to recall: *To any action there is always an opposite and equal reaction; in other words, the actions of two bodies upon each other are always equal and always opposite in direction*.). This law is usually acknowledged to be without exception in the macroscopic and mesoscopic world. It holds not only in static cases but also during accelerations: the force that a tow-horse exerts on a barge has the same magnitude as the opposite force that the barge exerts on the horse. These "two" forces are inside the system: trying to generate motion from them is as vain as blowing into the sail of the boat we are in. Accelerations are never to be explained by differences between action and reaction (since there are no such differences), but always by differences between forces belonging to distinct action-reaction pairs. Action and reaction are forces that apply to different objects. If we want to explain the acceleration of an object, we have to sum the forces that apply on that object. The reason why the barge accelerates is that the pulling force that the horse exerts on the barge is greater that the opposite friction force that the water exerts on it.

If we agree that forces are relations, the most literal reading of the Third Law, however, is not that they are symmetrical relations. Rather, it is that forces are asymmetrical relations that come in action-reaction pairs. Each time a body *a* exerts a force on another body *b*, *b* exerts a *second* opposite force on *a*. There are two forces crossing between *a* and *b*. Newton's Third Law appears to refer to pairs of asymmetrical forces. Now, is this literal reading the one that we should accept ontologically? The only thing that distinguishes the two forces of an action reaction pair is their arrow, that is, their sense. They share all their other properties: they always come together, they are determinates which fall under the same determinable, they relate the same entities, they have the same line of action (or orientation), the same magnitude and the same spatial location. Therefore, to ask whether we should read the Third Law literally amounts to asking: ontologically, should we take the sense of forces seriously? There are I think three reasons to answer negatively.

First, it is not clear how we can distinguish action and reaction by observation. If we put a dynamometer between the two bodies, is it registering the intensity of the first force or of the second one? If we put our finger between them, do we feel the pressure of *a* on *b*, or the pressure of *b* on *a*?

The second argument in favour of the symmetry of forces relies on Ockhamist considerations. The view according to which forces are symmetrical is more economical: in order to account for an interaction between two bodies *a* and *b*, the upholder of asymmetrical forces needs then *four* entities: *a*, *b*, the force that *a* exerts on *b* and the reciprocal force that *b* exerts on *a*. There would be two crossing asymmetrical forces between the bodies. On the other hand, if we adopt symmetrical forces, we need only three entities: *a*, *b*, and the force between them.

The third reason in favour of symmetrical forces I put forward is an argument by analogy. Like force, the distance from a body *a* to a body *b* can be represented by a distance vector (although distance-vectors are more rare than displacement ones, they are quite respectable vectors). We can then express the following "law":

> *To any distance there is always an opposite and equal distance; in other words, the distances from one body to the other are always equal and always opposite in direction.*

"Distance" being here understood as a vector, this is undoubtedly true. But does it follow that there are two asymmetrical distances relations between *a* and *b,* namely, the distance from *a* to *b* and the distance from *b* to *a*? This would be highly counter-intuitive. The truth is rather that there is only one symmetrical distance between *a* and *b*. Asymmetry here is only introduced in the picture as a convenient means to focus on a single system, taking the other one as the referential. Asymmetry is a feature of the vectorial representation of distances, not of distances themselves. Likewise, consider the two sentences:

(1) "Fabrice is five meters from Kevin"

(2) "Kevin is five meters from Fabrice"

(1) and (2) are certainly two ways of referring to a same fact, namely, that Fabrice and Kevin are five meters apart. That there are different sentences here and that each sentence appears to present distance in an "arrowed" way does not indicate a genuine difference in the fact referred to by those sentences.

If true, given the strong analogy between the distance's law and Newton's Third Law, there is no reason to consider the asymmetry of forces-vector, but not the asymmetry of distance vectors, to be of ontological importance. Likewise, the asymmetry of forces is only a feature of their vectorial representations, but not of forces themselves. Forces are symmetrical relations, which may be referred to through asymmetrical representations, namely vectors.

Note that stressing the analogy between forces and distances as regards symmetry does not undermine their key difference, pointed out in the introduction: distances are symmetrical *spatial* relations, while force are symmetrical *dynamical* relations irreducible to mere spatial relations.

Those three reasons (observability, economy, analogy) suggests the following more general metaphysical principle:

> *(SR) For any two particulars, if their exemplifying an instance of what appears to be an asymmetrical relation necessitates their exemplifying another instance of that very same relation but in opposite sense, then what they exemplify is in fact one and the same instance of a symmetrical relation.*
> *For any dyadic relation, if each*

A problem remains: if forces are symmetrical relations how are we to account for the distinction between attractive and repulsive forces, between tensions and pressures? The usual way of capturing these distinctions is by using the notion of opposite directions: attractive and repulsive forces are forces that have the same module and line of action and the same point of application, but have opposite directions. If F*ab* means "the force exerted on *a* by *b*", and if we focus on the body *a*, an *attractive* force of *b* on *a* will be represented as follows:

On the opposite, a *repulsive* force exerted on *a* by *b* is represented thus, still focusing on *a:*

The key feature that allows us to distinguish between attraction and repulsion, or tension and pressure is, then, the direction of forces, and more especially their sense. How are we to secure these distinctions if the sense of forces is given up?

My proposal is to introduce a new feature of symmetrical forces, namely their *polarity*. Symmetrical forces are either repulsive, or attractive. This is a primitive feature of forces that cannot be reduced to any other. Polarity is compatible with symmetry. The repulsive forces (such as pressures) tend to move away the objects they relate, while the attractive forces (such as tensions) tend to bring them closer. We should think of forces in the following way:

Attractive forces:

Repulsive forces:

On the present view, attraction and repulsion are two determinates of the determinable relation of force. Forces have at least two dimensions of variations: intensity (which has infinitely many values) on the one hand, and attraction-repulsion (which has only two values) on the other.That view holds only for component forces. What about resultant ones?

There are two reasons why the reality of component forces so conceived threatens the reality of resultant ones, conceived as irreducible to Boolean combinations or mereological sums of component forces. First, it is commonly agreed that resultant forces and component ones, if distinct, cannot be both real on pain of causal overdetermination. The acceleration of a body would be completely caused one first time by the component forces acting on it, and one second time by the resultant force acting on it.

The second challenge to the *sui generis* reality of resultant forces goes as follows. Forces are relations between bodies. But very often, the resultant forces do not relate different bodies. When two horses, located on each side of a canal, are pulling a barge, the resultant force on the barge, if it were real, should relate the barge with some point located in the air above the canal. But clearly that point is not pulling the barge, nor would any dynamometer placed between it and the barge indicate any intensity. There is no resultant force there to be found, over and above the component ones.

What are resultant forces then? Contrary to Cartwright (1983), and in accordance with Creary (1981), I think resultant forces are mathematical fictions. A resultant force is only a mathematical vector, that result from the addition of the vectorial representations of component forces. One may pretend that this resultant vector is representing a genuine force and say that a body acted on by many component forces, will behave as if it were acted on by one single fictive resultant force. But this is only a useful fiction. What are added are not the component forces, but their vectorial representations. The forces themselves, when considered together (through mereological summation or Boolean combination), do not yield new forces, but sums, sets or conjonctions of forces. Such sums or sets are not themselves forces (it is not clear they are relations, and even if they are, they are clearly not symmetrical).

If Newtonians component forces are symmetrical relations, how is it that Newton and many followers appear to conceive them as asymmetrical? One first reason may be that they tend to confuse the property of the representations of forces (vectors) with the property of forces themselves. The second possible reason for the common belief that forces are asymmetrical relations is that Newton, like many of his followers, conceived of forces in terms of muscular effort. But effort implies an asymmetric relation between the active term (the voluntary subject) and the passive one (the resisting object). That is, the presence of a conation introduces an asymmetry between the exerter and the exerted upon. Conceiving forces on the basis of voluntary effort leads to an anthropomorphic notion of forces, as many opponents of forces have rightly pointed out since Hume: conations (intentions, volitions, tryings…) being essential to effort and being also mental episodes, any conception of physical forces in terms of effort tends to endow force-exerting bodies with the power of willing or intending. This is one important reason to prefer the sense of touch (cutaneous pressure perception) to the sense of effort in the epistemology of forces.

3.2. Objections answered

Five objections can be raised against the view that Newtonian forces are symmetrical relations.

(i) First, this view appears to undermine the argument of the second part, according to which forces are relations rather than monadic properties. The argument was that the only way to account for the direction of forces is to conceive them as relations. Now if forces are symmetrical the argument collapses, or so it seems. This worry is misguided for two reasons. First, I claimed that the direction of vector should be analysed in terms of orientation and sense. Now, if forces are symmetrical they have indeed no sense, but they still have orientation. The argument against the intrinsicness of orientation still applies to symmetrical forces. Second, symmetry (as well as asymmetry) is still a property of relations. Forces could not be symmetrical if they were monadic properties of single bodies.

One thing that I have *not* shown, however, is that forces cannot be monadic properties of pairs or sums of bodies. To use Russell's terminology, I have objected to force-monadism, but not to force-monism. Monadism reduces each relation to monadic properties of each relata. Monism reduces each relation to a single monadic property of the two relata taken together. The main objection to monism is its inability to deal with non-symmetrical relations. If forces are indeed symmetrical relations, they may be reduced to monadic properties of sums of bodies. I have nothing to object to such an option. My only point is that forces cannot be monadic properties of single bodies.

(ii) Second, one may object that the thesis of the symmetry of forces leads to the rejection of the whole vectorial calculus of forces. If forces are not single but double arrows, then vectorial representation of forces becomes seriously misleading and should therefore be abandoned in favour of a more straightforward representation of forces, which would reflect their symmetry.

However, even though the present proposal is indeed revisionary to the extent it conceives of forces as having a magnitude and orientation, but not sense, it is not committed to the rejection of vectorial calculus about forces. Even if force-vectors might be misleading representation of reality, to the extent that they ascribe sense to forces, they are still very useful. We should endorse *instrumentalism* about force-vectors, at least for their "sense" constituent. The reason why vectors are convenient representations lies in the fact that force vectors are monadic reductions or derelativisation of true relations, as argued by Newman (1992: 151, 197): they are "one-sided way of looking at a force relation, and it is the force relation that has the claim to being an element of reality". The monadic property of "being pressed upon by B" is an abundant, non-natural one, which is only a linguistic way to refer to the sparse or natural pressure relation that holds between A and B. The two sentences "A has the property of being pressed upon by B" and "B has the property of being pressed upon by A" have the same truthmaker, the fact that A and B enter in a pressure relation. Monadic reductions shouldn't be taken literally, as far as metaphysics is concerned. But they are useful because they allow us to focus on a single body in a net of interacting bodies.

(iii) The third objection to thesis of the symmetry of forces argues that we can express analogues of Newton's Third Law not only with symmetrical relations like distances, but also with relations that are clearly asymmetric. From the relation *is heavier than* we can construe the following "law":

> *To any "heavier than" relation between two bodies there is always an opposite and equal "lighter than" relation between these bodies; in other words, the differences of weight between two bodies have always the same absolute value and are always opposite in sign.*

We presumably do not want to conclude nevertheless that instances of "heavier than" and "lighter than" should be fused into single symmetrical relation. So principle (SR) must be false. Therefore, if *F* stands for "exerts a force on", the fact that *aFb* and *bFa* imply each other, according to Newton's Third Law, should not suggest that the two asymmetrical forces should be fused together into one symmetrical relation. The only conclusion that we are entitled to draw from Newton's Third Law is that all forces have a converse, not that all forces are symmetrical. So the objection claims.

The mistake in that objection is the following. The proposed principle (SR) makes clear that the two (apparent) instances of the asymmetrical relation must be of *opposite* senses. But it is not the case that $a>b$ and $b<a$ are of opposite senses. The sense of a relation can be written out in two different ways. Either we use the place of the arguments: the relation R(x, y) has not the same sense as the relation R(y, x). Or we use the notation for converse relations: R (x, y) has not the same sense as R^{-1} (x, y). There are then two different conventions in order to invert the sense of the relation R (x, y): R (y, x) or R^{-1} (x, y). Now, if we use *both* notational devices *at once*, then we come back, so to speak, to the first relation. The following formula is a logical truth:

$$(A) \qquad (x)(y)\ [R\ (x, y) \quad R^{-1}\ (y, x)]$$

Likewise, in ordinary language the propositions "John loves Mary" and "Mary is loved by John" are equivalent. These two propositions have the same truthmaker: they are just two ways of denoting a same relational fact. We have just changed the place of the arguments (Mary and John) *and* inverted the expression of the relation, here by using passive voice. It should be clear now that this is precisely what happens when we pass from "*a* is heavier than *b*" to "*b* is lighter than *a*". Although the linguistic presentation has changed, the sense of the represented relational fact is the same. These two expressions do not refer to different relational facts of opposite sense. So the proposed principle (SR) simply does not apply to this kind of expressions: it does not imply that non-symmetrical relations are indeed symmetrical ones.

By contrast, it is clear from Newton's Third Law that action and reaction are of *opposite* sense. The law does not state only that if the horse pulls the barge, then the barge is pulled by the horse (if so, the law would be completely trivial). It states that if the horse pulls the barge, then the barge pulls the horse. So the law should be written, logically, as follows:

$$(B) \qquad (x)(y)\ [F(x, y) \quad F(y, x)]$$

Unlike (A), (B) is not a logical truth.

(iv) The fourth objection question argues that the Third Law only holds for some forces, namely central ones, but is not necessarily true of non-central forces. Central forces are forces that acts along the line joining the two bodies between which they hold. Non-central force, such as the Lorentz magnetic force that two charges moving at right angles to each other produce on each other, are neither co-linear nor of opposite direction, so do not satisfy the Third Law.

A first way to accommodate the apparent exceptions to the Third Law is to try to dismiss them. The most standard strategy to do so, that can be only roughly sketched here, is to claim that not only the charges, but also the magnetic fields carry momentum. This allows us to say that the *relata* of forces in those cases are not the two particles, but each particle and the magnetic field. In that case, the Third Law still holds. As soon as the momentum of the particles and of the magnetic field are taken into consideration, the Third Law still holds. Such an answer however is controversial and the way to reconcile Newton's Third Law with non-central forces is a matter of on-going debates.

A more cautious way to deal that difficulty, which shall be endorsed here *faute de mieux*, is to restrict the scope of the present thesis, by claiming that only forces that satisfy Newton's Third Law, namely central forces, are symmetrical. The price to pay is that the concept of force dislocates, some forces being symmetrical, some others not. The term force does not pick out a natural kind, but a disjunction of natural kinds. This is a bullet we should bite. One may fear that such a view paves the way for the standard reading of the Third Law (i. e. the view that there are two crossing forces between interacting bodies). The standard reading appears to have a comparative advantage for it can avoid dislocating the concept of forces: it will simply hold that all forces are asymmetrical relations, only some of them satisfying the Third Law. However, that view has its own drawbacks. It has to claim that entities that are of a very same natural kind do not all fall under the same laws, a problem that the disjunctive view avoids.

(v) The fifth objection claims that even if Newton's Third Law is indeed nomologically necessary, the view that forces are symmetrical relations requires more: for forces to be symmetrical, Newton's Third Law would have to be conceptually or metaphysically necessary, which it is not. Newton clearly considered his Third Law as a metaphysically contingent, empirically testable one:

> I have tested this with a lodestone and iron. If these are placed in separate vessels that touch each other and float side by side in still water, neither one will drive the other forward, but because of the equality of the attraction in both directions they will sustain their mutual endeavours toward each other, and at last, having attained equilibrium, they will be at rest. (1999/1687: 428).

Since we can confront the Third Law with observation, it seems that it could have been the case that action and reaction were not equal. The thesis of the symmetry of forces appears to make it a metaphysically necessary truth when it is a metaphysically contingent one. There are two possible attitudes for the upholder of symmetrical forces here.

First, he can bite the bullet and accept that Newton's Third Law is only a matter of nomological necessity. As a result, he will have to claim that forces are symmetrical only in Newtonian worlds.

A second answer, which I favour, is to claim that Newton's Third Law states in fact a metaphysical necessity, and to argue the conceivability of its violations is indeed a modal mistake. The impression we have that Newton's Third Law could be violated may be just wrong. Consider the law according to which "The distance from *a* to *b* equals the distance from *b* to *a*". Plausibly, this law is metaphysically necessary. Nevertheless one can conceive of tests in which it would fail to be confirmed. Take your meter rule, put the zero on *a* and read the distance from *b*. Then return it, put the zero on *b* and read the distance from *a*. If the two distances are the same, the law is verified (or non-falsified). But suppose that the two distances read on the rule are different. Would we say that the law according to which distances are symmetrical has been empirically falsified? Certainly not: we would rather assume or postulate some hidden interfering factors. We will assume, for instance, that *a* and *b* have invisibly moved relatively to each other, or that the meter rule somehow changed of length. Now, the same holds with Newton's Third Law. How are we to test it? If the dynamometer does not indicate the same intensity between *a* and *b* and between *b* and *a*, we will assume, for instance, that a variation of the force between *a* and *b* occurred. Is Newton's experiment more crucial? Imagine the two vessels had described a continuously accelerated motion. Here again, we have the alternative of rejecting the Third Law, or postulating another force external to the system of the two vessels. Most physicists would be strongly inclined toward the second option.

4. Forces are not causal relations

It has been argued that forces are real symmetrical relations. I shall now argue that they are not causal relations. To say that forces are non-causal relations, or that they are not causal relations is ambiguous. It can mean either that forces have no causal powers, which amounts to say that they cannot be causes; or it can mean that forces are not species of causal relations, that is, that they are not themselves a sub-type of the relation of causality or causation. When I say that forces are not causal relations, this is only to be understood in this second sense: forces are not species of causation. I do not intend to deny that forces have causal powers (= can be causes). *Au contraire*.

Hume endorses those two theses: (1) forces are species of singular causation. (2) There is no singular causation. Most realists about forces as relations disagree with him on the second thesis because they agree with him on the first one. They consider themselves to be defending the existence of singular causal relations. Thus Creary (1981: 152), Strawson (1987), Bigelow, Ellis, Pargetter (1988), Fales (1990), Newman (1992), or Johansson (2004:177 sqq.) claim that forces are species of causal relations. Some even go so far as to identify every type of causation with forces (Bigelow and Pargetter, 1990). True, forces, as dynamical relations, are clearly relations that contradict the thesis of humean supervenience: they are relations that are not spatio-temporally reducible. But it is a mistake to jump from the premises that forces are non-humean relations to the conclusion that they are singular causal relations. I believe that forces and causation are two different things. This is not to say that forces have no causal powers. Obviously they have: they make a difference in the motions of physical bodies. But the same is true of distances, and we do not want to claim that distances are species of causal relations. Forces, rather, are *relata* of causal relations. They are causes and effects. But they are not causations. Why?

There are two versions of the view that forces are causal relations. The strong one, endorsed by Bigelow & Pargetter (1990) has it that all forces are causal relations and that all causal relations are forces. The weak one, which is more widespread, claims that all forces are causal relations but that some causal relations are not forces.

Let us start with the strong view. There are two objections to it. First, forces are symmetrical relations, while causation is traditionally understood as having a direction or sense: one distinguishes causes from effects. This direction of causation is often connected with the claim that causes precede their effects (if there is such precedence, one can reduce the direction of causation to the direction of time, or reduce the direction of time to the direction of causation). But it needs not be the case: even if all causation is simultaneous, it may still have a direction or sense: if flows from the cause to the effect, and not the reverse.

Because of Newton’s Third Law, there is no way of distinguishing, when two bodies press against each other, which one is the cause and which is the effect. So forces and causal relations cannot be identical. One could bite the bullet and claim that the direction or sense of causation is a feature that should be given up. But this amounts to an important revision of our ordinary concept of causation, since it asks us to admit causal relations without a distinction between causes and effects. I take it that *ceteris paribus*, we should prefer the view that minimizes the revision of our commonsense beliefs: therefore, the view according to which causation is a symmetrical relation should be adopted only *faute de mieux*.

A second objection to the strong view goes as follows. Nothing positive has been said so far about the relation between forces and accelerations, except that it is not identity. The most intuitive and common account of this relation is that forces *cause* accelerations. Since Newton at least, forces are said to *cause*, to *produce*, or to *generate* accelerations or quantity of motion. It is natural to say, for instance, that the pressure of the water caused the collapse of the dam, or that the attraction of the moon causes the tides. Besides, contrary to forces, the relation between forces and accelerations has a sense: the collapses of the dam did not cause the pressure of the water. All this suggests that it may well be a causal relation. I shall therefore assume that Newton's Second Law is a causal law. Such an assumption is completely neutral regarding the very nature of the causal relation: maybe it is a primitive metaphysical relation, maybe it can be analysed in terms of regularity, counterfactual dependence, existential dependence, powers, intervention, transference, conserved quantity… The only point here is that is that the relation between forces and accelerations must be a causal one, however we construe causality.

Now, it is clear that this causal connexion is not itself a force: forces do not themselves exert forces on accelerations. (Forces are not force exerter. And nothing can press on an acceleration. The *relata* of the forces relations are bodies.) Then some causal relations are not forces. The strong view is false.

Now consider the weak view according to which forces are only a type of causal relations *among others*. Such a view can dispose of the argument from the direction of causation in the following way. It may be that *some* types of causal relations have a direction, while *some other* types (namely, forces) have no direction. The type "causal relation" would be a non-symmetrical relation, with certain asymmetrical sub-types and other symmetrical ones. If so, the argument from symmetry is only a straightforward argument against the strong view that *all* causal relations are forces. By contrast, the view that forces are one type of causal relation among others only asks for a limited revision of our ordinary view about causation. In some cases, there is no cause-effect distinction, no causal direction. Such a modest revision may seem acceptable. In the same way, the weak view can dismiss the second objection to the strong view by claiming that forces on the one hand and the causal relations between forces and accelerations on the other, are causal relations of different types. But because it multiplies the different species of causation, the weak view is open to the following general objection:

(i) Causation is a natural kind.

(ii) If forces were causal relations, they would be strongly disanalogous to the others types of causal relations.

Forces are not causal relations.

Any realist about causality should adopt the first premise: causal relations must have something in common, they must resemble in some way, independently of our perception or our thinking about them. It is because all causal relations share something that they fall under the concept of causality, not the reverse. The second premise needs to be argued for. In order to distinguish the relations between forces and accelerations from forces, let us call it *production* (since forces are often said to *produce* accelerations). There are at least six important disanalogies between these two types of alleged causal relations, forces and productions.

(i) Forces are symmetrical relations while productions are asymmetrical ones (If *a* exerts a force on *b*, *b* exerts a force on *a*. But if a force *F* produces an acceleration *a*, *a* does not produces *F*).

(ii) The *relata* of forces are bodies (which may in turn be analysed in terms of fields, masses, locations…) while the *relata* of production are relations between bodies (forces) and changes in the relations between bodies (accelerations).

(iii) Consequently, forces are first-order relations while production is a second-order relation, since one of its *relata* at least is a relation (a force).

(iv) Production is a necessary connection in the sense that one of its terms (resultant forces) *necessitates* the other (accelerations) — no matter how one construe necessitation (in terms of logical necessity, metaphysical necessity, regularity…). Given one term, it is necessary that the other occurs. Forces, one the other hand, *are not relation of necessitation*: the bodies that enter in a force relation do not necessitate each other.

(v) Forces have causal powers: when not counteracted by other forces, they cause accelerations (they keep those causal powers even when they are counteracted). But it is not clear that the very production relation between forces and accelerations has itself any causal power. Certainly, the production relation confers causal powers to its *relata* (forces are causes in virtue of producing accelerations), but plausibly it does not itself possess causal powers (one should not be confused by the fact that production is a necessitation relation: this does not mean that production itself necessitates, but only that one of its *terms* necessitates the other). My argument for that claim is that any realist about causation should admit that some causal relations at least have no causal power (=cannot be causes), on pain of both regress and mystery. Let us start with the regress: if every causal relation had causal power, then every causal relation would have not only causes and effects as its *relata*, but would also be itself the *relatum* of another possibly exemplified causal relation, which would in turn be the *relatum* of a third possibly exemplified causal relation, etc. Now for the mystery: it is very difficult to see (i) what new species of causal relation would relate production to its effects and (ii) what new species of effect production would then bring about. Therefore, the causal relation between forces and accelerations seems to be the right place to stop in order to avoid the causal regress: it is a causal relation that has no causal powers, that is not itself a cause. To be clear: there are two senses in which a relation can be said to be "causal": either we mean that *it is a possible cause*, which amounts to saying that it has causal powers; or we mean that *it is a relation of causation*. I am arguing that forces are causal in the first sense, but not in the second, while production is causal in the second sense, but not in the first. If, on the opposite, one were to maintain that forces are also causal relations in the second sense (that forces are causations), then one would have to say that some types of causation have causal powers (forces) while some other (production) are causally impotent.

(vi) This leads to a sixth —maybe more controversial— disanology, between forces and production. Forces are material relations, while production is a formal relation (like resemblance, identity, parthood, logical consequence, existential dependence, instantiation in Armstrong's theory of states of affairs, compresence…): though production is a real relation, it is not a new element in reality, in addition to its *relata*. Production is an internal relation that supervenes on its terms and comes ontologically for free, unlike forces. Here is an argument for that claim. According to a common metaphysical principle, dubbed "The Eleatic Principle" (Oddie, 1982), or "Alexander's Dictum" (Kim, 1993: 348sqq):

> Everything that is real (as Frege says, "wirklich") possesses causal powers (can "wirken")

If this is true, the production relation, since it has no causal power, cannot be real, unlike forces. Then the difference between forces and the relation between forces and acceleration becomes crucial: forces are real, while the production relation is not real. Such a conclusion would definitely secure the view that forces and production are strongly distinct relations. But it is certainly too hasty. The fact that the Eleatic principle entails anti-realism about certain causal relations at least (here, production) can as well be considered as a good reason to reject the principle itself. The Eleatic Principle should certainly be qualified. A first proposal is due to D. M. Armstrong (1997: 41):

> Everything that exists *makes a difference* to the causal powers of something.

One of the advantages of this new version, according to Armstrong, is to allow for the reality of causal relations, which have no causal power (=which cannot themselves be causes). Such a revised principle, nevertheless, faces two problems. First, it implies that epiphenomenal properties, which are effects but cannot be causes, are real: they make a difference to the causal powers of their cause. This is a problem since the Eleatic Principle is often used as an argument against epiphenomenal properties. Secondly, this revised principle contains a hidden disjunction: everything that exists either *has* causal powers or *confers* causal powers on other entities. Nothing ensures that the two disjuncts have anything in common. If so, Armstrong's revised principle is *ad hoc*. A better revision of the Eleatic Principle, which avoids the two previous objections, goes as follows:

> Everything that is *material* possesses causal powers.

This principle does not exclude the reality of causally impotent entities, but only their materiality.

Granting that such a principle is the best way to capture the intuition behind the Eleatic Principle, we should now say that the relation between forces and accelerations is a non-material one. This could mean that production is an *immaterial* relation. An example could be some version of Malebranchism, which identifies causal relations with God's interventions. But few people, including dualists, are willing to claim that such immaterial connexions are required in the explanation of the physical world. A better interpretation of the view that production is not a material relation is that it is neither material, nor immaterial: production may well be a *formal* relation. Such relations are internal, in the sense of being nothing "more" than their terms, they are no to be reified. They have no causal powers. But they still are real, connecting different entities without being anything "more" than them. This is not the place to argue in favour of formal relations (many arguments in their favour point to the threat of a regress if we reject them. For instance, "Russell's Resemblance Regress', or the regress that threatens if exemplification is conceived as a material relation). The point is only that once we agree that there are some formal relations, the best way to deal with production is to claim that it is a formal relation.

As a result, there are six important disanalogies between forces and production. Only one of the two can deserve the label "causation", on pain of dismantling causation. We have seen that production has a good right to be called "causation". There is, on the other hand, some reasons to think that forces are not instances of causation. First, they have no direction. Second, as this spreadsheet makes clear, forces are more like distances than like production:

Production	**Force**	**Distance**
Non-symmetrical relation	Symmetrical relation	Symmetrical relation
Relata: relations between bodies	*Relata*: bodies	*Relata*: bodies
Second-order relation	First-order relation	First-order relation
Necessitation relation	Not a relation of necessitation	Not a relation of necessitation
Has no causal powers	Possesses causal power	Possesses causal power
Formal relation	Material relation	Material relation

Distances have causal powers (they are not epiphenomenal), but they are clearly not causal relations in the sense of being themselves kinds of causation. Since forces are more akin to distances than to production, they presumably are not a species of causation. They are causal *relata*, but not causal relations. On the view defended here, then, there are (at least) three basic types of external relations in the material world: spatial, temporal, and dynamic ones. These three fundamental kinds of relations have causal powers, which mean that they can be causes, but there are not species of causal relations themselves.

I conclude that forces are real symmetrical relations, but that they are not species of causation.

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