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The Metaphysics of Forces

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Abstract

This paper defends the view that Newtonian forces are real, symmetrical and non-causal relations. First, I argue that Newtonian forces are *real*; second, that they are *relations*; third, that they are *symmetrical* relations; fourth, that they are *not species of causation*. The overall picture is anti-Humean to the extent that it defends the existence of forces as external relations irreducible to spatio-temporal ones, but is still compatible with Humean approaches to causation (and others) since it denies that forces are a species of causation.

I shall defend the view that Newtonian forces are real, symmetrical and non-causal relations. In the first introductory part I put forward a characterization of forces intended to be acceptable to everyone involved in the debates to be addressed later (e.g. realists vs. anti-realists about forces, relationists vs. anti-relationists about them, defenders vs. opponents of the symmetry of forces, defenders vs. opponents of the view that forces are species of causations). In the second part, I 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 behaviour. In the third part, I argue 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 fourth 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 main reason for that being that they are symmetrical.

1. Introduction: Newtonian forces

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Newtonian Mechanics (NM) may seem to be of little interest for contemporary metaphysics since it has been superseded by better physical theories (quantum

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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, NM 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 NM: 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, NM 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, which is denied by eliminativism. I shall only assume that eliminativism about NM is wrong. I will not decide between anti-reductionism and reductionism concerning Newtonian entities. In both cases, the ontology of NM 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, 1687/1999):

> *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. This is a problem because not only is the reality of Newtonian forces controversial, but also their very nature. Indeed, the concept of force present in NM is likely to be subject to different metaphysical interpretations.

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One suggestion for instance is that the definition of forces is to be found in the Second Law.[1] 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[2]:

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

(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[3], 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:

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

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

[1] Maupertuis (see Jammer 1999, 210; Mach 1904, 239; Hesse 1962, 136ff.).

[2] Another equivalent formulation is that the force is the *rate of change of momentum* (or quantity of motion): $\mathbf{F} = \mathrm{d}(\mathrm{m}\mathbf{v})/\mathrm{d}t$

[3] Before stating the Second Law, Newton gave a definition of mass in Definition 1.

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body must then be something other than the acceleration of that body.[4] 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" (1923, 165).[5]

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 other than accelerating masses, the realist about forces simply has 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, or initial characterization, 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).[6] Dynamic properties include mass, force, energy, momentum, work and so on. Kinematic properties include motion, velocity and acceleration. With other properties such as distances or shapes, kinematic properties amount to spatio-temporal properties.[7] 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, etc.[8] But since I intend to define forces by dynamicity, I need a definition of dynamics

[4] Creary (1981, 152).

[5] See also Feynman (1963, vol 1, ch. 12). Note that this assertion is compatible with anti-realism about forces (to which Broad subscribed).

[6] Trickily, the term « kinetics » is often used in physics as a synonym to « dynamics ».

[7] For such a use of the dynamic/kinematic distinction in philosophy see Heil (1983, 38–39).

[8] Note that statics is then a part of dynamics, since it explains the absence of motion with the same kinds of dynamical entities.

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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* spatio-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 properties which are not purely spatio-temporal ones. 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 essentially 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.[9] 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.[10]

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.[11]

[9] Strictly speaking, Newton does not use the notion of vector but he comes very close to it he attributes both a module and a direction to forces, and uses the parallelogram method to add forces (1687/1999, Law 3, Corollary 1).

[10] One may worry about the proposal that the way forces are represented should enter in the definition of forces. But we are not yet looking at a full-blown definition of forces but rather at a preliminary characterization of them, that tries to leave open as many options as possible. It should be able to make room for the debate between realists and anti-realists about forces, but also for divergent realist conceptions of forces. One disagreement among the realists, as we shall see in the third part, opposes those who think that forces do indeed have a direction to those who hold that direction is only a feature of the representations of forces, but not of forces themselves.

[11] One upshot of this is that forces claim to be natural properties, by contrast to abundant ones, but do not necessarily claim to be fundamental ones in the sense of inter-level irreducibility. Some natural properties, those treated by special sciences, are not fundamental from an inter-level perspective: they supervene on more fundamental entities, and may or may not be reduced to them. Naturalness and fundamentality may come apart.

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Finally, forces are *properties* in the generic sense that they are not substances.[12] 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 they 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.[13]

Putting these remarks together, we can rephrase the preliminary 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 characterisation, 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.

2. *Forces are real: a truthmaker argument*

Are forces real? Following a long tradition[14], which has been recently revived by Wilson (2007), I want to argue that Newtonian forces are real, i.e. that forces exist independently of our thinking about them and are irreducible to other same-level

[12] I'm not considering force fields here, which might be regarded as substances. They might be analysed as bundles of forces, or as bundles of dispositions to exert forces. If so, fields are not a basic kind of dynamical entity.

[13] This violation of Humean Supervenience however is not straightforward since forces may be reducible to entities of a lower level that are themselves compatible with Humean Supervenience. But it still implies that Humean Supervenience would be false in worlds where Newtonian mechanics provides the fundamental theory.

[14] *Realists about Newtonian forces* include Boscovich (1763/1966), Euler (1750) – see Gaukroger (1982) and Boudri (2002), Kant (1786/2004), Bolzano (1837/1972) – see Konzelmann Ziv (forthcoming), Creary (1981), Strawson (1987), Tooley (1988), Fales (1990), Newman (1992), Armstrong (1997), Molnar (2003), Johansson (2004), Wilson (2007). Bigelow, Ellis and Pargetter (1988) have also defended realism about forces though not Newtonian ones: the relata of forces, according to them, aren't bodies, but fields and particles. *Anti-realists about forces*, on the other hand, include Berkeley (*De Motu*, 1721/1975, *Siris*, 1744/1975), Hume (1739/2000), Maupertuis (1756), d'Alembert (1758) – see Boudri (2002), Carnot (1803, Préface), Kirchhoff – see Poincaré (1902, ch. 6), Hertz (1899), Poincaré (1902), Russell (1903/1992), Mach (1904), Broad (1923, 166 ff.), Ellis (1965, 1976), Jammer (1957/1999), van Fraassen (1980).

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properties (such as, for instance, mass or acceleration). Many objections to the existence of forces have been advanced (unobservability, redundancy, overdetermination . . .). 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[15]), have been reluctant to endorse a full-blooded realism about forces. Anti-realists about forces have to claim that the term "force", as it appears in NM, either is not referential or refers to something other than *sui generis* forces. One rather radical way of making sense of that claim, which I have just rejected, is to argue that the Second Law is a definition of force. But defining the force that exerts on a body in terms of the acceleration and mass of *that* body is not the only option available to 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.[16] 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 example.

Imagine two equally strong people 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 relative to

[15] See Jammer (1957/1999, 124ff.). According to him, Newton « came very near to the operational concept of force and gravitation » (1957/1999, 203). For the opposite interpretation, see Bernard Cohen (2002).

[16] See for instance Carnot (1803), Russell (1903/1992, 483), Broad (1923, 166ff.), Jammer (1999, 245), Ellis (1976, 183–184).

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each other, nor relative to anything else. Still, the friend of forces has the strong intuition 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 (1968, 85–88) 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:

P1 In some cases, the disposition to move of a system changes without occurrence of any kinematic changes inside the system.
P2 The proposition that the intrinsic disposition of a system has changed must have a truthmaker in the system (Armstrong's truthmaker argument).
C1 Some dynamic changes do occur inside certain systems.[17]
P3 The best candidates for the changing dynamic properties are forces.
C2 Some forces are real.

[17] I'm here assuming that dispositions to move, if not identical or grounded in kinematic properties have to be identical or grounded in dynamic ones. This sounds reasonable: the only other option would be to claim that dispositions to move are identical or grounded in a secondary qualities such as colours, e.g. a properties which are spatio-temporally irreducible but deprived of any essential causal power. Grounding disposition to move on such secondary qualities, I take it, is hopeless.

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(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 or episodes 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. That said, it is quite tempting to take the plunge and 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 the magnets. Potential energy is a dynamic entity: it is not reducible to a pure kinematic entity and it essentially possesses causal powers. Why prefer forces? Though energy-based mechanics has superseded forces-based mechanics, both remain equivalent (they are inter-translatable).[18] Ontologically, we have still to choose between forces and energy.

[18] Feynman (1963) claims that Newtonian and Lagrangian dynamics are "exactly equivalent".

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Briefly, one can mention two reasons to prefer forces in the explanation of our medium-sized world. First, energy-based mechanics holds the principle of least action to be primitive, but this principle has often been claimed to have undesirable teleological implications.[19] Second, unlike energy, forces can be perceived (felt pressures on our skin).[20] 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 (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.[21]

(2) Only component forces are real.[22]

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

- (3a) Resultant forces and the component forces that constitute them are real.[23]
- (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.[24]

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

[19] Wilson (2007).

[20] See note 56. In 1899, Hertz pointed out that "there is no text-book of mechanics which from the start teaches the subject from the standpoint of energy, and introduces the idea of energy before the idea of force" (1899/2003, 14). This seems to remain true today, to a large extent. The explanation of this didactic order may lie in the perceptibility of forces by contrast to energy.

[21] Cartwright (1983, 54–73), Wilson (2009).

[22] Creary (1981), Johansson (2004, 167–168), Molnar (2003, 194–198).

[23] Mill (1843, Book III, ch.VI), Forster (1988). Although he does not explicitly endorse this view, the argument of Sheldon (1985) can be used to support it.

[24] Bigelow and Pargetter (1990b, 108).

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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.

3. 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.[25] Despite the relational character of the expression 'body *a* exerts a force on body *b*', some philosophers (Bolzano 1837/1972; 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.[26] Force monadism may be developed in two quite different ways. According to the first, forces are monadic *categorical* properties. According to the second, forces are monadic *dispositional* properties.[27] I aim to show that both options fail. The argument I propose is that neither 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 metres from a tree.[28] 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).[29] This implies that the monadic natural properties exemplified by a body do not involve other bodies. Forces, as natural properties or relations, must be intrinsic to their bearers. If forces

[25] In recent years, relationism about forces has been endorsed by authors such as Strawson (1987), Bigelow, Ellis and Pargetter (1988), Bigelow and Pargetter (1990b), Fales (1990), Newman (1992, 2002), Johansson (2001, 2004), Ingthorsson (2002).

[26] Following Russell (1903, section 212ff.). Concerning vectors, monadism seems to be the rule rather than the exception. Thus Lewis (1999, 226) writes: ". . . Vector-valued magnitudes may count as intrinsic properties. What else could they be? Any attempt to reconstrue them as relational properties seems seriously artificial".

[27] I borrow the distinction between categorical and dispositional properties from Armstrong (see notably 1997, 69ff.). Note that dispositional properties claim to be as *actual* as categorical ones: what may be non-actual, if the dispositionalists are right, are not the dispositions themselves but their manifestations.

[28] Armstrong (1997, 92), Molnar (2003, 39ff. and 159).

[29] "All perfectly natural properties come out intrinsic", Lewis (1999, 27).

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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*.[30]

3.1. Forces are not categorical monadic properties

According to the first kind of force monadism, advocated by Armstrong (1997, 76 ff.)[31], 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 and Pargetter (1989, 1990a), Armstrong claims that we have to take at face value the attribution of physical vectors to bodies at instants.[32] 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 force vectors. I shall grant, for the sake of the argument, that such a generalisation from kinematic vectors to force vectors is possible.[33] 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 his followers. It was adopted by Newton, and was clearly stated by Russell (1903/1992). 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

[30] If forces were causal relations, this would entail causal singularism: the fact that two entities are in causal relation does not depend on any fact outside these entities and their relations to each other at that time (contrary to Humean views about causation).

[31] Actually, Bigelow and Pargetter (1990a, 70) also claim that forces constitute intrinsic monadic properties of bodies. Nevertheless this seems to contradict their later claim (1990, 282–285) that forces are relations. I'm not sure how they intend to reconcile those two claims. Since the second one is developed at length in a discussion focused on forces, while the first one is mentioned in the course of a more general discussion concerning vectors, I shall consider them as holding that forces are relations.

[32] See also Forrest (1984), Dieks (2001), Johansson (2001 and 2004, 161–170).

[33] This is controversial: Johansson (2001 and 2004, 161ff.) is a monadist concerning accelerations, but a relationalist concerning forces. Monadism about accelerations does not entail monadism about forces.

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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 occupy 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 and intrinsic motion. Absolute motion is still a relation between a body and 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 relative to absolute space, nor to anything else.[34]

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 there 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 over time – extrinsic motions? The vector monadist's answer 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 (understood in a metaphysical and not only epistemological sense). Vector velocity, far from being constituted by changes of position, *explains* them

[34] There may be a more subtle way in which the idea of absolute space introduces the idea of intrinsic states of motion: as soon as we ask about the motion of absolute space itself, one common answer is that absolute space is *intrinsically* immobile. The immobility of absolute space is not relative to any other frame of reference. Absolute space, or its origin, would be the only bearer of an intrinsic state of motion. One other option, which seems preferable, is to claim that it does not make sense to ask whether absolute space is moving or not, for the very same reason that it does not make sense to ask whether time accelerates.

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(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 that of the relationist. 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 for one kind of velocity to occur without the other. For instance, it ought to be possible for an entity to 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 further argument.

Rather than reviewing these arguments[35], I shall raise a general difficulty for vector monadism: it cannot account for the direction of vectors.

[35] One usual strategy of vector monadists is to put forward real or imaginary cases where we are drawn to apply kinematic concepts despite the absence of extrinsic motions or velocities. I shall only mention one example proposed by Bigelow and Pargetter, which is dubbed *Newton's Cradle*. It is intended to show that some intrinsic kinematical vectors are present even in absence of any relational motion. Two rigid spheres *a* and *b*, of the same size and mass, hang in contact with each other. A third sphere *c*, of the same size and mass, moving along the line joining the centres of *a* and *b*, hits the sphere *b* with velocity ***V***. Then *c* stops, *b* remains motionless and *a* moves off with velocity ***V*** along the same line. Bigelow and Pargetter draw the following conclusion: "The velocity of *a* is transferred from *a*, through *b*, to *c*. There is a moment in time when *b* has velocity *V* even though there is no appropriate series of past *or* future positions for *b* which will yield velocity *V* as a limit . . . Instantaneous velocity does not entail any sequence of position which generates a mathematical limit" (1990a, 67). (As pointed out to me by I. Johansson and C. Wüthrich, it may be unfortunate that Bigelow and Pargetter speak here of velocities rather than accelerations or momentum). The argument appears to be the following:

(i) In certain cases, objects that have no extrinsic velocities nevertheless mediate the extrinsic velocities of other objects.

∴ Some mediating process must occur in such stationary objects.

(ii) Only velocities can mediate velocities.

∴ Some intrinsic velocities occur in objects that mediate extrinsic velocities.

The intermediate conclusion sounds plausible: the momentum and kinetic energy of *a* and *c* are the same, so they must somehow have been conserved in "passing through" *b*. The argument points, rightly, to the need for a mediating process in *b*, between the motions of *c* and *a*. But why should this mediating process in *b* take the form of a velocity? A mediating process need not necessarily be of the same kind as those processes thereby mediated. It is not the case that the only way for a quantity to be conserved is to pass through a medium without undergoing any change. There are reversible laws that connect kinematic magnitudes with dynamic ones: Newton's Second Law connects force and mass with acceleration. The principle of conservation of energy connects kinetic energy with potential energy. Why not describe the process that occurred in *b* in terms of potential energy, or force? The upholder of intrinsic velocities may reply that *both* intrinsic velocities and forces are involved in that process, but then he has to say more about their relation and to explain why they are not redundant. Since we can explain the mediation just in terms of forces, the motivation for introducing intrinsic velocities is still

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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.[36] 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 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.[37] This line of argument can be reinforced if we try to understand more precisely what the notion of direction of vectors amounts to.

missing. Once we have forces, intrinsic velocities appear to be pointless. Here is a possible explanation of this redundancy: it may be that the only grip that we have on the notion of instantaneous velocity (or instantaneous acceleration) comes from our concept of force. The suggestion is that all alleged monadic kinematical properties are in fact disguised dynamical properties or relations. If so, an ontology with instantaneous velocity (or accelerations) and forces is redundant. And an ontology with instantaneous velocities (or accelerations) but no forces is cheating. Robinson (1989) finally recognises something close to this suggestion. While he postulates intrinsic "quasi-qualities" of motion in order to save Humean Supervenience he points out that it is actually not clear that such qualities of motion are in fact compatible with the spirit of Humean Supervenience.

Johansson (2004, 163ff.) suggests two different original arguments in favour of intrinsic states of acceleration, which he calls alternatively "partial acceleration", "non-realized acceleration" and "tendencies to accelerate" (which are distinct from forces according to him). First, they make sense of Newton's Second Law as far as component forces are concerned. I claimed (section 1.2) that Newton's Second Law was only true for resultant forces, but Johansson maintains that it also holds for component ones. Since each component force does not yield acceleration, Johansson has to claim that it still causes a tendency to accelerate. This argument sounds circular to me: the only way to justify the truth of a "component version" of the Second Law is to assume the existence of partial accelerations, but then one cannot ground the existence of acceleration on the truth of that Second Law. Second, Johansson stresses (in correspondence) that we need truthmakers for our ascriptions of tendencies to accelerate to bodies and that those truthmakers must be intrinsic to the bodies in question. I agree with the need for truthmakers but not with the need for *intrinsic* ones: what makes it true that the painting hanging on the wall tends to fall is the gravitational force-relation between it and the Earth. This is not something intrinsic to the painting. As a result, I think that the "component version" of the Second Law simply does not hold, and that partial acceleration and forces are indeed redundant in Johansson's ontology. This has the advantage of avoiding both the debatable notion of "non-realized accelerations" and the splitting in two of the Second Law.

[36] This has been disputed by Bigelow and Pargetter (1988). See Armstrong (1988) for a response.

[37] On version of that argument was put forward by Kant (1928) in the context of a defence of absolute space. Direction of an entity, according to Kant, cannot be intrinsic for it is always a direction towards a region of absolute space. (See van Cleve 1987 for a presentation and critic of that argument. Van Cleve's objection to Kant – p. 49 – needs not concern us here however, for it does not affect Kant's point that direction is extrinsic, but only his further point that the extrinsicness of direction commits us to absolute space).

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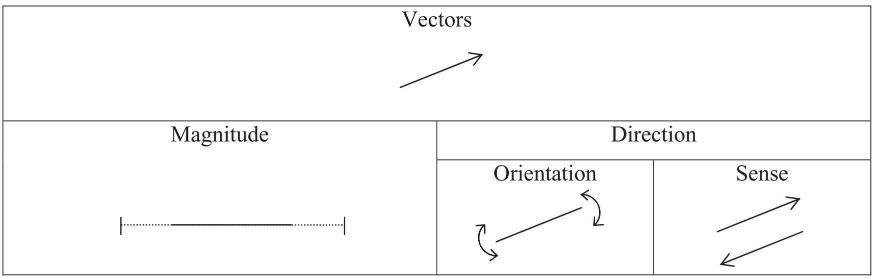
At first sight, direction appears to be *one* single feature of vectors, besides their magnitude. Indeed, it can be represented by one number: the most straightforward way to represent a vector in a two-dimensional plane is to use a value for its magnitude, and another value for its direction. The numerical value θ that represents the direction of the vector is the value of its angle from the abscissa, anticlockwise. But this is misleading: θ in fact embeds *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 relative 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 represents the sense of the vector. The very same oriented line can be travelled over in two ways. My argument against vector monadism is that neither of these two features, orientation and sense, can be intrinsic to a single body.



Concerning orientation, the monadist faces two problems. First, if orientation is intrinsic, it should be possible for two bodies that bear exactly the same relation to everything else to have different orientation. But this is hardly conceivable. Similarly, one cannot think of some body changing its orientation without changing its relation to anything. For instance, one cannot conceive of a body rotating without changing its spatial relations to anything else (be it another body, a part of that body, absolute space, an observer, or whatever other background one might hold fixed in order to make sense of the rotation). 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), etc. I suspect that the intuitions concerning "intrinsic orientation" fail to consider these other *relata*.

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Second, even if the notion of an intrinsic orientation was 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 (Johansson 2001; 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. It is however unclear how exactly chirality can render the asymmetry essential to the concept of sense. Even if it can, the intrinsicness of chiral properties is a matter of important controversy.[38]

A second problem concerning the intrinsicness 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 sense of the force exerted by a particle depends on the nature of the other particles around. It is not intrinsic to one single particle.[39]

[38] Van Cleve (1987). In a recent manuscript, Parsons (2007) argues that chiral properties are intrinsic, but himself underlines the important costs of such a position.

[39] Note that this extends to vectorial fields. The field of a positively charged particle is represented by lines flowing out from the charge and the field of a negatively charged particle is represented by lines flowing in toward the charge. But these representations are purely conventional: they rely on the arbitrary choice of a *positive* test charge. The field of a positive charge is not intrinsically repulsive: it is repulsive only relatively to other positive charges. Then the multiple arrows that enter in the representation of the field are not intrinsic to it. They depend on the polarity of the test charge that we choose. This may be a problem for those dispositionalists who claim that fields are intrinsic powers.

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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.

3.2. 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, 60ff.). *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.[40] They do not seem to address the issue of whether forces themselves are categorical or dispositional. Presumably, the hypothesis should be the following: forces are monadic powers whose manifestations are accelerations.[41] 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 than 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.[42]

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 vectors' directionality and powers' directedness is misleading*. We have seen that the direction of forces is in fact a complex property that includes their orientation and their sense. Neither of them fits with the directedness of powers.

[40] Molnar (2003, 164): "The fundamental powers in nature are powers to exert a force" (see also pp. 134 and 195) and Ellis (2001, 128): "A causal power is a disposition of something to produce forces of a certain kind. Gravitational mass for example, is a causal power". For difficulties in the interpretation of Cartwright's view, see Schrenk (2007).

[41] Wilson (2002), Schrenk (2007).

[42] Armstrong (1997, 79).

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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[43], 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 fruitless 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.[44]

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 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.[45] The sense of a force would be metaphysically grounded in the sense of its kinematic manifestation. But this would be to put the cart before the horse: powers are supposed to explain or ground their manifestation, not the contrary. It is because forces have the senses they have that their manifestations have the senses they have, not the reverse. If the force-power has no direction by itself, why should its acceleration-manifestation be of such and such a direction? The direction of the kinematic manifestations of forces would be left entirely indeterminate. (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.

[43] See Molnar (2003, 64).

[44] For distinct arguments against the view that forces are dispositions see Bigelow, Ellis and Pargetter, (1988, 106).

[45] For a close position concerning the direction of forces see Bigelow, Ellis and Pargetter (1988, 629). Nevertheless, these authors deny that forces are dispositions. They claim that they are asymmetrical relations.

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In conclusion, the directionality of vectors cannot be accounted for in any monadist framework. Forces are not monadic properties, categorical or dispositional.[46] They must be relations.

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

4.1. 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: Maxwell (1877, 26), Foulkes (1951, 176 and 1952), Bunge (1959, 153), Hellingman (1989), Newman (1992, 151), Ingthorsson (2002).[47] Physicists also appear to assume that forces are symmetrical relations when they use the terms 'forces' and 'interaction' interchangeably.[48]

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.[49] 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

[46] Note that nothing I've said here rules out the following possibility: forces may still be dispositional *relations*.

[47] The view that forces are symmetrical relations also seems to be assumed by writers such as Kant, Boscovitch, Helmholtz or Broad.

[48] This is clearly the case with gravitation. Consideration the law $F = (km_1m_2)/r^2$, physicists speak as if there is only one relation between m_1 and m_2.

[49] But see the proviso about non-central forces discussed below.

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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.[50] 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.[51]

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 parsimonious: 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:

[50] Either between the two bodies they relate, or nowhere, as Bigelow, Ellis and Pargetter claim – universals having no location according to them.

[51] I will later (section 4.2) consider how this approach affects my previous argumentation against monadism about force.

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(1) "Fabrice is five metres from Kevin"
(2) "Kevin is five metres from Fabrice"

(1) and (2) are certainly two ways of referring to the same fact, namely, that Fabrice and Kevin are five metres 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.

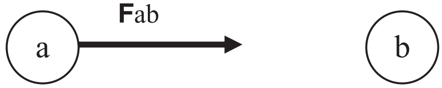
If true, given the strong analogy between the distance's law and Newton's Third Law, there is no reason to consider the asymmetry of force-vectors, but not the asymmetry of distance vectors, to be of ontological importance. Likewise, the asymmetry of forces is only a feature of their vectorial representations, 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 forces are symmetrical *dynamical* relations irreducible to mere spatial relations.

Those three reasons (observability, parsimony, 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.*

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 (e.g. orientation) and the same point of application, but have opposite directions.[52] 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:



(an attractive force extերted upon *a* by *b*)

[52] The fact that attractive and repulsive forces have the same point of application, that is, the fact that they exert on the same body, is what distinguishes them from action-reaction pairs.

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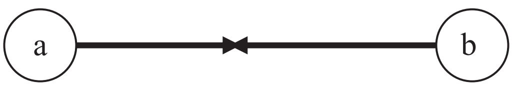
On the opposite, a *repulsive* force exerted on *a* by *b* is represented thus, still focusing on *a:*

(a repulsive force exerted upon *a* by *b*)

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.[53] 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.[54]

[53] It may be possible to reduce attractive force to repulsive force, or the reverse, but in any case some basic notion of attraction or repulsion is needed.

[54] A possible objection to the view that attraction and repulsion are determinates of the force-determinable, pointed out by a referee of this journal, is that one can conceive of two bodies that attract and repel each other with the very same intensity. This indeed is even a common phenomenon: the earth and an apple relying on it both attract each other (thanks to gravitational force), and repel each other (thanks to normal force – note that gravitation and the normal force are *not* an action-reaction pair). Since determinates of the same determinable are incompatible, attraction and repulsion cannot be determinates of the same force-determinable.

One first reply would be to argue that we are indeed thinking about different entities here (for instance: the attraction is exerted by the centres of mass of the bodies, while the

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If Newtonian component forces are symmetrical relations, how is it that Newton and many of his 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.[55] 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 some conation (intention, volition, trying . . .) 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 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.[56]

4.2. 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 vectors 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.

repulsion is related to the boundaries of the bodies or their charges). But it might still be at least conceivable that the very same entities attract and repel each with the same intensity. Then the right answer that can only be hinted at here, is to deny that determinates falling under the same determinable are necessarily incompatible (see Armstrong 1978, 113 for such a suggestion).

55 Jammer (1999, 124). Broad writes: “Unquestionably the sensational basis of the scientific concept of force is the feelings of strain that we experience when we drag a heavy body along, or throw a stone, or bend a bow” (1923, 162).

56 This view has been endorsed by Weber (1905), Perkins (1983), Fales (1990, 15ff.), Armstrong (1968, 97 and 1997, 213). See also Wilson (2007) who appears to think that forces are observable both by the sense of touch and by the sense of agency.

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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.[57] 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 that it conceives of forces as having a magnitude and orientation, but no sense, it is not committed to the rejection of vectorial calculus about forces. Even if force-vectors are a 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 de-relativisations of true relations, as argued by Newman (1992, 151 and 197): they are a "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 into 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 web of interacting bodies.

(iii) The third objection to the 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.*

[57] Russell (1903, section 212).

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We presumably do not want to conclude that instances of "heavier than" and "lighter than" should be fused into one 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 it 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 $R(\mathrm{x}, \mathrm{y})$: $R(y, x)$ 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) $(x)(y)\ [R(x, y) \Leftrightarrow R^{-1}(y, x)]$

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 the same relational fact. We have changed the place of the arguments (Mary and John) *and* inverted the expression of the relation, here by using the 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.[58] So the proposed principle (SR) simply does not apply to this kind of expression: 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) $(x)(y)\ [F(x, y) \rightarrow F(y, x)]$

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

[58] See Segelberg (2000, 190), Williamson (1985), Newman (2002).

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(iv) The fourth objection argues that the Third Law only holds for some forces, namely central ones, but is not necessarily true of non-central forces.[59] Central forces are forces that act along the line joining the two bodies between which they hold. Non-central forces, such as the Lorentz magnetic force that two charges moving at right angles to each other exert on each other, are neither co-linear nor of opposite direction, so do not satisfy the Third Law.[60]

A first way to deal with that difficulty would be to restrict the scope of the thesis that forces are symmetrical, by claiming that only forces that satisfy Newton's Third Law, namely central forces, are symmetrical. The price to pay however is that the concept of force dislocates, some forces being symmetrical, some others not. If symmetry/asymmetry are essential features of forces, the term force does not anymore pick out a natural kind, but a disjunction of natural kinds. One may fear therefore 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.

A better 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. We have to give up the assumption that forces *relata* are necessarily bodies. 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.[61]

(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 metaphysically contingent and empirically testable:

> 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

[59] I am indebted to an anonymous referee for this objection and a suggestion for an answer.

[60] Since forces have different orientations in such cases, they falsify even the so-called « weak » version of Newton's Third Law, according to which action and reaction must have the same direction, but can fail to be co-linear.

[61] It has to be noted however that such an answer remains controversial and that the way to reconcile Newton's Third Law with non-central forces is a matter of on-going debate. See for instance Breitenberger (1968), Cornille (1995).

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> sustain their mutual endeavours toward each other, and at last, having attained equilibrium, they will be at rest (1687/1999, 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 that 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 metre rule, put the zero on *a* and read the distance from *b*. Then turn it around, 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 metre rule somehow changed 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.[62]

5. *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

[62] See Johansson (1980) for the view that alleged counter-instances to Newton's laws can be accounted for by taking into account forces that were forgotten.

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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*.[63]

Hume endorses the following 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 and Pargetter (1988), Fales (1990), Newman (1992), or Johansson (2004, 177 ff.)[64] claim that forces are species of causal relations.[65] Some even go so far as to identify every type of causation with forces (Bigelow and Pargetter, 1990b). True, as noted above (section 1.2) forces, as dynamical relations, are clearly relations that contradict the thesis of Humean supervenience: they are relations that are not spatio-temporally reducible. But one should not 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 view, endorsed by Bigelow and Pargetter (1990b) has it that all forces are causal relations and that all causal relations are forces. The weak view, 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 need not be the

[63] The view defended here presents some close affinities with the one defended by Ingthorsson (2002): he, too, claims that interaction (forces) is a symmetrical relation that is the relata of a causal relation.

[64] See also Armstrong (1997, 74). Though he thinks that forces are monadic properties, Armstrong suggests that "all *interactive* causality involves forces".

[65] Tooley (1988, 241) is a notable exception: though he holds that forces are relations, he rightly distinguishes the causal relation itself from the forces.

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case: even if all causation is simultaneous,[66] it may still have a direction or sense, if it 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 common-sense 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 quantities 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 collapse 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 causation.

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 exerters. And nothing can press on an acceleration. The *relata* of the forces relations are bodies.) So 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*

[66] As argued by Ingarden (1948), Huemer and Kovitz (2003), Johansson (2004, 192). See Kistler (2006, 39–44) for a defence of the opposite view that causation is never simultaneous.

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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. However because it multiplies different species of causation, the weak view is open to the following general objection:

P1 Causation is a natural kind.
P2 If forces were causal relations, they would be strongly disanalogous to the others types of causal relations.
C Forces are not causal relations.

Any realist about causality should adopt the first premise: causal relations must have something in common, they must resemble each other 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 five 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 construes 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 relations of necessitation*: the bodies that enter into a force relation do not necessitate each other.

(v) Forces essentially 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 production relation between forces and accelerations has itself any causal power, at least essentially.[67] Certainly, the

[67] See Armstrong (1997, 42) for a close suggestion.

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production relation *confers* causal powers to its *relata* (forces are causes in virtue of producing accelerations), but plausibly it does not itself essentially *possesses* causal powers (that production is a necessitation relation 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.[68] 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, rather, 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 essentially have causal powers (forces) while some other (production) are causally impotent.[69]

As a result, there are five 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 strong right to be called "causation". There are, on the other hand, some reasons to think that forces are not instances of causation. First, they have no direction. Second, as this table makes clear, forces are more like distances than like production:

[68] Production cannot cause accelerations on pain of overdetermination (accelerations are already caused by forces).

[69] That production might be deprived of causal power suggests a sixth disanalogy between forces and production (which cannot be properly defended here), namely that forces are *material* relations while productions are *formal* relations – on a par with resemblance, identity, parthood, conjunction, existential dependence, instantiation in Armstrong's theory of states of affairs, compresence, etc (see Mulligan 1998, section 4 on the distinction between formal and material concepts). One proponent of the view that production is a formal relation is Johansson (2004, 181–185) who argues that the relation between forces and acceleration can be analysed in terms of existential dependence.

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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
Does not essentially have causal power	Essentially has causal power	Essentially has causal power

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 macroscopic 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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