

LEIBNIZ AND THE PERFECTION OF CLOCKS

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Abstract. Throughout his life, Leibniz showed serious interest in the construction of clocks and actively contributed to their technical improvement. He described the mechanical and especially the pendulum clock as a paradigmatic kind of machine, and therefore as a suitable model for exploring the nature and boundaries of mechanistic philosophy. After an overview on Leibniz's technology and physics of clocks (Section 1), this paper reviews the main occurrences of the clock analogy in his philosophical writings. Section 2 considers the epistemological use of the clock analogy and its evolution from an early stress on the hypothetical component of natural science to a later concern with the full inspectability and intelligibility of natural processes. Section 3 details the manifold uses of the clock analogy in metaphysics to illustrate features of the world, of both inanimate and living bodies, and even of God, the soul, and the soul-body union. The possibility of construing machine metaphors in terms of either structure or function solves the apparent ambivalence of Leibniz's approach to the clock analogy. It also explains his persistent reference to perfection and standards of perfection, thereby bringing to the fore the teleological strand of this concept.

Keywords: Leibniz, clock, machine, artefact, mechanism, perfection, function, teleology

1. The nature of clocks

In Leibniz's writings,¹ clocks and watches often appear along with mills as paradigmatic kinds of machines. For instance, the *New Essays* claim that "a sentient or thinking being is not a mechanical thing like a watch or a mill."² This proximity notwithstanding, clocks are sometimes described as antithetical to mills from the mechanical point of view, insofar as their construction pursues the opposite aim than that of mills. Whereas the mechanics of mills aims to accelerate a machine's motion, the constructor of a clock strives above all to obtain slowness and regularity.³ The motion of clocks must be minimal in order to prolong their endurance, but it must be as regular as possible for the sake of exactitude. Endurance and exactitude thus jointly constitute the main standard of a clock's perfection: the longer and more correctly a clock can tell the time without needing repair or resetting, the more perfect it is. This paper argues that the possibility of ascribing degrees of perfection to clocks and mechanical timepieces in general is crucial to understanding Leibniz's various (and sometimes *prima facie* inconsistent) uses of the clock analogy.

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The technology of Leibniz's day offered two types of devices to make clock hands move uninterruptedly and regularly: pendulum and spring-driven clocks. As the ongoing publication of his technical writings confirms with ever more evidence, Leibniz took a serious interest in the construction of both sorts of clocks and actively contributed to improving the mechanism of the latter.⁴ As early as 1675, he was able to announce his invention of a new "principle of exactitude" for portable timepieces.⁵ Some 40 years later, he could still remember the circumstances of this early publication. Indeed, after reading the manuscript of Henry Sully's treatise on clocks, he wrote some remarks in which he evoked various 1670s discoveries and polemics, regretted not seeing his invention realized, and described the state of the art concerning both kinds of clocks.⁶

In accepting the division of artificial clocks into the two classes of pendulum and spring-driven devices, Leibniz also makes clear that he considers the distinction not merely conventional but dependent upon the actual, essential properties of each device. Against Locke's claim that there are different species of clocks only insofar as we introduce different names to distinguish them, Leibniz maintains that the various differences that we can identify in clocks – such as "the varieties of contrivance [*artifice*] and in particular how the balances differ"⁷ – in fact constitute different species. Of course, this realist stance towards types of artefact is in keeping with Leibniz's overall realism about natural kinds, but it also manifests the profound unity between the natural and artificial realms, as both are governed by the same forces and laws. Artificial pendulums and springs exploit the gravity and elasticity of bodies respectively, which the young Leibniz explains as two related phenomena that both result from a common cause, the circular motion of ether.⁸ Together, gravity and elasticity provide the motive principles of not only all artificial but also all natural machines.⁹

The affinity from the point of view of physics between the natural and artificial worlds is the ground of Leibniz's use of the clock metaphor in both metaphysical and epistemological contexts.¹⁰ Since clocks are typical machines, they can serve as a model not only for investigating the essential features of machines such as living bodies or the world itself, but also for reflecting on our epistemic relation to them. Let us begin with this latter issue.

2. The epistemology of clockwork

2.1. Hermetic clocks

The dependence of clocks and artefacts upon the fundamental forces and laws of nature has an epistemic counterpart in the dependence of technology upon physical science. Since the functioning of clocks depends on natural forces, the invention of the former requires knowledge of the latter. Leibniz considered Huygens's invention of the pendulum clock emblematic in this respect, as it basically consisted in the rigorous application of Galileo's scientific discoveries about the "remarkable properties of pendulums."¹¹ Leibniz is aware that primitive pendulum clocks were reportedly constructed even earlier, but he insists that Huygens must be credited as the actual inventor of this device, since he was the first to know the scientific reason for the pendulum's regularity.¹²

For the same reason, useful inventions such as clocks should be regarded as “the mark of true science” like Galilean science;¹³ by contrast, the sterility of Cartesian philosophy in terms of technological progress is evoked to cast doubt on its soundness. According to Leibniz’s rhetoric – if not to his actual intellectual practice – the invention of devices is neither a purely empirical discovery nor the outcome of mere speculation, but rather the fruit of scientific knowledge of the inner mechanisms of nature. The question, however, arises of how this knowledge is to be acquired. From the early 1670s onwards, Leibniz frequently addresses this and other epistemological questions by means of the clock metaphor. On the other hand, the meaning of this metaphor appears to vary considerably from Leibniz’s early to his middle and late years, as though his sojourn in Paris (1672–1676) marked a divide even in his use of mechanistic imagery.

In Leibniz’s writings from the early 1670s, nature is compared with a clock in order to clarify the concept of hypothesis and stress the difference between hypotheses and observations. Nature appears as a closed clock with an inner structure that is therefore inscrutable. Imagine that you are led to admire a newly invented clock and asked by its maker to guess how it is made simply by observing its visible motions.¹⁴ You are allowed neither to open the clock case nor to touch it, let alone turn it around. Natural philosophers are often in a similar epistemic situation with respect to the objects of their investigation, as they try to explain phenomena without having access to the inner structures that produce them:

Indeed, almost all the ingenious philosophers who even in our century participated in deducing the inner nature of corporeal things [...] have followed the path that a man could use if, led to a clock, he could not open it, turn it around, or touch it, and was nevertheless asked to conjecture something about the inner structure and the reason of motion from the progress of the clock hand that he would see, or from the sound of the bell that he would hear.¹⁵

In such cases, the only alternative to scrutability consists in forging hypotheses, in devising a possible cause of the effects observed: “If he is an expert at automata, he would devise something such that, once it is admitted or even realized, all that he perceives from outside the clock would also happen; which is the kind of possible supposed cause that philosophers call *hypothesis*.”¹⁶

Hypotheses are surrogates of observation-based explanations. Forging a hypothesis corresponds, in the clock analogy, to constructing an ersatz machine that performs the same observable operations carried out by the original, inscrutable device. The comparison, however, also highlights the shortcomings of the hypothetical method, since there is no guarantee that the contrived mechanism (i.e. the hypothesis) really corresponds to the actual clock (i.e. the internal structure of nature), even though both bring about the same results. Leibniz adds, however, that a hypothesis can be deemed reliable if its predictions are confirmed:

If an automata maker leads me to a clock he constructed and asks me to guess its construction, perhaps I can exhibit a construction that performs the same [function] as the clock on display, since the same phenomena can be produced in several ways, but I cannot determine the precise way used by the craftsman unless the work is dismantled. However, if a hypothesis not only satisfies present experiments but also provides some non-deceptive prediction about the future, we must firmly rely on it.¹⁷

By contrast, the purely observational approach, free from hypotheses, is viable where causal links are fully exposed so that there is no need to devise inner structures and one can simply reason from phenomena. This epistemic situation is compared with observing a solar clock:

For instance, if after being led to a clock, one sees that the place is illuminated by the sun and that an opaque body placed against its light produces a shadow which falls on the hour's number, certainly he cannot reasonably move to contrive other causes than those he sees or to invent I don't know what progress of an insensible body casting a shadow here and there.¹⁸

The world, however, is more like a hermetic clock than a sundial. Due to the limited extent of our present knowledge, cosmological hypotheses about the entire world machine might even be premature: “[...] we still do not know enough about this world clock, as much as a perfect hypothesis requires.”¹⁹

2.2. Uncovered clocks

In his middle and later years, Leibniz evokes clocks as a model of mechanistic intelligibility when arguing against occult qualities. In two major works, he famously makes fun of the forms and qualities invoked by scholastic philosophy and traditional medicine by stressing how ridiculous it would be to explain a clock's functioning in terms of some “horodictic” quality.²⁰ It is not yet enough, however, to simply say with Boyle that nature is mechanism, nor is it enough to replace occult qualities with the generic mention of a mechanical cause: “So, for example, in explaining a clock, it is not sufficient to say that it is driven by a mechanical principle [*ratio*] unless you distinguish whether it is driven by a weight or by a spring.”²¹ Here, the clock analogy actually serves to point to the shortcomings of some popular versions of the mechanistic doctrine. We still need to know, however, why the clock specifically – even more than the mill – appears so suitable for denouncing the explanatory gaps and limits of old and new physical theories.

As hinted at above, the artificial clock sets a standard of intelligibility. Imagine the clock case is now open so that you can inspect all its wheels and workings. Once you are perfectly acquainted with its inner structure, you necessarily understand how it works to bring about its intended effects: typically, the periodic clock's strokes. Scientific explanations meet this standard only insofar as they derive natural phenomena from their causes as intelligibly as the clock's strokes can be derived from its mechanical construction:

First of all, I take it to be certain that *all things come about through certain intelligible causes, or causes which we could perceive if some angel wished to reveal them to us.* [...] Let us imagine, therefore, that some angel comes to explain to me the true cause of magnetic declination and the periods observed in it. He will surely not really satisfy me by saying that this is the nature of the magnet or that there is a certain sympathy or a kind of soul in the magnet by which it happens. Rather he must explain some cause to me, such that, if I understand it, I can see that the phenomena follow from it as necessarily as the cause of the hammer stroke when a given time has elapsed follows from my knowledge of a clock.²²

Thus, the very point of the clock analogy (in its epistemological use) apparently shifts after the Paris years from stressing the hypothetical character of scientific theories to illustrating the conditions of their acceptability. Leibniz appears more confident that natural phenomena can be explained in terms of inner structures that are observed and not merely hypothetically reconstructed. To some extent at least, the case of the *horologium mundi* is no longer unfathomable but can be opened for inspection.

3. The metaphysics of clockwork

3.1. World

Although the young Leibniz might have doubted whether we could specify the construction details of the world machine, he had no doubt that the world could be aptly described as a machine. In the late 1660s and early 1670s, the world-as-clock analogy already proves its metaphysical relevance and displays its powerful imagery.²³

However, the artificial clock is evoked by the young Leibniz not only as an emblem of the mechanistic worldview but also as an illustration of finalism. Just as it would be highly implausible (though not absolutely impossible) for a clock to be the product of chance and not of an intelligent maker, we have moral certainty that the world is ruled by providence.²⁴ As the focus shifts from the clock's structure to its artefactual character, the interpretation of the clock metaphor shifts from mechanism to finalism, and the world appears as a divine artefact or *horologium Dei*: "[...] there is in fact no wisdom in nature and no appetite; yet a beautiful order arises in it because it is the timepiece of God."²⁵

Banishing soul-like entities from physics, mechanism deprives nature of any knowledge, instinct, or appetite. It thereby provides support to artefactualism, the doctrine that nature and natural beings are God's artefacts, for if nature is not self-ordering, it must be ordered by an external agent. In Leibniz's use, the world-as-clock metaphor shows how deeply mechanistic necessity and finalistic harmony are actually intertwined. In their search for material causes, modern physicists "neglect rational causes, although the creator's wisdom shines out chiefly in that he set up the world clock in such a way that afterwards everything would ensue as if by a sort of necessity for the greatest harmony of all beings."²⁶

In the late 1670s and early 1680s, on the other hand, Leibniz tends to emphasize the deterministic aspect of artificial clocks as devices whose behaviour is

entirely predictable from their structures and initial conditions. In this vein, he uses the clock analogy instead to denounce the necessitarian implications of extreme mechanism, which leads one to believe that everything in the universe happens “with automatic necessity, just like in a clock,” whereas “the middle path is to consider God not only as the first principle and not only as a free agent.”²⁷

By contrast, to consider God *only* as the first principle would mean to conceive of him as part of the world machine, just as the clock’s motor is part of the clock. The clock metaphor becomes dangerous when it is extended beyond the world’s boundaries to include its creator. This explains Leibniz’s use of the world-as-clock analogy to cast a sinister light on the Neo-Stoic doctrine that God is the soul of the world: “The sect of the new Stoics believes [...] that God is the soul of the world [...], that he is the cause of matter itself, if you wish, but that a blind necessity determines him to act; for this reason, he will be to the world what the spring or the weight is to a clock.”²⁸ The best antidote to this radical naturalism and its denial of final causes consists in maintaining, with Anaxagoras, that the world must be produced by an intelligent being, since everything in it is as perfect as possible.²⁹ As Margaret Wilson once pointed out, perfection joins value and purpose as key elements in Leibniz’s response to necessitarianism and Spinozism.³⁰

The concept of perfection is also the theoretical core of Leibniz’s late construal of the world-as-clock analogy in his polemics against Newtonian metaphysical cosmology. Leibniz holds to a principle of conservation to the effect that the total amount of force in the world remains constant, in spite of local variations and redistributions caused by the interactions of bodies. Thus, he strenuously opposes Newton’s claim that the world is gradually losing its motive force and would eventually stop like a dead clock if God did not intervene to wind it up.³¹ Nevertheless, Leibniz is willing to follow the Newtonian rhetoric in comparing the relation between God and the world to the relation between clockmaker and clock, for he thinks that he can turn that comparison to his own advantage. Indeed, he had previously used the very same comparison in the late 1690s when arguing against the occasionalist account of the laws of nature and its postulation of continual interventions by God. Bad clockmakers are bound to adjust their work, but God is not:

One should not think that nature obeys God’s command just as the subjects obey a promulgated edict, or that God always keeps it on track as though it tended to derail, and corrects his work just as bad automata makers usually do; but rather that God, when giving laws, also gave to things the force and tendency to observe them, in which consists the nature of entelechies.³²

By virtue of both the conservation principles of force and direction respectively,³³ Leibniz’s system of the universe is causally closed even with respect to God – except, of course, for God’s continuous and unvarying concurrence.³⁴ As a perpetual pendulum, the world is by no means independent from its maker. On the contrary, it has been made so perfect that no subsequent correction or change is needed. By contrast, the machine of Newton’s world is afflicted by manifold

imperfections. Against Clarke's denial, Leibniz insists that the world's gradual loss of its force must count as a defect. His argument draws on the clock analogy: "However, that which would make the machine of the world as imperfect as that of an unskillful watchmaker [*mauvais horloger*] surely must necessarily be an imperfection [*défaut*]." ³⁵

Leibniz uses the clock metaphor to highlight that Newton's wind-up world in fact requires a variety of divine interventions.³⁶ Not only must God periodically wind up his creation, he also has to clean dirt from the mechanism and even repair some of its parts:

According to [Newton's and his followers'] doctrine, God Almighty needs to wind up his watch from time to time, otherwise it would cease to move. He had not, it seems, sufficient foresight to make it a perpetual motion. No, the machine of God's making is so imperfect, according to these gentlemen, that he is obliged to clean it now and then by an extraordinary concourse, and even to mend it, as a clockmaker mends his work; he must consequently be so much the more unskillful a workman as he is more often obliged to mend his work and to set it right.³⁷

When Clarke replies that God's continual intervention manifests his glory and not his imperfection because he did not merely put together the parts of the world but created it in its entirety, Leibniz rebuts the argument as inconclusive.³⁸ Consider timepieces once again. When you buy a timepiece, you are not primarily interested in whether its maker made all of its parts by herself. What really matters to you as the timepiece buyer is whether the device is working properly and will continue to do so, regardless of the origin of its components:

He who buys a watch does not mind whether the workman made every part of it himself, or whether he got the several parts made by others and only put them together – provided the watch goes right [*comme il faut*]. And if the workman had received from God even the gift of creating the matter of the wheels, yet the buyer of the watch would not be satisfied, unless the workman had also received the gift of putting them well together. In like manner, he who will be pleased with God's workmanship cannot be so without some other reason than that which the author had here advanced.³⁹

What is at stake here is what criterion to consider when assessing the perfection of an artefact and consequently the level of craftsmanship of its maker, for the same criterion should apply to the perfection of the world and the excellence of its creator. Whereas Clarke's focus is on the production of the single components, which amounts to privileging the maker's causal power, Leibniz's holistic approach puts the arrangement of the parts first, thereby exalting the maker's mastery of his craft: "The true and principal reason why we commend a machine is rather based on the effects of the machine than on its cause. We do not inquire so much about the power of the artist [*puissance du machiniste*] as we do about his skill in his workmanship [*artifice*]." ⁴⁰ If

the world is a divine artefact, the excellence of its creator cannot be assessed merely in terms of his productive power or causal efficiency:

[...] the reason why God exceeds any other artisan [*machiniste*] is not only because he makes the whole, whereas all other artisans [*artisan*] must have matter to work on. This excellence in God would be only on the account of power. [...] The bare production of everything would indeed show the *power* of God but it would not sufficiently show his *wisdom*. They who maintain the contrary will fall exactly into the error of the materialists and of Spinoza, from whom they profess to differ. They would, in such case, acknowledge power but not sufficient wisdom in the principle of all things.⁴¹

By contrast, the clockmaker's "artifice" evoked by Leibniz corresponds to God's wisdom, as distinct from his power. Wisdom provides an independent reason for God's excellence, as by virtue of wisdom "his machine lasts longer and moves more regularly than those of any other artisan whatsoever."⁴²

Two main parameters determine a clock's perfection: duration and precision. Even duration must actually concern the machine's state of functioning, since the survival of a broken clock, its mere persistence as a material object, cannot be a sufficient mark of perfection in Leibniz's sense, as something that an average buyer would consider a good reason for choosing that clock. After all, a machine's lifetime is usually identified with the period of its ability to perform its function. Thus, it appears that in Leibniz's view the perfection of both clocks and worlds is to be evaluated according to functional standards. The more a machine is perfect, the less it requires assistance or adjustments in order to prolong its lifetime and proper work.

This suggests a first conclusion. In light of the above, Leibniz's adoption of the world-as-clock metaphor, usually regarded as the hallmark of mechanism, turns out to be committed to a functional and therefore teleological concept of the machine. Furthermore, the extension of the clock analogy to express the relation between creator and world reveals that teleology and functions may play a crucial role in assessing the degrees of perfection of different worlds.

3.2. Living bodies

A clockwork structure is also typically ascribed by Leibniz to living bodies. In their case, however, the application of the clock metaphor is marked by more ambivalence. On the one hand, he stresses that analogy so as to foster a fully mechanistic account of organic processes.⁴³ When Clarke rejects pre-established harmony by arguing that the denial of the soul's influence on the body would either make human actions supernatural or turn the human being into "as mere a machine as a clock,"⁴⁴ Leibniz does not hesitate to choose the latter but restricts mechanism to the body alone: "For man does not act supernaturally, and his body is truly a machine acting only mechanically, and yet his soul is a free cause."⁴⁵

Moreover, as Clarke claims that, based on Leibniz's concept of miracles, even "the generation and formation of plants and animals" should be considered miraculous,⁴⁶ Leibniz insists on the mechanical character of living bodies: "Whatever

is performed in the body of man and of every animal is no less mechanical than what is performed in a watch. The difference is only such ought to be between a machine of divine invention and the workmanship of such a limited artist [*ouvrier*] a man is.⁴⁷

On the other hand, Leibniz sometimes so stresses the difference as to represent clocks as the opposite of living bodies. First, mechanisms *per se* are not alive insofar as they are not animated by a soul. They can imitate living beings, but life proper requires perception in the soul; “otherwise it will be only an appearance, like the life which the savages in America attributed to watches and clocks.”⁴⁸ As the soul is the only truly unifying principle, clocks also lack genuine substantial unity.⁴⁹

Contrasted with unified, animated bodies, mechanical timepieces appear to be mere aggregates of extended parts. Thus, they serve as a paradigm of material bodies as such: “All bodies have parts, therefore they are no more than heaps or multitudes, like a flock of sheep, or a pond full of water drops and fish, or a clockwork full of gears and components.”⁵⁰ This perspective results in grouping artificial machines together with inorganic masses. In the *New System*, both are compared with social and natural collective entities and contrasted with natural machines, which alone display a true unity: “Such a unity could not occur in the machines made by a craftsman or in a simple mass of matter, however organized it may be; such a mass can only be considered as an army or a herd, or a pond full of fish, or like a watch composed of springs and wheels.”⁵¹

Even natural inorganic materials like salts, minerals, and metals turn out to be more similar than living bodies to clocks:

It is true that there appear to be species which are not really *unum per se* (i.e. bodies endowed with a genuine unity, or with an indivisible being which makes up their whole active principle), any more than a mill or a watch could be. Salts, minerals and metals could be of this nature, that is, simple structures [*contextures*] or masses in which there is some regularity.⁵²

Here, the clock metaphor appears to apply to virtually anything but living bodies. Having a regular structure is sufficient to be like a clock but not for being alive. Immediately afterwards, however, Leibniz points out that inanimate and animated bodies are similar in the respect that the species of each body is sufficiently determined by its physical structure, so we can classify any given body without considering a soul that might unify it:

But both kinds of bodies, animate bodies as well as lifeless structures [*contextures sans vie*], will fall into species according to their inner constitutions [*seront spécifiés par la structure intérieure*]; since even with the former – the animate ones – the soul and the machine is each sufficient by itself to determine [the species], since they agree perfectly. [...] Thus, when things are to be ranked into species it is useless to dispute about substantial forms.⁵³

Thus, even leaving aside the issue of the unifying principle, some difference between living and non-living bodies should be apparent from the bodies

themselves.⁵⁴ How, then, does the inner structure of a living body differ from that of lifeless matter and artefacts? Leibniz's well-known answer consists in his doctrine of natural machines. He maintains that the difference between natural and artificial machines is not merely one of degree, as though the former were simply more complex than the latter, but an essential one, since it involves the infinite: "We must then know that the machines of nature have a truly infinite number of organs [...]. A natural machine still remains a machine in its least parts."⁵⁵ This is why natural machines require "infinite wisdom and power."

[...] the whole of *nature* is, so to speak, the *workmanship of God* [*artificium Dei*], indeed, so much so that any natural machine you may choose consists of a completely infinite number of organs (which is the true and insufficiently appreciated distinction between the natural and the artificial).⁵⁶

The difference, however, is not as clear as it appears intuitively. Why should the nesting of structures that is typical of natural machines, every part of which is itself a smaller machine, not pertain to every kind of body, whether natural or artificial, whether living or otherwise? Why not consider the world itself as the top-level machine whose components are machines down to their smallest parts? After all, this corresponds to the mechanistic worldview, as Leibniz himself sometimes suggests.⁵⁷

In terms of mere structures, it is difficult to establish a clear-cut division between natural machines and the rest of the physical world. However, there is a precise sense in which artificial machines are not machines down to their smallest parts. If we take the term 'machine' to include in its meaning a functional character, then artefacts turn out to be machines only down to a certain level of the analysis of wholes into parts. Whereas in a living body all the parts and parts of parts are designed to serve the functions of their respective whole, the components of an artefact (e.g., the wheels of a clock) are made up of parts that may not themselves be machines. Indeed, it is in such functional terms that Leibniz characterizes natural vs. artificial machines in *Monadology*:

Thus each organized body of a living being is a kind of divine machine or natural automaton, which infinitely surpasses all artificial automata. For a machine constructed by man's art is not a machine in each of its parts. For example, the tooth of a brass wheel has parts or fragments which, for us, are no longer artificial things [*qui ne nous sont plus quelque chose d'artificiel*], and no longer have any marks to indicate the machine for whose use the wheel was intended. But natural machines, that is, living bodies, are still machines in their least parts, to infinity. That is the difference between nature and art, that is, between divine art and our art.⁵⁸

In saying that the wheel tooth has parts that, "for us, are no longer artificial," Leibniz in fact conflates the artificial and what we would rather term 'artefactual' (i.e. made for some intended purpose). Those parts are said to lack artificiality "for us"

insofar as they are not designed for the intended use of the wheel. In functional terms, the clock's wheels are not composed of further machines, although in merely structural terms they presumably are, namely insofar as 'machine' denotes any composite entity, the behaviour of which is entirely determined by its structure and the laws of nature.⁵⁹ Moreover, when Foucher takes Leibnizian unities to be merely functional, as clocks are,⁶⁰ Leibniz vigorously rejects that interpretation. For him, the functional unity displayed by a clock is by no means sufficient to constitute a substantial unity.⁶¹

Further textual evidence supports this position regarding the functional meaning of 'machine'. The incipit of *Corpus hominis* shows that the functional and teleological account of both living bodies and artificial machines was already fully in place by the early 1680s. Here, Leibniz uses the clock analogy to argue that every sort of machine is best characterized in terms of its function or intended use:

The human body, like the body of any animal, is a sort of machine. Any machine, moreover, is best defined in terms of its final cause, so that in the description of the parts it is therefore apparent in what way each of them is coordinated with the others for the intended use. Thus one who is to describe a given clock will say that it is a Machine made to display equal divisions of time [...].⁶²

According to this text, each animal body is primarily intended to conserve a certain species of machine of perpetual motion. A later text elucidates the functions of the human machine by subordinating conservation to the higher end of wisdom: "I would think that even the animal's anatomy is to be treated by the method of ends, e.g., by considering the human body as a machine devised for the sake of propagating wisdom, from which [result] both the organs of cognition and the conservation of the animal and the species."⁶³

With a dash of rational reconstruction, we may distinguish three levels of body unification: the structural, the functional, and the substantial. Artificial machines such as clocks are both structurally and functionally unified. They share the former feature with all natural bodies, for even inanimate matter behaves mechanically and is in this respect comparable with a machine. By contrast, inanimate matter has no functional unification, although it may of course serve some purpose in the overall economy of creation. Functional unification belongs to living bodies down to their tiniest parts; it also belongs to artificial machines, but only to the limited extent that their parts are designed to contribute to the purpose of the whole. Finally, substantial unification is not a strictly physical property, since it is effected by the soul; thus, it pertains to animated bodies alone.

The intermediate position of clocks in the scale of unification explains why they can serve as a model for both inorganic and living bodies. Framed from the structural point of view, clocks accord with the former, but from the functional point of view they are comparable only with the latter. Indeed, it is only by adopting the functional and teleological perspective that we can view natural machines as divine artefacts. Once again, however, considering the functions and purposes of clocks and

bodies evokes the concept of perfection. *Qua* artefacts, natural machines share the standard of perfection that applies to all artefacts (see above); as Leibniz explains to Masham, they are designed so as to keep functioning without continual maintenance by their maker.⁶⁴

3.3. God and soul

Of course, the divine clockmaker is “infinitely more skilled” than any human clockmaker,⁶⁵ but the criteria of excellence are the same for both. In terms of precision and regularity, God can even be compared with the clock itself, as Leibniz did in 1677. When Nicholas Steno objected that the theological application of the principle of sufficient reason would introduce a “mechanical God,” Leibniz warned against this “metaphorical expression” but also pointed out its correct interpretation: “The sense is that God acts as determinedly as a clock; indeed, even the reason why the clock acts determinedly is to be credited to the determined way that God acts, namely the most perfect way.”⁶⁶

The functional standards of the perfection of clocks are so meaningful to Leibniz as to justify the extension of the clock metaphor not only to God but also to the human soul: “I have compared the soul with a clock only with regard to the regulated precision of its changes, which is only imperfect even in the best clocks, but which is perfect in the works of God. And one can say that the soul is a most exact immaterial automaton.”⁶⁷

This is even more significant when, on the other hand, the soul is expressly contrasted with the clock. As noted above, both clocks and mills feature in closely related metaphors as examples of fully inspectable machines. Indeed, the comparison of clock and soul provides a variant of Leibniz’s famous mill argument to prove that perception cannot be a mechanical process. It is as impossible to find the origin of perception in the tiniest structures of living bodies as to find it either “in a watch, where the constituent parts of the machine are all visible, or in a mill, where one can even walk around among the wheels. For the difference between a mill and a more refined machine is only a matter of greater and less.”⁶⁸ Here again, the ambivalence of the mechanical analogy depend on whether machines are considered from the merely structural or from the functional point of view.

3.4. Body and soul

The automatic character that Leibniz ascribes to both soul and body is a necessary precondition of pre-established harmony. Leibniz even praises Wolff for noting that pre-established harmony can be usefully illustrated by comparing the faculties of the soul with the parts of a machine.⁶⁹ He does not hesitate to interpret Locke’s “uneasiness” as “the disquiet of our clock,” thereby comparing it with the restless swing of the clock pendulum.⁷⁰

At the same time, that automatic character makes it possible to describe the relation between soul and body in terms of two synchronized clocks. From the 1880s until only recently, scholars have debated whether the two-clock analogy should be traced back to Geulincx (as suggested by Edmund Pflleiderer, who took this alleged source as evidence of Leibniz’s plagiarism from Geulincx) or rather to the Cartesian

milieu.⁷¹ In fact, the first to realize the possible application of the clock metaphor to Leibniz's hypothesis of concomitance was Foucher; chronological evidence suggests that his remarks were the immediate source of Leibniz's analogy, as even Pfliederer eventually recognized.⁷² If the soul is conceived as a kind of machine, observes Foucher, then prearranging its modifications so that they correspond to the motions of the body without there being any causal interaction between them is no more impossible for God than making two clocks strike synchronously.⁷³ Thus, the clock metaphor provides an argument for maintaining that pre-established harmony is possible.

Leibniz immediately grows fond of this comparison and extends it to all three systems of soul-body commerce, which are thus compared with the three possible ways of synchronizing two clocks: mutual influence, perpetual maintenance, and "natural accord," which means an accord that follows from the clocks' own natures. While the terms of the comparison have been widely discussed, there is an aspect that has largely been overlooked and has to do with the much debated issue of the difference between the occasionalist and harmonist accounts.⁷⁴ Using the clock metaphor, Leibniz often emphasizes that the difference between these two systems lies not only in how the creator's causal agency is exerted but also in the intrinsic qualities of the artefacts. The clocks corresponding to occasional causes are described as "bad" precisely because they need perpetual maintenance, "as if a man were charged with constantly synchronizing [*accorder*] two bad [*mechantes*] clocks which are in themselves incapable of agreeing."⁷⁵ This is the same argument later advanced against Newtonian cosmology; a machine that needs mid-course corrections along the way must be defective and thus reveals the inadequate technical skills of its maker.

By contrast, pre-established clocks are praised as good and accurate. The clockmaker makes them "from the outset so accurate and good that they can keep together [*s'accorder*] by their own structure."⁷⁶ Accordingly, soul and body are brought into harmony with one another "by an exact ordering [*reglement*] of each of these two beings in isolation, such that they can agree in virtue of their own natures, which is the most beautiful and the most worthy of God."⁷⁷ Pre-established harmony requires perfectly functioning and perfectly adjusted machines, such as only the most perfect maker can produce.⁷⁸

4. Conclusions

Although most of the clock analogies considered so far may not appear particularly innovative with respect to the early modern background,⁷⁹ the full range of meanings that they come to cover in Leibniz's epistemology and metaphysics is impressive. In light of the considerations discussed above, Leibniz's use of the clock metaphor turns out to be less ambivalent than at first appears; it originates in the sheer ambivalence of the early modern concept of machine, which may denote either all that exhibits a unified structure or be restricted to what enjoys functional unification. *Qua* machines, clocks can be viewed either as paradigmatic examples of mechanical structure or as typical artefacts, that is as functional devices. Of course, as they lack any metaphysical principle of substantial unification, they cannot count as substances in the way that living machines can. However, it would be incorrect to

infer that they do not enter the metaphysical scale of the perfection of beings. In fact, the functional, artefactualist consideration of clocks dominates in many of the same contexts in which the concept of perfection also becomes prominent. As I have shown, this is no mere coincidence; on the contrary, it agrees with recent suggestions that Leibniz's concept of perfection – at least when specified in terms of relative perfection – involves a teleological component that is also essential to the functional concept of machine.⁸⁰

Remarkably, even the two-clock analogy has finally confirmed the point repeatedly made above. If we are to compare and evaluate the structures of different clocks, we must consider their relative perfection, which consists in their functionality to some intended purpose and not in the brute fact that all machines, however poorly constructed, follow the laws of nature.⁸¹ My suggestion is therefore that, in most if not all of its occurrences, the clock analogy is not meant by Leibniz to be in any relevant sense reductionist. In his view, even the teleological account of living bodies indeed appears inseparable from describing them in terms of machines. In the end, teleology need not be reconciled with mechanism, for Leibniz's clocks show that functions and purposes are already intrinsic features of the machine.

Appendix: Leibniz's Remarks on Henry Sully⁸²

Remarques sur le Discours de Mr. H. S. touchant la maniere de gouverner les Horloges à Pendule & les Montres à Spirale.

Il seroit fort à souhaiter qu'il y eût un Ouvrage sur *l'Horlogerie*, propre à faire entendre toute la *Pratique de l'Art*, non seulement dans le *principal*, qui est la *Mesure du Temps*, mais encore par rapport à l'accessoire, qui consiste en quantité de jolies inventions pratiquées par les Maîtres de l'Art. L'Auteur de ce Discours, qui a joint la *Theorie* à la *Pratique*, & qui a encore le talent de s'exprimer assez bien, y seroit très-propre.

La partie *Arithmétique*, par rapport à la Denture, a été bien traitée en Latin par MR. OUGHTREAD.

Ce qui appartient au *Réglement des Pendules*, c'est à dire des *Poids en vibration*, a été bien expliqué par MR. HUGUENS premierement dans un Discours Flamand, qu'il fit imprimer lors qu'il donna au public les premières *Pendules*; & puis plus amplement & plus entierement dans son Ouvrage Latin, *de Pendulis*, où il rend raison de la *Cycloïde*. Mais il y auroit encore quelque chose à dire de la Nature des *Vibrations des Ressorts*, dont l'égalité est vérifiée par celles des *Cordes touchées*, qui rendent toujours le même ton, quand elles sont également tendues.

Ce fut environ en 1674. qu'on fit paroître dans le Monde le premier *Ressort spiral* réglant la Montre par ses vibrations. Je fus alors à Paris, où MR. HUGUENS fit executer cette invention par MR. TURET fameux Horloger. MR. HOOK luy fit une querelle là-dessus, prétendant dans un Ecrit public d'avoir déjà fait auparavant une Montre réglée par les *vibrations d'un Ressort*; Mais on n'avoit encore point vu de *Montres* de sa façon, au moins avec un *Ressort vibrant spiral*. Un François nommé MR. HAUTE-

FEUILLE intenta même un procès au Parlement de Paris à MR. HUGUENS, prétendant que c'estoit son invention, mais il fut débouté.

Il y a des *Horloges à Pendule* d'une espece toute particuliere, ou [sic] le *Poids vibrant* ne va pas en *allant & retournant*, mais toujours d'un même côté. Ces Horloges ont cela de particulier, qu'elles vont sans bruit, & ont été recherchées quelquesfois par ceux, qui manquent de sommeil et veulent avoir des Horloges dans leurs Chambres, qui ne les empêchent pas de dormir. MR. HUGUENS en a fait un Discours, qui n'a pas été imprimé; où au lieu de *Cycloïde* il a employé une espece de *Solide parabolique* pour en rendre les vibrations égales.

Lorsque MR. HUGUENS publia son *Ressort vibrant à spirale*, je publiay un peu après dans le JOURNAL DES SÇAVANS un autre *Principe d'égalité*, qui n'est pas *phisique* [sic], comme est la supposition de l'égalité des vibrations des *Pendules* ou des *Ressorts*, mais purement *mécanique*, consistant dans une parfaite *Restitution de ce qui doit vibrer*, puisqu'alors les Vibrations sont égales, parcequ'elles sont justement les mêmes. MR. HOOK en écrivant contre MR. HUGUENS dit, qu'il avoit aussi eu la même pensée que moy, mais qu'il avouoit de ne l'avoir point fait paroître. J'ay pensé quelquesfois à faire executer cette Invention, qui promet des nouveaux avantages assez considerables; Mais j'ay toujours manqué de l'assistance d'un bon Maître, qui eût une bonne volonté d'y travailler; les Ouvriers ordinaires, sur tout en Allemagne, n'ayant point d'envie de s'écarter de leur routine. Cependant une *Montre* ou Horloge, faite de cette maniere, pourroit se passer de la *Fusée*, & iroit de même, quand on en redoubleroit le *Poids* ou la force du *premier Mobile*. Elle seroit aussi plus propre aux voyages de mer que l'*Horloge à Pendule*.

Par rapport aux *Ressorts à spirale*, dont on se sert dans les *Montres de poche*, il seroit important d'examiner, combien l'Air a de l'influence sur les *Vibrations* d'un tel *Ressort*, & particulièrement, combien le froid & le chaud en changent l'égalité.

Entre les Causes, qui changent la justesse de l'*Horloge* ou de la *Montre* vulgaire, est aussi le *Temps*, qui se perd en les remontant, lorsqu'elles sont arrêtées pendant ce temps là, comme il arrive ordinairement; Car le temps de la remonte n'est pas toujours le même: Mais des bonnes *Pendules*, & d'excellentes *Montres* ont, ou peuvent avoir une construction, suivant laquelle elles continuent d'aller, pendant qu'on les remonte.

Dans la Comparaison de la *Resistence de l'Air aux Vibrations du Balancier des Montres*, avec la *Resistence que l'Air fait aux Oscillations des Pendules*, il semble qu'il faudroit rabattre quelque chose, par ce que le chemin du *Poids*, qui va & vient, est plus grand que celui du *Balancier*.

Il est vray, que la *Pendule* a beaucoup plus de part au gouvernement de l'*Horloge*, que le *Ressort à spirale*, n'en a au gouvernement de la *Montre*. Outre la preuve qu'on en a alleguée, en voicy une autre tout aussi sensible; C'est que l'*Horloge à Pendule* ne sçauroit aller, à moins qu'on ne mette la *Pendule* en vibration; mais la *Montre* va par sa propre force, & fait vibrer le *Ressort spiral*.

Les *longues Pendules à Secondes* font des Vibrations assez égales, par la raison, qu'un si petit *Arc de Cercle* d'un si grand Rayon ne sçauroit guères être distingué sensiblement d'un *Arc de Cycloïde*. Cependant il faut avouër, que le *premier Mobile* & le *Roüage* ont encore quelque influence sur le *Temps* de la *Pendule*, puisque dans l'*Axe de sa vibration* elle tombe dans la *Denture*, & agissant sur les dents qui resistent, ne sçauroit

vibrer avec une liberté entière, ce qui fait aussi, que la *Pendule* est un peu avancée par une grande augmentation de la force du *premier Mobile*.

On pourroit régler la Figure de la *Fusée des Montres* par l'*Expérience*, en bandant le *Ressort* avec des *Poids*, & marquant par quelque *addition de poids*, jusqu'où le *Ressort* est bandé; & les *Diamètres* des endroits de la *Fusée* seront réciproquement comme les *Poids*, qui peuvent tenir le *Ressort* dans l'état, où il est en agissant sur cet endroit de la *Fusée*.

Je ne veux point parler icy de la *Reduction* du *Tems égal* au *Tems apparent*, cependant je reconnois, que si la Machine de l'*Horloge* ou de la *Montre* faisoit cette *Reduction* par elle même, suivant ce que l'ingenieux *Auteur* de ce *Discours* nous fait esperer, ce seroit quelque chose de très-beau & de très-commode.

References

¹ Abbreviations: A+series+volume = Leibniz, G.W., *Sämtliche Schriften und Briefe* (Berlin: Akademie Verlag, 1923ff.); AG = Leibniz, G.W., *Philosophical Essays*, trans. R. Ariew and D. Garber (Indianapolis, Ind.: Hackett, 1989); GP+volume = Leibniz, G.W., *Die philosophischen Schriften*, ed. C.I. Gerhardt (Berlin: Weidemann, 1875–1890); L = Leibniz, G.W., *Philosophical Papers and Letters*, trans. L.E. Loemker, 2nd ed. (Dordrecht: Kluwer, 1989); LCA = Leibniz, G.W., and Clarke, S., *Correspondence*, ed. R. Ariew (Indianapolis and Cambridge: Hackett, 2000); LWG = *Briefwechsel zwischen Leibniz und Christian Wolff*, ed. C.I. Gerhardt (Halle: Schmidt, 1860); RB = Leibniz, G.W., *New Essays on Human Understanding*, ed. P. Remnant and J. Bennett (Cambridge: Cambridge University Press, 1996); WF = *Leibniz's New System and Associated Contemporary Texts*, ed. R.S. Whoolhouse and R. Francks (Oxford: Oxford University Press, 1997).

² Leibniz, G.W., *Nouveaux essais sur l'entendement humain*, Préface, A VI vi, 66, transl. RB. Further passages mentioning both timepieces and mills are quoted below: cf. sections 3.2 and 3.3 along with footnotes 3, 20, and 68.

³ Leibniz, G.W., *Wilhelmus Pacidius* (1671–1672?), A VI ii, 512: “Mechanicae referre exponi rationem procurandi motum celerrimum ad molendina, tardissimum ad horologiorum durationem, regularissimum (qualis penduli est) ad certitudinem eorundem.”

⁴ See esp. the section *Technica* in the newly published volume of the Akademie-Ausgabe (A VIII ii).

⁵ Cf. *Extrait d'une lettre de Mr. Leibniz à l'Auteur du Journal, touchant le principe de justesse des horloges portatives de son invention*, A III i, 181–201, first published in *Journal des Sçavans* (25 March 1675): 93–96. Leibniz contrasts his principle, described as purely mechanical, with Huygens's principle, which “dépend d'une observation Physique” (A III i, 194). An account of Huygens's invention had appeared in a previous issue of the journal: “Extrait d'une lettre de Mr. Hugins à l'Auteur du Journal, touchant une nouvelle invention d'horloges tres-justes et portatives,” *Journal des Sçavans* (25 Februar 1675): 68–70.

⁶ See the text in the Appendix.

⁷ Leibniz, G.W., *Nouveaux essais*, III vi §39, A VI vi, 326, transl. RB.

⁸ On the concept of ether see Beeley, P., *Kontinuität und Mechanismus: Zur Philosophie des jungen Leibniz in ihrem ideengeschichtlichen Kontext* (Stuttgart: Steiner, 1996), 145–150.

⁹ See Leibniz, G.W., *Hypothesis physica nova*, §58, A VI ii, 249–250: “Nam aether circulatione sua res justo densiores aut dispergit, aut cum non potest, deprimit: ex hoc oritur *gravitas*, ex illo *Elatere*. Desiderant omnes philosophi recentiores physica mechanice explicari: id hic perfecte praestatur. Quemadmodum enim omnia naturae, ex hypothesi nostra; ita et omnia artis horologia et machinamenta consensu communi vel ex *gravitate* vel ex *Elatere*, vel ambobus junctis pendent. Ex gravitate omnia horologia in quibus naturalis ponderis alicujus gravitas

vectibus, rotis, trochleis, cochleis *tardatur* [...]. Ex vi Elastica pendent horologia illa minora portatilia vi quadam tendenda.” Cf. Leibniz to Oldenburg, 11 March 1671, A II i², 144: “Omnia vel naturae vel artis, ut sic dicam, horologia et machinamenta, vel a Gravitate, vel ab Elatere pendere, re expensa nemo diffitebitur: utramque, unicum quem explicui motum aetheris circularem, modo supponatur, consequuturam non est difficile cogitatu. Atqui hic est cardo totius contemplationis meae.”

¹⁰ The literature on Leibniz’s metaphors, especially the clock metaphor, is not abundant: see Albus, V., *Weltbild und Metapher. Untersuchungen zur Philosophie im 18. Jahrhundert* (Würzburg: Königshausen & Neumann, 2001), 131–149; Marras, C., *Metaphora translata voce: Prospettive metaforiche nella filosofia di G.W. Leibniz* (Firenze: Olschki, 2010), 169–171; and Neumann, H.P., “Machina Machinarum. Die Uhr als Begriff und Metapher zwischen 1450 und 1750,” *Early Science and Medicine* 15 (2010): 122–191, at 162–172. A somewhat questionable reading is offered by Mayr, O., *Authority, Liberty and Automatic Machinery in Early Modern Europe* (Baltimore and London: John Hopkins University Press, 1986), 70–73, 98–101.

¹¹ “[...] pendulorum proprietates mirabiles” (Leibniz to Conring, June 1678, A II i², 632). In *On the Elements of Natural Science* (1682–1684), L, 282, the “invention of the chronometer after the equality of pendulum vibrations was known” is mentioned as an example of the “combinatorial” method.

¹² See, e.g., Leibniz to Burnett, 22 Nov. 1695, GP III, 169: “Mais ce que des artisans ont fait de cette nature estoit sans le sçavoir et comme en tâtonnant. Aussi ces horloges n’ont jamais esté louées ny recherchées pour leur exactitude. L’invention de M. Hugens est une suite des découvertes de Galilei. Les anciens ouvriers ne sçavoient rien de l’egalité des vibrations.” Cf. *De usu geometriae* (1676), A VI iii, 445: “Huc usque rem produxit Galilaeus, duoque posteritati absolvenda reliquit, applicationem Penduli ad Horologium, quo numerandi abesset labor, et inventionem lineae curvae, cuius evolutione alia rursus curva describeretur a pendulo, quae cordarum circuli proprietatem haberet.”

¹³ “[...] la marque de la veritable science” (Leibniz to Malebranche, 22 June (2 July) 1679, A II i², 718).

¹⁴ A similar comparison between conjecturing about the internal parts of a clock and formulating hypotheses regarding the inner structure of natural bodies appears in an influential passage of Descartes’s *Principia philosophiae*, IV, §203, in *Oeuvres*, ed. C. Adam and P. Tannery (Paris: Vrin-CNRS, 1964–74), vol. VIII i, 326. See Laudan, L., “The Clock Metaphor and Hypotheses: The Impact of Descartes on English Methodological Thought, 1650–1670,” in Laudan, L., *Science and Hypothesis: Historical Essays on Scientific Methodology* (Dordrecht: Reidel, 1981), 27–58.

¹⁵ Leibniz, G.W., *Summa Hypotheses Physicae Novae* (1671), A VI ii, 327: “Scilicet philosophi ingeniosi plerique omnes, qui nostro quoque seculo ad rerum corporearum naturam interiorem [...] colligendam accessere, eam viam institere, qua uti posset homo ad horologium adductus, qui aperire, huc illuc versare, attingere non posset, et conjectare tamen aliquid de interiore structurae motusque ratione ex eo quem videret, indicis progressu, aut quem audiret campanulae sono juberetur.”

¹⁶ Leibniz, G.W., *Summa Hypotheses Physicae Novae* (1671), A VI ii, 327: “Is enim si rei Automatariae peritus est, comminiscetur aliquid quo admissio, aut etiam elaborato, evenirent ea omnia quae in horologio extrinsecus sentit, quod causae possibilis suppositae genus philosophi *Hypothesin* vocant.”

¹⁷ Leibniz to Conring, May 1671, A II i², 153: “Si me Automatopeus ad horologium a se confectum adducat, jubeatque ut divinam constructionem: potero fortasse constructionem exhibere, quae idem praestet, quod Horologium monstratum: quia eadem phaenomena pluribus modis produci possunt: ipsum praecise modum quo Artifex usus est, nisi dissoluto

opere definire non possum. Si qua tamen hypothesis non tantum experimentis praesentibus satisfaciatur, sed et prophetiam quandam non fallentem praebet de futuris, ei valde fidendum est.”

¹⁸ Leibniz, G.W., *Summa Hypotheses Physicae Novae* (1671), A VI ii, 329: “Uti si quis ad Horologium adductus, videat locum sole illustrari, et corpus aliquod opacum luci eius objectum umbram efficere, hanc autem in horae numerum incidere, is certe ad alias quam quas videt excogitandas causas, fingendumque nescio quem insensibilis corporis umbram huc illuc agentis progressum cum ratione transire non potest.”

¹⁹ Leibniz, G.W., *Summa Hypotheses Physicae Novae* (1671), A VI ii, 341: “[...] nondum satis constare nobis de hoc Horologio Mundi, quantum perfecta Hypothesis requirit.”

²⁰ Leibniz, G.W., *Discours de métaphysique* (1686), A VI iv, 1543. Cf. *Nouveaux essais*, Préface, A VI vi, 68: past philosophers and physicians “sauvoient les apparences en forgeant tout exprés des qualités occultes ou facultés [...]; comme si les montres de poche marquoient les heures par une certaine faculté horodeictique sans avoir besoin de rouës, ou comme si les moulins brisoient les grains par une faculté fractive.”

²¹ Leibniz, G.W., *De ipsa natura sive de vi insita actionibusque creaturarum* (1698), GP IV, 505, transl. AG, 157.

²² Leibniz, G.W., *De modo perveniendi ad veram corporum analysin et rerum naturalium causas* (1677), A VI iv, 1971–1972, transl. L, 173. Cf. Butts, R.E., “Leibniz on the Side of the Angels,” in *The Natural Philosophy of Leibniz*, ed. K. Okruhlik and J.R. Brown (Dordrecht: Reidel, 1985), 207–226, at 209.

²³ Cf. Leibniz, G.W., *Hypothesis de systemate mundi* (1671), A VI ii, 294: “Ex Hypothesi nostra totus mundus Automati instar est, ex infinitis rotis eccentricis sibi implicitis vel trochleis in puncto aut per se, aut per funem se tangentibus, compositi.”

²⁴ Cf. Leibniz, G.W., *Conversation du Marquis de Pianese et du Pere Emery* (1679–1681), A VI iv, 2268: “Si je me trouvois transporté dans une nouvelle region de l’univers, où je voyois des horloges, des meubles, des livres, des bastimens, j’engagerois hardiment tout ce que j’ay que cela seroit l’ouvrage de quelque créature raisonnable, quoyqu’il soit possible absolument parlant, que cela ne soit pas.”

²⁵ Leibniz to Jakob Thomasius, 20 (30) April 1669, A II i², 35, transl. L, 101. Cf. Moll, K., *Der junge Leibniz*, vol. III (Stuttgart and Bad Cannstatt: Frommann-Holzboog, 1996), 67, 235; and Nunziante, A.M., *Organismo come armonia. La genesi del concetto di organismo vivente in G.W. Leibniz* (Trento: Verifiche, 2002), 47–50.

²⁶ Leibniz to Jakob Thomasius, 19 (29) December 1670, A II i², 119: “Par est physicorum recentium ratio, qui causas materiales rerum quaerentes, rationales negligunt, cum tamen in eo potissimum eluceat sapientia auctoris, ita instituisse horologium mundi, ut cuncta deinde, velut necessitate quadam ad summam omnium harmoniam consequerentur.”

²⁷ Leibniz, G.W., *Conversation du Marquis de Pianese et du Pere Emery* (1679–1681?), A VI iv, 2269: “Il y a deux extremités à éviter quand il s’agit des loix de l’univers: car les uns croient que tout y va avec une nécessité machinale, comme dans une horloge; les autres se persuadent; que la souveraineté de Dieu consiste dans une liberté sans regle. Le juste milieu est de considerer Dieu non seulement comme le premier principe et non seulement comme un Agent libre.”

²⁸ Leibniz, G.W., *Sentiments de Socrate* (1678–1680?), A VI iv, 1385, transl. AG, 282. Cf. Garber, D., *Leibniz: Body, Substance, Monad* (Oxford and New York: Oxford University Press, 2009), 233–234.

²⁹ Leibniz, G.W., *Sentiments de Socrate* (1678–1680?), A VI iv, 1386: “[...] si le monde estoit l’effect d’une intelligence, tout seroit fait de la maniere la plus parfaite qui eût esté possible. C’est pourquoy je croyois que celui qui voudroit rendre raison pour quoy les choses

s'engendrent ou perissent, ou subsistent, devrait chercher ce qui seroit convenable à la perfection de chaque chose."

³⁰ Cf. Wilson, M.D., "Leibniz's Dynamics and Contingency in Nature," in *Motion and Time, Space and Matter. Interrelations in the History of Philosophy and Science*, ed. P.K. Machamer and R.G. Turnbull (Columbus: Ohio University Press, 1976), 264–289, at 285.

³¹ See, e.g., Leibniz to Bourguet (1716), GP III, 590: "Newton croit que la force de l'Univers va en diminuant, comme celle d'une montre, et a besoin d'être retablie par une action particuliere de Dieu, au lieu que je soutiens que Dieu a fait les choses d'abord, en sorte que la force ne sauroit se perdre."

³² Leibniz to Bernoulli, 20 (30) September 1698, A III vii, 913: "Neque enim putandum est naturam praescripto Dei obedire, velut edicto promulgato subditi parent, aut Deum ipsam semper velut exorbitantem in viam cogere, et opus suum corrigere, ut mali automatopoei solent; sed Leges dando simul dedisse rebus vim nisumque eas observandi, in quo ipso consistit natura Entelechiarum."

³³ Cf. Favaretti Camposampiero, M., "The Direction of Motion: Occasionalism and Causal Closure from Descartes to Leibniz," in *Occasionalism: From Metaphysics to Science*, ed. M. Favaretti Camposampiero, M. Priarolo and E. Scribano (Turnhout: Brepols, forthcoming).

³⁴ Leibniz, G.W., Second Letter to Clarke (1715), GP VII, 358: "Je ne dis point que le Monde corporel est une Machine ou Montre qui va sans *l'interposition* de Dieu, et je presse assés que les Creatures ont besoin de son influence continuelle: mais je soutiens que c'est une montre qui va sans avoir besoin de sa *correction*: autrement il faudroit dire que Dieu se ravise."

³⁵ Leibniz's Fifth Letter, §101, GP VII, 414, transl. LCA, 60.

³⁶ Cf. Vailati, E., *Leibniz and Clark: A Study of Their Correspondence* (Oxford and New York: Oxford University Press, 1997), 37–42.

³⁷ Leibniz's First Letter, §4, GP VII, 352, transl. LCA, 4.

³⁸ Cf. Clarke's First Reply, §4, in LCA, 6; and Leibniz's Second Letter, §6, GP VII, 357: "Ainsi la raison qu'on allegue pour louer la Machine de Dieu, de ce qu'il l'a faite tout entiere, sans avoir emprunté de la matiere de dehors, n'est point suffisante."

³⁹ Leibniz's Second Letter, §6, in LCA, 9.

⁴⁰ Leibniz's Second Letter, §6, in LCA, 9.

⁴¹ Leibniz's Second Letter, §§6–7, in LCA, 9.

⁴² Leibniz's Second Letter, §6, in LCA, 9.

⁴³ See Leibniz, G.W., *Machina animalis* (1677), edited by Pasini, E., *Corpo e funzioni cognitive in Leibniz* (Milano: Angeli, 1996), 210–211. As Pasini observes (*ibid.*, 111), here Leibniz still rejects any reference to functions in a machine's description, a sharp contrast with his later view (see below).

⁴⁴ Clarke's Fourth Reply, §33, in LCA, 34.

⁴⁵ Leibniz's Fifth Letter, §95, GP VII, 413, transl. LCA, 58.

⁴⁶ Clarke's Fourth Reply, §43, in LCA, 35.

⁴⁷ Leibniz's Fifth Letter, §116, GP VII, 418, transl. LCA, 63.

⁴⁸ Leibniz, G.W., *Nouveaux essais*, III x §22, A VI vi, 348–349, transl. RB.

⁴⁹ Cf. Leibniz's reply to Foucher, quoted below (GP IV, 494).

⁵⁰ Leibniz to Sophie and Elisabeth Charlotte, October (?) 1696, A I xiii, 48: "[...] alle Körper theile haben, mithin nichts anders seyn, als hauffen oder vielheiten, wie eine herde schaffe, oder ein teich voll waßer-tropfen und fische, oder ein Uhrwerck voll räder und zugehör."

⁵¹ Leibniz, G.W., *Système nouveau de la nature et de la communication des substances* (1695), GP IV, 482, transl. AG, 142.

⁵² Leibniz, G.W., *Nouveaux essais*, III vi §24, A VI vi, 318, transl. RB.

⁵³ Leibniz, G.W., *Nouveaux essais*, III vi §24, A VI vi, 318, transl. RB.

- ⁵⁴ Cf. Phemister, P., “Monads and Machines,” in *Machines of Nature and Corporeal Substances in Leibniz*, ed. J.E.H. Smith and O. Nachtomy (Dordrecht: Springer, 2011), 39–60.
- ⁵⁵ Leibniz, G.W., *Système nouveau* (1695), GP IV, 482, transl. AG, 142.
- ⁵⁶ Leibniz, G.W., *De ipsa natura* (1698), §2, GP IV, 504–505, transl. AG, 156.
- ⁵⁷ See, e.g., Leibniz, G.W., *Reponse aux reflexions de Bayle* (1702), GP IV, 556: “Il est vrai que le monde n’est pas un composé d’un nombre fini d’atomes, mais plutôt comme une machine composée dans chacune de ses parties d’un nombre véritablement infini de ressorts.”
- ⁵⁸ Leibniz, G.W., *Monadologie* (1714), §64, GP VI, 618, transl. AG, 221.
- ⁵⁹ A characterization of this sort is suggested, for instance, by Leibniz’s Fifth Letter, §116 and §124, GP VII, 418–419: “Tout ce qui se fait dans le corps de l’homme, et de tout animal, est aussi mécanique que ce qui se fait dans une montre [...]. Les forces naturelles des corps sont toutes soumises aux loix mécaniques [...]. [Elles] operent sans liberté, comme une montre.”
- ⁶⁰ Cf. Foucher, S., “Objections contre le nouveau système de la communication des substances,” *Journal des Savants* (Sept. 1695), GP IV, 488: “Vous apportez d’autre part une autre sorte d’unités qui sont, à proprement parler, des unités de composition ou de relation, et qui regardent la perfection ou l’achèvement d’un tout, lequel est destiné à quelques fonctions, étant organique. Par exemple, un horloge est un, un animal est un.”
- ⁶¹ Leibniz, G.W., *Éclaircissement du nouveau système* (1695), GP IV, 494: “L’unité d’une horloge dont vous faites mentions, est toute autre chez moy que celle d’un animal: celui-ci pouvant estre une substance douée d’une véritable unité, comme ce qu’on appelle moy en nous; au lieu qu’une horloge n’est autre chose qu’un assemblage.”
- ⁶² The text is edited by Pasini, E., (1996), 217–218; transl. by Smith, J.E.H., *Divine Machines: Leibniz and the Sciences of Life* (Princeton and Oxford: Princeton University Press, 2011), 290. Cf. Smith, J.E.H., (2011), 68–74. Also see Leibniz’s reaction to Stahl’s use of the clock analogy: Leibniz, G.W., *Animadversiones circa assertiones aliquas Theoriae Medicae verae Clar. Stablii*, §7, in *Opera omnia*, ed. L. Dutens, tome II/2 (Genevae: Tournes, 1768), 137. Cf. Duchesneau, F., *Leibniz. Le vivant et l’organisme* (Paris: Vrin, 2010), 137–138; Andrault, R., “The Machine Analogy in Medicine: A Comparative Approach to Leibniz and His Contemporaries,” in J.E.H. Smith and O. Nachtomy (2011), 95–114, at 98–100.
- ⁶³ Leibniz to Wolff, 9 November 1705, in LWG, 43: “Anatomiam quoque animalis finium methodo tractandam putem, ex. gr. considerando corpus humanum ut machinam propagandae sapientiae causa excogitatam, inde tum cognitionis organa, tum conservatio animalis et speciei.”
- ⁶⁴ Cf. Leibniz to Masham, 13–27 November 1705, A II iv (Vorausedition; unpagé): “Il est vray que je trouve plus philosophique d’expliquer la formation des animaux comme le reste par la machine de la nature, mais predisposée par la sagesse divine: comme il est d’un plus habile ouvrier de faire une horloge qui va bien avec moins d’aide d’une direction particuliere.”
- ⁶⁵ Cf. Leibniz, G.W., *Théodicée*, §188, GP VI, 229: “Dieu, infiniment plus habile qu’un horloger.”
- ⁶⁶ Leibniz, G.W., *Conversatio cum domino episcopo Stenonio de libertate* (1677), A VI iv, 1376: “Sensus est, Deum aequae certo agere, ac horologium, imo contra potius quod horologium certo agit ratio referenda est ad certum modum quo Deus operatur nempe perfectissimum.”
- ⁶⁷ Leibniz, G.W., *Éclaircissement des difficultés que M. Bayle a trouvées* (1698), GP IV, 522, transl. L, 495.
- ⁶⁸ Leibniz to Bayle (1702?), GP III, 68, transl. WF, 128. Cf. *Nouveaux essais*, Préface, A VI vi, 66 (quoted above); and GP VII, p. 328: “[...] in molendino aliquo vel horologio nude sumto nullum repiriri principium percipiens, quid in ipso fiat; et nihil refert, solida sint an fluida, vel ex utrisque composita, quae in machina habentur.”

⁶⁹ Leibniz to Wolff, 1706, in LWG, 56: “Bene notas ad illustrandam doctrinam Harmoniae praestabilitae prodesse, ut conferamus partes machinarum corporearum cum diversis animae ejusdem facultatibus.” Cf. Wolff, C., *Methodus serierum infinitarum* (1705), Corollarium 7, in *Meletemata mathematico-philosophica* (Halle: Renger, 1755), sect. II, 318–319. Wolff, however, interpreted the clock analogy in the more literal sense that the mind performs its operations mechanically (“mechanica ratione,” *ibid.*). Writing to Leibniz, he expanded on the corollary just mentioned by applying to the mind the structural concept of machine with all its deterministic consequences: “In Coroll. 6 [read: 7] mechanismi mentis memini, quem in analogia modi operandi in mente cum modo operandi in machinis constituo, et inter disputandum sic explicavi. Quemadmodum plures in machinis dantur partes, quarum una ad motum excitata seu determinata in motum partis alterius juxta certas motus leges necessario influit; ita similiter in mente plures dantur facultates seu Potentiae, quarum una ad cogitandum determinata juxta certas cogitandi leges in cogitationem alterius necessario influit” (Wolff to Leibniz, 5 May 1706, in LWG, 54). Leibniz may have felt uncomfortable with such a heavy emphasis on the deterministic character of mental life, but he tactfully preferred to stress the points of agreement with his young disciple without mentioning the problems.

⁷⁰ Leibniz, G.W., *Nouveaux essais*, II xx §6, A VI vi, 166: “On appelle *Unrube* en Allemand, c’est à dire inquietude, le balancier d’un horloge: on peut dire, qu’il en est de même de nostre corps qui ne sauroit jamais estre parfaitement à son aise [...]; ce qui produit un combat perpetuel qui fait pour ainsi dire l’inquietude de nostre Horloge.” I see no convincing reason to interpret disquiet and conflict here as the “opposites” of the clock’s “expected connotations” of regularity and precision, as does Riskin, J., *The Restless Clock: A History of the Centuries-Long Argument over What Makes Living Things Tick* (Chicago and London: University of Chicago Press, 2016), 104.

⁷¹ Cf. Pflleiderer, E., *Leibniz und Geulinx. Mit besonderer Beziehung auf ihr beiderseitiges Uhrengleichnis* (Tübingen: Laupp, 1884); de Vleeschauwer, H.J., “Occasionalisme et harmonie préétablie – Geulinx et Leibniz,” in *Theoria cum praxi. Akten des II. internationalen Leibniz-Kongresses*, ed. A. Heinekamp *et al.* (Wiesbaden: Steiner, 1974), 279–292; and Kulstad, M., “Causation and Preestablished Harmony in the Early Development of Leibniz’s Philosophy,” in *Causation in Early Modern Philosophy*, ed. S. Nadler (University Park: Pennsylvania State University Press, 1993), 93–116, at 99–101.

⁷² Cf. Pflleiderer, E., (1884), 72.

⁷³ Cf. Foucher, S., (1695), GP IV, 488–489.

⁷⁴ See, e.g., Brown, S., “Malebranche’s Occasionalism and Leibniz’s Pre-established Harmony: An ‘Easy Crossing’ or an Unbridgeable Gap?” in *Nicolas Malebranche: His Philosophical Critics and Successors* (Assen and Maastricht: Van Gorcum, 1991), 81–93, at 87.

⁷⁵ Leibniz, G.W., *Éclaircissement des difficultés que M. Bayle a trouvées* (1698), GP IV, 520, transl. L, 494. Cf. *Extrait d’une lettre de M.D.L. sur son hypothèse de philosophie* (1696), GP IV, 501: “La seconde maniere de faire toujours accorder deux horloges *bien que mauvaises*, pourra estre d’y faire toujours prendre garde par un habile ouvrier, qui les mette d’accord à tous momens: et c’est ce que j’appelle la voye de l’assistance” (*italics mine*).

⁷⁶ Leibniz, G.W., *Extrait du Dictionnaire de Bayle [...] avec mes remarques*, GP IV, 530, transl. WF (modified), 75.

⁷⁷ Leibniz, G.W., *Extrait du Dictionnaire de Bayle [...] avec mes remarques*, GP IV, 531, transl. WF (modified), 76.

⁷⁸ Cf. Leibniz, G.W., *Considérations sur les principes de vie et sur les natures plastiques* (1705), GP VI, 541: although there is no interaction between soul and body, “ces deux Estres d’un genre tout à fait different, se rencontrent ensemble et se repondent comme deux pendules parfaitement bien réglées sur le même pied, quoyque peutestre d’une construction toute differente.” Cf.

Leibniz to Wolff, 9 Nov. 1705, in LWG, 44: soul and body are “instar duorum Horologiorum diversissimae quidem constructionis, sed a summo tamen artifice ita temperatorum, ut dum unumquodque suas leges sequitur, perfecte inter se conspirent.”

⁷⁹ See, e.g., the overview of the modern uses of the clock analogy in Shapin, S., *The Scientific Revolution* (Chicago and London: University of Chicago Press, 1996), 32–37, 101–102, 142–143.

⁸⁰ Cf. Favaretti Camposampiero, M., “Perfection as Harmony: Leibniz’s 1715 Doctrine and Wolff’s Teleological Reformulation,” in “Für unser Glück oder das Glück anderer.” *Vorträge des X. Internationalen Leibniz-Kongresses. Hannover, 18.–23. Juli 2016*, 5 vols., ed. Wenchao Li et al. (Hildesheim: Olms, 2016), vol. 4, 465–477.

⁸¹ My reading disagrees with Scott’s arguments against Leibniz’s two-clock example mainly in that they overlook its functional and teleological strand. Cf. Scott, D., “Leibniz and the Two Clocks,” *Journal of the History of Ideas* 58/3 (1997): 445–463.

⁸² The text is transcribed from Sully, H., *Règle artificielle du tems, pour apprendre la division naturelle et artificielle du tems, et connoître toutes sortes d’horloges et de montres, et la maniere de s’en servir adroitement* (Vienne: Heyinger, 1714). Sully inserted Leibniz’s *Remarques* in an unpagged appendix after the following *Avertissement*: “Ayant fait voir cet Ouvrage en Manuscrit à cet Illustre Sçavant, Monsieur le Baron de Leibnitz, demurant présentement à Vienne, il a eu la bonté d’écrire la dessus les Remarques suivantes, dont je suis bien aise d’obliger le public.” Some years later, the text was reissued in a review of Sully’s book, *Mémoires pour l’histoire des sciences et des beaux arts* (= *Mémoires de Trévoux*, March 1718): 531–536; and eventually in Leibniz, *Opera omnia*, ed. L. Dutens, tome III (Genevae: Tournes, 1768), 502–504.