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The development of the machine paradigm

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What did God exactly, when he created the world? One of the last serious responses to this question could simplified be read in this way: God made something like a machine, respective its parts; he determined its operational principles, by defining the spatial order of the parts and their relation and their movements; and he let the machine run, by giving it a certain amount of force/energy.
The historical upcoming of this response can be located clearly in the 17th century. The cosmos had metaphorically been called a machine also in earlier times of course, but the consequence that it actually is a machine, and that it functions like a machine, was drawn for the first time then.
The superficial historical classification of this phenomenon is also clear: the early modern times are characterised by a degree of mechanisation and of the use of non-organic energy sources unknown up to then; the transformation of the material basis of the occident had begun in the Middle Ages, and after four to five hundreds years of increasing mechanical mastery of nature the conception came up that in the mode of operation of machines the explanation for all the diverse natural phenomena could also be found. The question however in which way these material changes could affect the realm of ideas in such a way needs closer inquiry.

In the following this question shall be answered in a framework of categorical development of space and time, movement (kinematics) and causality (dynamics) in regard to their historical relatedness.
To unfold this historicity of categories we start with the claim of the nowadays structural insufficiency of the above-mentioned response and also of the preceding question. Their structure of explanation is not evident anymore. To just derive the explanandum from an intentional explanans is not an evident form of explanation. At least in a scien-

tific framework we have to come to grips with the emergence of something (structurally) new by describing the relevant conditions of the immanent genetic process.
And this applies of course also to the emergence of explanatory structures themselves. And here mechanism on the one hand belongs to the transcendent and derivative kind, but already implies elements of the immanent and procedural kind. God has the role of the wilful mechanic or watchmaker, but the machine can already run independently of him. Though the world machine requires a planning creator as a last reason, the internal structure of this machine incorporates already substantial features of the transformation of the explanatory form. Because in their most consistent form the world machine demands no further interventions from the divine outside, everything is in connection with everything and nothing, neither 'matter' nor 'motion', gets lost.
The mechanistic notion of force - which is not yet the force of classical physics - reflects this double-sidedness of the world machine. On the one hand there are strong efforts to integrate force into the system of relative (kinematical) magnitudes; on the other hand force remains an absolute magnitude that can be located as the potential to act of a body in motion.

The relay between historical and categorical development is individual ontogenesis. The historical (and ontological) variety of categorical structures contradicts any apriorical attribution to a transcendental or a biological subject. Such apriorisms obviously adhere to the derivative logic themselves. The reverse reduction of the individual categories on a socially based generality, e.g. 'language', does not solve the problem either. The way via a general substrate, might it be of subjective or social nature, is blocked.
If one does not want to suppress the interplay of the subjective and social side, one is referred to a procedural reconstruction through the evolution of man. Each new member of human society is in dealing with the world forced to develop the structures enabling him to act in the world to which he is born. The generality and the variance of the structures are thereby the result of the generality and variance of the material and social conditions, under which one grows up.
The early cognitive structures are confronted with comparable organic, physical and social conditions, so that the formation of some fundamental general structures is sufficiently probable over all times. Regarding the variance of structures we have to look for in the diverging historical condition. The equilibration between the cognitive structures

and the (different) conditions shows a progressive order; the structures developed belong to the conditions of their further advancement. Because the advanced structures integrate former ones, the structural sequence is not arbitrary. So concerning the generality and variance of the structures their sequenciality has also to be taken into account. The development of the structures can therefore be generalised as a spiral of formalization. More and more the structures abstract from the superficial sensorial contents or qualities.
Not only are the historical conditions relevant for the cognitive development, but also the cognitive competences are conditioning the standards of the technical and social organisation of a society. Social and categorical change are thus linked.

Regarding the transformation from the derivative to the procedural logic there will mainly be mentioned developments in the material and representational realm. The tremendous sociological transformations, like, e.g., the denominational schism and the state building in early modern times, will not be cared for in the following. Among the relevant material conditions there are the mechanisation of different areas of life and the pervasiveness of machines therein. Also the development of specific representational systems (and their institutionalised proliferation) had by their formalising tendency a substantial influence on the transformation of the fundamental logic of explanation.

The conceptional development since the 17th century passed over the machine paradigm because it grew evident that order had to be understood in a historizing way. According to its origin from a proceeding plan the world machine has a static structure. Structural transformations that became scientific problems later - to name the most important: the emergence of live and of ‘geist’ - cannot take place in such a machinelike world.

In front of this theoretical background we can call the machine paradigm - underlying the world machine - a means of representation and description derived from a real (wilfully man-made) object to describe specific (not wilfully man-made) circumstances in the framework of categorical structures, specific in their historicity and building the basis for (the early modern) understanding of this object. Therefore we must treat machines in the context of the systematic relatedness of different fields of historical factors: it has to deal with the machine as a technical object as well as with the means of representation and categorical structures that together are used to understand machines. So the following investigation into the development of the machine paradigm will not give priority to individual factors or a certain field of factors, but to the procedural connection of the different fields.

These fields can be determined in a wider perspective: first we have what can be called the external world; the factors, we are interested in are above all technical circumstances. The second field concerns the media, with which certain phenomena are socially communicated and/or subjectively represented; geometry as a representational system for physics is most relevant here. Thirdly there is the field of the cognitive structures and their respective logic of development. The subject has to develop its cognitive structures in confrontation with the given historical conditions; among them are the symbolic systems used for specific purposes. Reversely the given representational systems supply the means, with which these constructions are carried out. Material objects whose structures are reconstructed in certain ways, likewise permit the transfer of these structures to other objects, which thereby are 'understood'.

In order to represent this complexity concerning the development of the machine paradigm, this study is oriented at a series of structural themes. These themes are a) the distinction of linear and circular movements, b) the distinction of the sub- and superlunary world, c) the distinction of movement and its cause (kinematics and dynamics), and d) the threefold relation of the physical space in regard of its kinetic and dynamic order and the abstract space of formal geometrical operations.

Linear/circular is the most fundamental distinction among these four, because it can be found in the different fields in specific ways, and because it plays a crucial role for the coherency of the pre-modern cosmology. The sequence provides a plot for the change of the explanatory conception of the world, i.e. in particular regarding the dissolution of the fundamental distinction of linear and circular, and the emergence of other principles of coherence like the homology between physical space and the geometrical means of its representation or like the distinction of primary (machinelike matter and motion) and secondary (only subjectively seeming) qualities.[1] But it is of course only one possible plot; and it allows attaching a number of further factors independent of these themes.

Linear - circular

The distinction of linear and circular movements is the starting point, because the interrelationship of the different fields is expressed by it in a fundamental and complex way. On its base influences from the different fields are connected to a coherent cosmological system that existed from antiquity to early modern times.

In the cognitive field the distinction of linear and circular movements shows up in a diverging cognitive processing of the two forms of movement. Whereas linear movements can be represented as simple changes of position, i.e. with 'jumps' in relation to the surrounding space, 'mental rotations' can mentally only be executed with a limited angular velocity in an analogue continuous form. Jumps are not possible here. In the experimental framework of genetic epistemology the ontogenesis of the conception of (linear) movement starts by neglecting the actual process of the movement in favour of the starting and terminating point; in early stages of cognitive development judgements of movements are thus recurring on mere changes of position.[2] Under the condition of the different experimental methods used by 'cognitive psychology' it can be shown that the orientation at the starting and terminating point is not possible in regard of circular movements. In their constitutive study Shepard and Metzler found out that for defining the identity of two figures which seem to be rotated against each other, the response time is linear dependent from the angle of the seemingly twist. From this they conclude (in agreement with the introspection of the tested subjects) that for the comparison one

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[1] Crucially for the understanding of machines is the differentiation of their function and their functioning based on the order of their parts. As the prototypical machine used for metaphorisation the differentiation between outward function of clocks and their inner mechanism is very important; it is analogue to the early modern differentiation of primary and secondary qualities, i.e. the reduction of the general term of 'motio' (change of quality, number and place) to local-motion.
Laudan, Laurens (1966), The Clock Metaphor and Probabilism. The Impact of Descartes on English Methodological Thought. 1650-65, in: Annals of Science, (22) 1966, 73-104.

[2] Piaget, Jean (1946): The Child's Conception of Movement and Speed, London and Henley 1970. Jean Piaget and Bärbel Inhelder: L'image mentale chez l'enfant, Paris 1966.

of the figures had to be mentally rotated with a constant angular velocity.[3] The crucial point is that there is no possibility of abbreviating the comparison by jumping, like it would be possible in mental linear translation.

Even when a movement is understood continuously, space is not necessarily constructed as an abstract container independently of a single movement. Only in the course of the development by the co-ordination of different movements a spatial conception is developed independently from the actual object or movement. A general space concept, which permits combinations of both forms of movement, hence requires for its development the integration of these different representational processes. Especially the correct conception of a transformation of linear and circular movements can be processed only in a homogeneous and continuous space without a center or designated direction, i.e. in the long run in a Euclidean space. If one imagines for instance the diameter of a wheel, which rolls on a level, and chooses any point on its diameter, then the construction of its trajectory presupposes such a space.[4]

The divergent cognitive processing of linear and circular movements and the problem of their integration in a general space concept find their expression in the history of technology; the development of techniques, which combine both forms of movement, show specific delays. These delays might have their cause in the fact that the combination of these two forms of movement presupposes a far developed operational space concept.

Probably the first milestone regarding the transformation of linear into circular motion is the so-called fire drill, which can already be found in the Stone Age. At first by just rubbing a stick between the hands it was used for making fire. Further a cord was wound around the drill and pulled back and forth. With fixing the cord in a bow this technique

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[3] Shepard, Roger N., Jacqueline Metzler (1971): Mental Rotation of Three-Dimensional Objects, in: Science 171, 701ff.
Concerning the relation between structural epistemology and cognitive psychology: Lejeune, Marc. (1992), Jean Piaget et Roger N. Shepard. Vers une compréhension de la genèse du processus de rotation mentale, in: Archives de psychologie 60, 71-87; Dean, Anne L. (1990): The development of mental imagery. A comparison of Piagetian and cognitive psychological perspectives, in: Annals of Child Development 7, 105-144.

[4] A limited number of such 'mechanical curves' stems from antiquity; this number was rapidly increased in the 17th century.

achieved a form that was used until modern times for a lot of different purposes, e.g. drilling or moving a turning lathe.

Also among the so-called simple machines are such, which combine linear and circular movements. To the simple machines belong the lever, the wedge, the inclined plane, the wheel or the axle, the pulley and the screw. The usage of the lever, the inclined plane and the wedge probably goes back far into prehistory. The wheel and the axle are in use already some thousands of years, as the proverbial invention of the wheel goes back at least into the 4th millennium BC. It was used in these early times of course as a wheel in the actual sense with axle for a cart, but also as a potter's wheel or as a "round flat stone with a hole in the centre to act as a flywheel when spinning thread for weaving".[5]

But until the 'combined' simple machines emerged it took a relatively long time. The first depiction of the pulley originates from the Assyria of the 8th century BC; McNeill argues somewhat surprised: "Though it was a natural progression for a civilisation that had the wheel, the Egyptians did not have the pulley."[6] After the above made remarks about the cognitive complexity of such a device, which combines linear forces in different directions and a rotation, the absence of this "natural progression" should not be so amazing any longer. The advancement or multiplication of the pulley to the pulley-block required further three centuries. Screw-like devices as the Archimedean screw probably developed between 5th and the 3rd century BC. The screw press for wine and olives is used since the first century BC.

Almost each branch can be used without great artistic effort as a lever; inclined planes and wedges are also at hand almost naturally. However the use of a wheel requires (usually) a planned manufacturing, which presupposes the imaginative power of the wheel's mode of operation. It is not amazing therefore that it emerges later than the 'linear' simple machines. Again the simple machines, which combine the two forms of movement, emerge substantially later. In regard of the screw this may also be connected with the problem of cutting good threads. However for the pulley such a problem

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[5] McNeil, Ian (1990): Basic Tools, Devices, and Mechanisms, in: An Encyclopedia of the History of Technology, London and New York, p. 16.

[6] Ibid., p. 17f.

can be excluded by and large. Surely there was also some requirement before its existence. Thus we seem to be referred to obstacles in the realm of ingenuity.
A last example for the retardation of combined techniques is the invention and the spreading of the crank as well as the crankshaft and rod from the Middle Ages on. Contrary to the rapidity of the total process of mechanisation Lynn White sees an "unbelievable delay ... in its assimilation to technological thinking" at work with the crank. He guesses that "the human mind seems to shy away from it."[7]
With the circulating whetstone begins the occidental history of the crank in the 9th century because earlier millstones beforehand were probably operated by a to-and-fro-motion. One finds the crank then in very limited fields of application: of course as part of hand mills, at hurdy-gurdies or at the traction mechanism of crossbows. Since the 15th century this technique in its more developed form as crankshaft has spread among the handicrafts. "The appearance of the bit-and-brace in the 1420's and of the double compound crank and connecting-rod about 1430, marks the most significant single step in the late medieval revolution in machine design."[8] Generally the development of the crank, crankshaft and piston rod before the 15th century did not gain momentum.
Thus, we still find toward the end of the 15th century the aforesaid turning lathes propelled by a cord in a bow. Constantly rotating turning lathes with a pedal-driven crankshaft (and a fly wheel) became usual not before the 17th century. White also mentions the "crowning absurdity in the history of the crank which occurred in Aug. 1780, when James Pickard of Birmingham was able to patent the crank and the rod which he had applied to the steam-engine, thus making steam power available for rotary motions and transports."[9]

Inventions may be contingent, yet their systematic use requires a certain understanding of their mode of operation. For the understanding of mechanical processes an adequate conception of the involved spatial and dynamic relations is required. The technical retardation might thus result from a constrained understanding of the mode of operation of

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[7] Lynn White (1962): Medieval Technology and Social Change, Oxford, p. 103ff. The lacking ability is expressed also in early figurative representations of the crank, ibid.
[8] Ibid..
[9] Ibid..

these techniques. And the cognitive development to a systematically integrated conception of linear and circular movements is also determined by prerequisites.

Among these prerequisites is a certain level of development of the material culture; so the occidental mechanisation, which wins its historical momentum by the increased use of wind and waterpower for a diversity of products from the Middle Ages onwards, contributes to the formation of an appropriate space concept. The different gears and the different forms of transmissions, which are increasing together with the mills, require for their understanding the reconstruction of their structure, i.e. along with a homogeneous and acentric space. To understand mills and its gears in last consequence the conception of the physical space homologous to the abstract space of Euclidean geometry is required.

sub - supra

The distinction between the sub- and superlunary world is directly linked to the one between linear and circular movements, because under the condition of a derivative logic and without a common explanatory base both forms of movement have to be founded in nature itself. Thus the distinction of linear and circular movements is reflected in the representational field of the geocentric world-picture as one of its fundamental principles of organisation: the two regions of the geocentric world: the terrestrial region under the sphere of the moon and the celestial spheres above it are determined by their own form of natural motion; the four terrestrial elements move linear, i.e. radially in relation to the center of the earth and the celestial *quinta essentia* moves circularly around it. The movements in the sublunary area, which are not caused by the natural motion of the elements, are considered as ‘counter-natural’, ‘forced’, or ‘mechanical’ movements. Thus, the unity and uniformity of physical space, as it later shows up in the mechanistic conceptions, is missing here, because there is no abstraction from its contents, as the determination of the different spaces is directly coupled to their natural form of movement, and because there is a definite centre.

The logical or syllogistic framework can be found in Aristotle's *De caelo*. Aristotle begins with the distinction of two simple lines and the appropriate trajectories of movements: the straight line and the circle. All other trajectories are mixtures of the two. The circle as the perfect figure (which is not yet a figure with an infinite number of angles and thus based on a construction starting from straight lines) receives thereby an ontologically privileged position. The consequence Aristotle draws from this distinction of two simple movements is the postulation of the fifth element, as a simple body that moves circularly. "Thus, if there is such a thing as simple movement, and movement in a circle is simple, and the movement of a simple body is simple and simple movement belongs to a simple body [...], there must be a simple body that is such as to move in a circle according to its own nature."[10]

The cause for the circular motion of the spheres is the essence of the simple bodies that they are made off. So Aristotle's physical space has got designated directions, structuring the space dynamically.

The role of circularity of the celestial movements is strengthened by the static order of the world, which is a regular expression of derivative logic. The statics of the geocentric order is thus ensured by the fact that the celestial rotations themselves are fixed in their place, i.e. the center of the earth, and by the supposition that their angular velocities are totally uniform - nothing new above the moon.[11]

Together with the 'fact' that the natural motion on earth is linear, this is the major problem of the genesis of the machine paradigm, because a cosmology on the basis of the terrestrial model of the machine must overcome the radical distinction between the sub- and superlunary world, between linear and circular physics. A machine is determined by the spatial order of its parts and the movements of these parts given thereby, and there cannot be a kind of order and movement inside the machine, which is contrary to the machine. If the terrestrial machine is to serve as a model for the cosmos, then the same concept of space and movement, which is a linear (but acentric) one, must apply to heaven and earth.

Among other reasons for the dissolution of the radical distinction of the cosmos there is the general mechanisation beginning in the Middle Ages. The diverse movements of the machines cannot be ascribed definitely to one area; as they utilise circular movements in different ways they let the celestial movements become terrestrial. First this applies to

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[10] Aristotle: De caelo, I/2.

[11] This complex has further (restabilising) consequences. The methodical prescription of Greek astronomy, the 'saving the phenomena', demands that to describe the celestial movements only uniform circular movements are to

wind and water mills, whose number is exploding since the Middle Ages. They are put into natural cycles, and are rotating thus on earth, in order to perform mechanical work - partly by linear movements.

Second it applies to clocks and watches, which propagate the measuring of time by the homogenous movement of the sun resp. the stars instead by the irregular daylight, and are thus bridging the gap between the perfect superlunary region and the corruptible terrestrial life.

Third it applies to perpetual motion devices, which try to install eternal movements on earth. They started their technical career in Europe together with the other machines; mostly they even looked like mills.

The majority of the water mills used in the Middle Ages had vertical wheels; depending on the slope of water stream and on the financial capacity of its builder they were undershot or overshot. The even cheaper horizontal wheel does not produce enough power to actuate some usage via gears; and these were necessary for the diversification of the mechanised working processes.[12] The expensive mills were enforced by the nobility because by compelling the peasants to use their centralised installation they could guarantee their share of the crop.[13]

The European windmill, which disseminated fast from the 13th century on, seems to be a technical descendant of the water mill; the difference is that the respective vertical wheel was (in different ways) mounted mobile to be turned into the wind.[14]

To get an impression of the increasing prevalence of mills: the ‘doomesday-book’ gives a number of more than 5600 mills in England at the end of the 11th century;[15] that

be used. The 'saving the phenomena' however neglects by and large to clarify the physical, i.e. causative, side of the celestial movements.

[12] "The Roman mill, described by Vitruvius in about AD 180, was the first machine in which gears were used to transmit power." McNeill, p. 19.

[13] So in areas with a large amount of yeoman not only the horizontal wheel but also hand mills could be found further on.

[14] Major, J. Kenneth (1990): Water, Wind, and Animal Power, in: An Encyclopedia of the History of Technology, London and New York 1990, p. 245ff.

[15] Some hand mills may be included however; ibid. p. 231.

makes approximately 1 mill per 250 inhabitants. Vauban estimated that there were about 95000 mills (80000 for milling corn) in France at the end of the 17th century.[16]

The diversification of the mechanised working processes is dependent on the multiplication of the forms of transmissions and gears:
Different devices for transformation can be connected to the vertical wheels:
- the simple gearless horizontal axle, which was already used in Antiquity for irrigation.
- the transmission into a vertical axle was of course mainly used for milling corn - already by the Romans; since the 11th century it was also used in pug mills to press, e.g., olives, oak crust, mustard, poppy or colours.
- gears propelling other horizontal axles with a different angular velocity can be found from the 13th century on for sharpening and polishing metal, since the 15th century for boring pipes, rolling plate metal, since the 16th century for the ventilation or drainage of mines.
- the cam shaft, which transforms rotary motion in linear to and fro motion, was used since the 10th/11th century for malting, for fulling and processing hemp, since the 13th century it serves for paper production, for forging hammers, blowers and saws, later also for crushing ore and for the operation of piston pumps.
- the crankshaft (and the piston rod) is a much more effective way of transforming circular in linear movement - and even vice versa. From the 16th century the mill-powered crankshaft becomes indispensable for the operation of pumps, saws and bellows.
Until and after the steam engine lead to a reorganisation of the industrial system the use of wind and waterpower was applied to a huge number of different working processes in different industrial fields.

The way mills used and transformed natural powers whose circles were understood in analogy to the celestial rotations[17] subverted the radical distinction between sub- and superlunary, between natural and counter-natural motion. The terrestrial circular motion of the mill wheels seemed natural as well as mechanical and they were used for tools

[16] Reynolds, Terry S. (1990): Mittelalterliche Ursprünge der industriellen Revolution, in: Newtons Universum, Heidelberg, p. 31.

[17] Heninger, S.K. (1977): The Cosmographical Glass. Renaissance Diagrams of the Universe, San Marino/Ca..

working linearly and circularly. With the crankshaft and rod even the one-way street from circular to linear was opened for the reverse, so that also the implicit hierarchy was subverted.

Considering the subversion of the radical cosmological distinction by mechanical devices one has also to look at clocks and watches. The ringing of their bells and the circulations of their dials were oriented at the uniform celestial revolutions; thus the general spreading of the equal hours against the variable hours, which comply with the irregular daylight, brought the homogenous regularity of the heavens to earth.
Mechanical clockwork has most probably been invented in the 13th century.[18] The important thing about it was that other mechanical devices like bells or dials could be driven by it quite easily as they were weight driven. In contrast to use gears with clepsydras, beside the sundial the usual time-telling device until and after that time, was quite difficult.[19]

Before the distribution of mechanical clocks the different mainly handmade urban bell signals were defined by a concrete meaning. Apart from the religious occasions (mass, prayer etc.) particular signals important for the urban community (market, fire, war etc.) were rung. Also work time regulations were organised with specific bell signals before the introduction of mechanical clocks. This multiplex pattern of different bell signals was insufficient for the development of an abstract understanding of time. For instance, during the day there was an amassment of the diverse bells, while there were long silent or empty times at night. Ringing the equal hour offered the possibility for a time scheme not defined by certain contents.
The enforcement of the abstract order of time resulted from a multilayered process, in which the regulation of the urban life and the increasing prestige of the equal hours played important roles. Different problems and conflicts of the urban life could be handled better by reference to this kind of time measurement. Above all the marketing of

[18] There are no documents about the invention of the first clockwork; it seems to be derivated from monastic alarm clocks; early clocks are almost symmetrically: on the on hand the foliot/escapement and the other hand the hammer; David S. Landes (1983): Revolution in Time. Clocks and the Making of the Modern World, Cambridge and London, p. 67f.

[19] The usage of alarm clocks and astrolabes refers to two different clerical problems: awakening the monks for the night and morning prayer and finding the date of Eastern.

time as such (e.g., of university teachers) demanded the increasing formalization of time. With the increasing formal freedom of work the understanding is changing from the working day to the (equal) working hour. Apart from working time regulations this also applies to such cases like meetings of the city council or the limitation of speeches therein or of sermons in churches; it also applies to attempts to control market prices by determining, when which group is allowed to buy what on the market, or for the organisation of schooling and teaching. So the change of the standard time was to a large extent a rather anonymous process, which progressed with many small steps in different and independent areas of urban life.[20]

It is to be noted that for the enforcement of the time management oriented at the equal hours mechanical clocks as the sole technical means would have been completely insufficient. E.g., they could not measure fractions of one hour, as they regularly did not have minute hands before the 'horological revolution' of the 17th/18th century. Sand glasses normally fulfilled this task. (Since the 14th century pictures of sand glasses show them in the form we still know.)

Not only the ringing of bells was driven by mechanical clockwork but also monumental show watches. They often intended to picture the whole world, resp. its different levels of time: the celestial time by an astrolabe (or later also by an armillary system, which could be read quite easily as it is similar to a rotating dial), the Christian year and its holidays by figurines, and everyday things like the aforesaid by bell signals. According to decreasing dignity from the fixed stars down to peccant earth it was iconologically consequent to relate the homogenous time of the stars with the divine. Thus, the distribution of clockwork driven public astrolabes lowered the prestige of the traditional variable hours and made it favourable to use equal hours.

So mechanical devices helped to increase the usage of the divine time of the stars for everyday matters, which is another form of the subversion of the radical distinction of the cosmos.

At last we come to the third mechanical items that propagated the dissolution of this distinction: the perpetual motion devices. Aristotle had ruled out perpetual motion in the

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[20] Dohrn van-Rossum, Gerhard (1992): Die Geschichte der Stunde. Uhren und moderne Zeitordnung, München and

sublunary sphere because of the general corruptibility within it, but from the Middle Ages onwards together with the general mechanisation it has been increasingly considered plausible.

One of the first European perpetual motion devices described by Pierre de Maricourt wants to prove its name by directly tapping the movement of the spheres; a spherical magnet ought to join in their movement because the sphere of the stars was supposed to be magnetic as well.[21] "Yet it is extremely unlikely that the PM idea, whatever its immediate origin, was not related in some way to the celestial and meteorological perpetuities that have been natural to wonder if analogous perpetuities on a more human scale could be reproduced by human industry and ingenuity."[22]

However the standard design of perpetual motion devices, valid for several hundred years, is similar to a mill: linear natural forces (above all gravity, partly also magnetism) should eternally propel the rotation of a specially designed 'mill wheel'.[23] So we have a quasi-natural rotation on earth, which was further designated to drive mechanical working processes. Thus, the believe in the possibility of perpetual motion was another form of the technological subversion of the difference of terrestrial and celestial movements, as we have seen it with the mills.[24]

To sum up the past two chapters: the general mechanisation and especially the technical transformations of linear and circular movements affect the modification of physical space on two different lines: on the one hand the requirement to understand machines leads to the formation of homogeneous space; and on the other hand it subverts and dissolves the fundamental distinction of the cosmos, and causes thereby the formation of a acentric linear spatial concept.

Copernicus and even more Kepler opted for the heliocentric system, because the causal explanation of the celestial movements seemed more plausible thereby, i.e. be-

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Wien, p. 250.

[21] Klemm, Friedrich (1983): Perpetuum mobile. Ein ‘unmöglicher’ Menschheitstraum, Dortmund, p. 16f.

[22] Gabbey, Alan (1985): The mechanical philosophy and its problems: mechanical explanations, impenetrability, and perpetual motion, in: Change and progress in modern science, Dordrecht e.a., p. 53.

[23] Perpetual motion devices emerged together with mills in the Middle Ages; their era came to end in 1775, when the Parisian Academy denied to except any further projects.

[24] "A windmill on a hill with constant breezes, a water-mill in a stream which never runs dry, were, to the Middle Ages, perpetual motion machines." White, p. 131.

cause it is more appropriate to the conceptual development of physical space. With the sun in center the cosmic break is done away, the earth becomes a star.
Imagining an unlimited linear movement the linearization of space leads to the concept of an infinite space. Regarding this linear opening of space Copernicus is still conservative. The sun as well as the earth function as center of their own spherical space. Space as a whole is limited, but Copernicus already blew it up too 'immeasurability'.

Kinetics - dynamics

An essential strand in the scientific transformation of the 17th century was the 'great synthesis' of sub- and superlunary physics on the one hand, and kinetics and dynamics on the other. Apart from the explicit distinction of the sub- and superlunary world the rather implicit distinction between already quantitatively oriented kinetics (phenomena) and still rather qualitatively oriented dynamics (causes) thwarted the formation of a uniform physics.[25] The present differentiation between kinetics and dynamics is already made before the background of such a uniform physics.
This 'great synthesis' can again be focused on the explanation of the celestial movements. As long as they were regarded essentially circular, their causation was somehow linked to this quality - either by some kind of natural motion or just by the spherical form itself as the cause.[26] Thus, the homogenisation and linearization of space and the subversion of the fundamental distinction of the cosmos affected increasing efforts to integrate the permanent movements of the celestial bodies into a uniform linear space based on terrestrial dynamics, which was becoming more and more quantitative in this process.

With the development of the respective relating competence and an adequate representation kinetics as mainly the knowledge of the relation of way, time and velocity gains an almost self-evident status.[27] This does however not affect the corporeality of the thing

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[25] Hall, A. Rupert (1970): From Galileo to Newton, London.

[26] There is a long tradition of causally linking eternal motion, including the one of the stars, just to their spherical form. This idea was expressed, e.g., by Nikolaus of Cusa and Copernicus.

[27] Concerning the development of the relating competence: Levin, Iris (1992): The development of the concept of time in children: An integrative model, in: Time Action and Cognition, Dordrecht e.a., 13-32

moved and the causation of this motion. The dynamic intuitions remain delayed compared to the kinetic ones. While there are sensory references to phenomena of motion, causal connections are imperceptible; nevertheless they have to be attributed to the objects as their proper characteristics. So, the development of causal connections is more based on subjective schemes and less on dealing with the circumstances than the development of kinetic conceptions. Thus to integrate force in a scientifically sufficient manner with the valid spatial and kinetic intuitions, a longer ontogenetic and historical development is required.

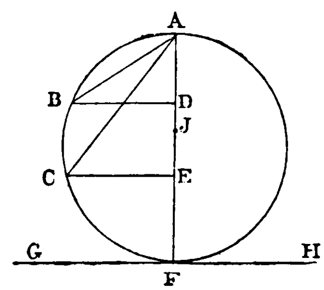
Beforehand however not only a formalization of space is needed for such a kinetics, but also an equivalent development of the conceptualisation of time. Before time is functioning as a homogeneous and constantly passing intuitional background it is structured as action time or as the proper time of the respective event; i.e. it is bound to the content of each individual action or event. Only in the course of a complexly conditioned development time detaches from its contents and becomes formalised. For instance, the aforesaid everyday time measurement until early modern times was content bound, as it was oriented to the seasonally changing rhythm of light and dark. So the enforcement of the equal hours has also to be seen under the perspective of the formalisation of the subjective time concept.

Concerning the infinitization and therewith the mathematization of time being bound to the content is a problem. The determination of the time as the proper time of an event implies that time appears as a finite duration. Under this condition there is no such thing as a point in time, which would be the basis for a mathematical treatment of time. Without a limit value calculus the smallest part of an extensive continuum, like time, must necessarily be also an extensive continuum. Thus, kinetics as the representation of movement in the sense that to a certain point in time magnitudes like place, speed and further on also acceleration are collated requires the infinitisation of time beforehand.
Being bound to the content hampers also the representation of time independent of the respective content; so durations were often represented by the covered distances (or other contents of the classical notion of *'motio'*); not only the comparison of movements

with different velocities gets difficult thereby.[28] This problem is intensified by the impossibility to express threefold relations, like distance-time-velocity, directly with classical proportions. The quotient v=s/t was not allowed, as only proportions between magnitudes of the same dimension were permitted.

Proportions compare only two pairs of magnitudes; this makes them unsuitable for continuous relations (function). In the 17th century however new geometrical methods are found to represent kinetic matters. Kepler's law of areas is an example for such a continuous and independent representation of distances (the way on the ellipse or the angle) and of infinitesimal times (the area covered by the radius). The importance of this law can hardly be overestimated; especially its use of geometrical infinitesimal (not really rigorous) methods for the representation of (wrongly analysed) dynamic circumstances is to be taken into account here.[29]

Beside his law of fall also Galilei's earlier secant theorem can be mentioned here. It predicates that a body falling from the apex of circle needs the same time for any secant, seen as an inclined plane. While all the infinitesimal differing circles cutting each other in the apex are isochronous lines of fall on any inclined plane, the vertical (or any other) can function as the general (not homogenous) measure of time.[30]



The understanding of space and time in a continuous relation was fostered by the constant transformation of movement in machines or their gears. Such an understanding is the prerequisite for the mathematical formalization (mainly by geometrical methods) of the respective physical magnitudes. In order to integrate the formalization of dynamics into this development (historically) it was necessary to differentiate force and motion, which are intermingled in the (ontologically) initial intuitions of causation.

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[28] Maier, Anneliese (1949): Die Vorläufer Galileis im 14. Jahrhundert, Rom, p. 111f.

[29] Kepler, Johannes (1609): Astronomia Nova, chp. XL.

[30] Drake, Stillman (1978): Galileo at Work. His Scientific Biography, Chicago and New York, p. 66ff.
Galilei, Galileo (1638): Discorsi e dimonstrazioni matematiche intorno a due nuove scienze attinenti alla mecanica ed i movimenti locali, 3. day, theor. V.

The development of dynamics brings us back again to the celestial movements. The fundamental problem of their etiologic explanation is their permanence. For centuries 'saving the phenomena' as a kinematics oriented to formal geometry was juxtaposed incompatibly to the causally oriented Aristotelian cosmology.

As long as the radical etiological distinction between rest and motion and the principle *'omne quod movetur ab aliquo movetur'* (which can be also tracked ontologically) is maintained, one is constrained to presume something transcendent, like e.g. the unmoved mover, which operates the eternally circulating cosmos as an energetic subsidy system. Following the Middle Ages however immanent explanations gained evidence; among other reasons because the general mechanisation promotes the understanding of space and time as general containers and thus without an (transcendent) outside. A further reason is the general secularisation; because the underlying social changes are apparently manmade they increasingly rule out the conception of divine causal intervention. The machinelike cosmos becomes energetically closed and grants God only the place of the intentional designer.

The late scholastic impetus theory is among other things a reaction to the causal secularisation and the mechanisation, insofar the physical concepts of the antiquity were increasingly insufficient for the technical developments. So it was also the most prominent theoretician, Jean Buridan, who was the first to explain the celestial rotations caused immanently by an impetus conserved in the celestial bodies after being initially impressed. The Impetus as the cause of the movement is conserved, because it is not used up like in terrestrial movements due to the material specificity of the spheres.[31]

However the solution of the problem of the permanent celestial movements is not situated in the conservation of the cause of motion, but in the conservation of (relative) motion as such, i.e. in the principle of inertia. This principle follows logically from the relativity of space: in a space without any absolute point of reference it is tantamount to say A moves (homogeneously) towards B, B moves towards A, or both approach each other, as long as the relative speed is the same. Rest and motion are equivalent therefore; if something rests on its place, it 'rests' also in (homogeneous) motion; thus the etiological difference between rest and motion and the need for a *movens* ceases.

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[31] Buridan, Jean (ca. 1340): Questiones super libris quattuor de caelo et mundo, New York 1970.

But the conclusion from the relativity of the space to the principle of inertia has historically not been drawn so simply. Already since the Middle Ages it was thought about the relativity of space and aspects of inertia were treated thereby; but this was done 'as if', i.e. it was assumed that there really was an absolute frame of reference and thus a difference of rest and motion; it was just conceded that it was impossible for an observer to determine phenomenally, which body is resting and which is moving.[32]

Later still natural philosophers, e.g. Descartes, acknowledged the relativity of space and at the same time made a dynamic difference between rest and motion; they still regarded moved bodies equipped with a certain force. However this force was not anymore the cause of the respective movement (like with the impetus), but the potential activity stored in the moved body. For Descartes "a body that is 'agité' or has 'agitation' can 'agir', and the more strongly it is 'agité' the more strongly it can 'agir'. To 'agir' is to communicate 'agitation', and the body which 'agit' loses as much 'agitation' as it communicates to another."[33]

The structural similarity between the conceptualisation of force, as the cause, which accompanies a motion, or as the potential to act impressed in a moving body, and acting results form the above-mentioned dependence of causality on rather intentional models. So force as something that in the beginning has been given as total amount to the world machine is still considered a kind of (teleological) substance.

Regarding the problem of combining dynamics with kinetics in a formal way Descartes' thinking shows a significant contradiction, because he links a relativistic concept of motion with a substantialistic force/causal theory. Although Descartes describes the relativity of the motion quite clearly: ”For the transference is reciprocal; and we cannot conceive [intellegi] of the body AB being transported from the vicinity of the body CD without also understanding [intelligatur] that the body CD is transported form the vicinity of the body AB ...” he continues: ”and that exactly the same force and action is required for the one transference as for the other.”[34] Though the transferences cannot be distin-

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32 Franklin, Allan (1976): The principle of inertia in the Middle Ages, Boulder, p. 67ff.

33 Westfall, Richard S. (1971): Force in Newton's Physics. The Science of Dynamics in the Seventeenth Century, London and New York, p. 61.

34 Descartes, René (1644): Principles of philosophy, Dordrecht 1984, II, 29.

guished and the same amount of force is needed for either of them, on the causal level they are not the same.
This contradiction is related to his twofold principle of inertia. First the status (motion and also form) of body is conserved; second the status of the motion, its linear direction (*determinatio*) is conserved.[35] "The first law of nature: that each thing, as far as is in its power, always remains in the same state; and consequently, when it is once moved, it always continues to move." - "The second law of nature: that all movement is, of itself, along straight lines; and consequently, bodies which are moving in a circle always tend to move away form the center of the circle which they are describing.[36]
The distinction of force and *determinatio* reflects the absence of a direct dependency of the relativism of kinetics and dynamics; the desubstantialisation of force can be a result of a relative space, but it needs more time to be developed.

The question is now of course how the force of a moved body could be measured. The mechanistic pre-Newtonian solution to this problem was based on the seeming (substantialistic) equivalence of weight and speed. And this equivalence was operationalized by the law of the lever and the principle of virtual velocity.[37] "The problem is to calculate 'how much more weight the motion adds'. Such was the standard definition of the problem, which implied the equivalence of percussion to static force and encouraged a solution by means of the simple machines."[38]
From our present point of view this equivalence is of course erroneous. The lever inducts solutions from statics into problems of dynamics. Weight, work performed at it, potential energy, impulse and kinetic energy are mashed together, because the following argument seems consistent: a load/force the size of 1, which moves down a distance of 2, can move up a load the size of 2 over a distance of 1; then concerning the velocity of the loads the general consequence (not only for machines, but also for per-

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[35] "Descartes' distinction denied that the two changes have anything in common, and left changes of direction in the anomalous status of changes that are not changes, changes that involve no act." Westfall, p. 65f.
This distinction touches therewith the separation of his two substances; he presumes that there is constant amount of quantitas motus (something like mv, but not vectorial) in the material world; but as humans control wilfully (res cogitans) their bodies (res extensa), this controlling must not involve some quantitas motus.
[36] Descartes, René, II, 37+39.
[37] The principle of virtual velocity means in today's words that for the translation of an arrangement of bodies no work is performed. Its implicit application can be traced back to the *mechanica* wrongfully ascribed to Aristotle.

cussions) seems possible to draw: the force of a load/body the size of 1 and the speed of 2 is equal the force of a body with size of 2 and the speed of 1. Thus the ‘force’ of weight and the ‘force’ of velocity seem not only equivalent but are also the force of velocity seems to be calculable by the force of weight.

In his early works Galilei worked out this consideration systematically; he reduced machines in a dynamic sense to the so-called simple machines (levers, hoist, pulley block, screw and wedge) and these again to the balance and/or the lever. The trick Galilei applied, in order to use the simple laws of the lever for the analysis of load lifting machines, was based on the principle of virtual velocity and the continuity principle, with which he transgressed a formerly essential distinction: rest and motion. He inferred: only a force minimally bigger was needed to move a load than to hold it. He concludes: because the force is only minimally bigger, it is possible to neglect the difference mathematically. Now he is able to calculate moved loads with simple proportionalities between force, weight, distance, time and velocity.[39] The velocity of the load and the opposite force are correlated like the lever arms, because the distances they describe are like the arms.

Due to its intuitiveness and its seemingly quantitative accuracy the lever paradigm (together with the principle of virtual velocity) was ubiquitous in the dynamic considerations 17th century - also in the field of impact laws. The measurability of the force of a moving body and building on this an operational maintenance of impact laws was crucial for the mechanistic world view, because it was based on nothing but the interaction, i.e. the percussions, of particles. How misleading these implications of the lever are can be shown by Descartes’ impact laws.

The general rule states that to determine the outcome of a percussion only the forces of the two bodies have to be subtracted from each other, whereas the rest will be the effect. The seven specific rules deal with bodies of equal or different size, with equal or different velocities, both in motion or one in rest, with opposite or equal *determinatio*. Regarding the dynamic implications of the law of lever #2 and #3 are most representa-

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[38] Westfall, p. 201f.

[39] Drake, Stillman (1958), Galileo Gleanings V. The Earliest Version of Galileo's Mechanics, in: Osiris, 13 (1958), p. 267. Galilei, Galileo (1590/1600): On Motion and On Mechanics. Comprising De Motu (ca. 1590) and Le Meccaniche (ca. 1600), Madison 1960.

tive: If two bodies B and C were moving with equal speeds in straight line, B from the left and C from the right and ”if B were slightly larger than C [...] then only C would spring back, and both would move toward the left at the same speed.” - ”If the two bodies were equal in size, but if B were moving slightly more rapidly than C; after their collision not only would ... both continue their movement toward the left ..., but also one half of B’s additional speed would be transferred from it to C.” Keeping the differentiation of force and determination in mind it is easy to see that these rules are modelled after the law of the lever: the stronger force, i.e. the heavier or the faster weight, will move the whole arrangement of bodies in its direction.

Taken this as just one expression of a general scheme the convincingness of the machine paradigm within scientific discourse was based on a faulty dynamic interpretation and over-generalisation of the law of lever and the principle of virtual velocity, because this interpretation masked the insufficient differentiation of the pre-Newtonian concept of force. One has to keep in mind however, that for the understanding of machines, which move loads, insofar they were considered to be in uniform motion, this interpretation was rather sufficient.[40] It allowed to calculate minimal forces for specific weights; or to compare forces like ‘a man’ with standard weights.

Inasmuch the determination of the force of a moved body (as kinetic energy) is systematically linked by the law of fall to time, the formalisation of time was constitutive for the one of force. With an infinitesimal representation of a continuous and homogeneous time independent of its contents the succession (and equivalence) of cause (gravity) and effect (acceleration) became manageable accordingly.

This can be seen in how Torricelli works out one of the last considerations of his teacher Galilei, who had begun to expand his law of fall into dynamics.[41] Thereby the crucial change of perspective in determining the force of a moving body consisted in grounding the problem on a time "*que continuamente scorre*" instead of an erroneous transfer from weight. Time as the basis variable allows to found weight and percussion on gravitation, which means now acceleration. Torricelli discusses this problem by means of an example, which still bears the old concept: he compares a weight breaking a marble table by

[40] The problems occur with machines that use percussion, e.g., a rammer.

just lying on it with a (smaller) falling weight, which has the same effect. But he conceptualises the falling weight now in a dynamic way, which is not based anymore on the statics of the law of the lever. On the contrary weight becomes a function of time and acceleration, accordingly he describes the motionless weight, which does not break the desk: "... with this momento of one hundred pounds it exerts its weight not only now, but it will always exert it uniformly on the plane that is placed below it, in such a way that in each of the instants of time - time that runs continuously - the body applies against the marble table its violence of just on hundred pounds at a time."[42] Thus acceleration of a falling body and the continuous renewal of its weight in each new instant are the same.
By the usage of concepts developed in the context of kinetics (law of fall) dynamics changes. The continuous addition of acceleration or momenti of weight replaces the law of the lever and the principle of virtual velocity for the formalisation of the relation of weight and force.[43] The triad weight-velocity-distance dissolves in favour of the triad weight-acceleration-time. Therewith weight is not anymore a fundamental quality of a body but something relative as it is generated through time.

After the clarification of the concepts of time and force there was still lacking a complete dynamic representation to solve the problem of the celestial movements. In Kepler's law of areas force was not represented. The way that was found to assimilate the dynamic characteristics of moved bodies operationally (geometrically) to kinetics was by representing forces as hypothetical movements.[44] To represent a single force it had to be

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[41] The respective discussion of the *Viviani Scholium* can be found with De Gandt, François (1995): Force and geometry in Newton's Principia, Princeton, p. 105ff

[42] Torricelli, Evangelista (1642): Lezioni Accademiche, cit. De Gandt, p. 102.
In the phrasing of the 'instants of a time which is continuously running' one can suppose an implicit limit value calculus.

[43] "Torricelli unifies machines, percussion, and free fall. What he renders possible is not the passage from static weight or 'mechanics' to the acceleration of fall, but rather the inverse: the instantaneous momento is first and makes it possible to understand what weight is. In slightly anachronistic terms, it could be said that Torricelli bases static weight on acceleration: the momento of weight is nothing without the time that creates and renews it." De Gandt, p. 103.

[44] Kepler contributed also to idea of representing forces by hypothetical movements: he measured reciprocally gravitating bodies by the ways each of them would travel until collision; Kepler, Johannes: Astronomia nova ..., Introduction.

analysed how the body would move omitting all other forces acting on it - the resulting trajectory is the representation of the wanted force.[45]

Physical space and formal geometry

For the development of classical physics it was necessary that a system of representational means for the different fundamentals was at hand by which the relevant (quantitative) relations between them could be worked out. This was achieved by the twofold process of the geometrisation of physics: on the one hand physical space was increasingly structured geometrically, and on the other hand the representational methods developed in the same direction.[46] The linearisation of physical space, the infinitesation of time as well as the spatialisation of causal concepts on the one hand and the increasing use of geometrical representations in physics, especially the geometrical formalisation of time and force, on the other hand yielded by their homology a new coherence and a crucial progress in the scientific development.

Oresme had already tried in 14th century to use geometry as a representation of homologous physical circumstances.[47] Yet firstly, he used still a geometry of figures (instead of a geometry of space or formal principles of production) and secondly he was doing this on the basis of the scholastic science of qualities and qualitative change. To let some of his ideas become fruitful the reduction of general change (*motio*) to local motion was necessary beforehand. The general mechanisation supplied appropriate examples for working processes where local motion of parts (primary quality, real) can be interpreted as the cause of qualitative change (secondary quality, seemingly): stirring machines were, e.g., used for processes like colouring or barking. This reduction was expressed by the machine paradigm, as a major feature of it is the differentiation of the function of the machine and its functioning.

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45 This procedure can be found elsewhere: omitting all acting forces the result is inertial motion.

46 The usual proportions were expressed in normal sentences with letters as variables.

47 Oresme, Nicole (1350-60): Tractatus de configurationibus qualitatum et motuum, Madison and London1968.

In mechanistic theory causality is spatialised; it is limited largely to contact and the concatenation of a cause and effect by power transmission while contacting.[48] The mechanistic rejection of Newton's general gravity as a seemingly *actio in distans* is of course based on this concept of causality.

Descartes had tried to explain the celestial movements by means of vortices. As above mentioned he is clear about linear conservation of motion (*determinatio*) and the tendency to tangential flight. Consequently he considers centrifugal force as the result of the tendency of a rotated body to escape tangentially. In the celestial vortices this tendency is compensated like in a centrifuge by the rotation of finer particles and their impacts on the larger bodies; thus the celestial bodies are held on their courses. Descartes went very far in explaining the celestial movements by terrestrial physics, as he reduces them into their linear components (the tangential escape and the pressure to the center of the vortex). His concept however is still based on the naturalness of celestial circulations - no more those of the spheres or the stars themselves, but those of the vortices.

Newton's *Principia* consist in great parts - above all the second Book and the hydrodynamics developed therein - in the attempt to prove the impossibility of such a vortex. One point he remarks is relevant for us: "Therefore, in order to continue a vortex in the same state of motion, some active principle is required from which the globe may receive continually the same quantity of motion which it is always communicating to the matter of the vortex."[49] Newton tolerates neither some permanent natural cause of circular movement nor the bare geometrical form as a cause.

In contrast to this he succeeds in the task of explaining the movements of the solar system by a physics unified on the basis of linear and terrestrial principles. He integrates dynamics and kinetics in a systematic and mathematical way by only using linear forces (gravity) and linear inertia;[50] this is the end of the ontologically privileged position of circular motion (and its intuitional self-reliance). "The reconstruction of Newton's dynamics

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[48] Impetus was transmitted 'mediante motu', i.e. while moving together. The equivalence of force and movement is here even more obvious.

[49] Newton, Isaac (1687): Mathematical principles of natural philosophy, Berkeley 1960, Book 2, Prop. LII, Cor. 4.

... points to the decisive role of the problem of circular motion. The most perfect and therefore least problematic motion of Aristotelian science had become the enigmatic riddle athwart the path of the new science of mechanics. The ultimate superiority of the principle of inertia lay in the possibility it offered to complete the program of rational mechanics by subsuming rectilinear and circular motion under a common dynamics. The ultimate leap of the imagination that carried Newton to his mature dynamics was the recognition that uniform circular motion can be treated as the dynamic equivalent of what had appeared to generations of scientists as its exact opposite - uniformly accelerated motion in a right line."[51]

As already mentioned the representation of forces by hypothetical movements is an important methodological aspect of the *Principia*. A force can be represented by the deviation of a movement from the trajectory, that the respective body (or mass point) would have taken without the effect of all other forces.

In a sketch of the proof done for Halley in 1684 Newton shows the connection between the law of a force inverse to the square of a distance and the elliptical trajectory; here we already find the crucial supposition for the application of the geometrical method on dynamic processes: "A body in a given time is carried by a combination of forces to the same place to which it is borne by the separate forces acting successively in equal times."[52] No longer so exposed but in the close context of the three laws then Corollar I of the Principia says: "A body, acted on by two forces simultaneously, will describe the diagonal of a parallelogram in the same time as it would describe the sides by those forces separately."[53] Further Newton possessed a conclusive method to use this (linear) rule also for curvilinear (e.g. elliptical or circular) movements.[54]

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[50] The equivalence of heavy and inert mass ensures the equivalence of cause and effect in this context; so at least potentially the universe becomes an energetically closed system - not so for Newton, as he concludes from the three-body problem that the solar system needs some divine readjustments from time to time.

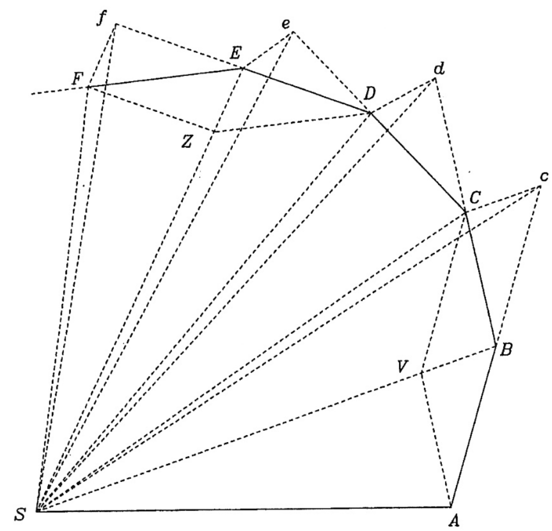
[51] Westfall, p. 187.
There is an important change of perspective from centrifugal are to centripetal force: while focusing on centrifugal force already presupposes, as with Descartes, a circulation, the centripetal force instead is one of two linear components, which cause the (elliptical) movements of planets.

[52] Hypothesis 3; cit. De Gandt, p. 18.

[53] Newton, Axiomata, Cor. I.

[54] Newtons *fluxions* deal with the infinitesimal relations of quasi-moved geometrical figures by approximating time to zero; thus he is able to deduce curvilinear circumstances from linear components.

At the beginning of the first book he gives an abridged account of Kepler's law of areas: "The areas which revolving bodies describe by radii drawn to an immovable centre of force do lie in the same immovable planes, and are proportional to the times in which they are described."[55] The proof of this proposition fascinates by its simple ingenuity, because it is based only on the equality of the areas ASB, SBc and SBC, on the equality of time and distance of AB and Bc (uniform inertial motion), and on Corollar I, with which the deviation from c to C can be maintained.



The infinitesation and thus the continuous curvature of the trajectory rounds up the proof: "Now let the number of those triangles be augmented, and their breadth diminished in infinitum; and [...] their ultimate perimeter ADF will be a curved line: and therefore the centripetal force, by which the body is continually drawn back form the tangent of this curve will act continually; and any described areas SADS, SAFS, which are always proportional to the times of description, will, in this case also, be proportional to those times."[56]

This law of areas is valid generally. The question is just which law of force correlates with which curve. And the *Principia* deal to a large part with a) conic sections and b) a gravitational force, which is inverse proportional to the square of the distance, in order to prove that the planets move on ellipses, which have the sun in a focus, and that such a trajectory obeys this law of gravitation.

Though Newton's complex and un-intuitional physics is actually post-mechanistic his *Principia* gave the machinelike cosmos some of their scientific aura. While its relation of cause and effect is based on the proportionality of force and change of motion (and the equivalence of heavy and inert mass), the more intuitional mechanistic formalisation is

55 Newton, Book I, Sec. II, Prop. I

56 Ibid..

based on proportionality of weight and the force of a moved body (systematised by the law of the lever and the principle of virtual velocity). Thereby force is something substantial given by god to the universe and now given from one particle to another while colliding.

So mechanism is something like an intermediate stage on the way to classical physics, however also a quite coherent stage. Accordingly it can still be said that it is ”until today the dominant structural model of Western civilisation.”[57] To define the order of a certain object by the relation of its parts and their successive causation is still quite a general standard. The coherence of the machine paradigm is a result of the coevolution of machines, of practical and theoretical mechanics the latter based on geometrical representations, and the respective categorical development.[58] This coevolution has been shown starting with the mechanisation in the Middle Ages which fostered the general usage of linear space, abstract time and terrestrial dynamics and their formalisation; while all this developments again fostered the technical development.

However the closed order of mechanistic thinking already implied the increasing expulsion of divine influence from the physical world, as well as from other domains of the world, and at last also from its outside.[59]

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57 Gloy, Karen (1995): Das Verständnis der Natur I. Die Geschichte des wissenschaftlichen Denkens, München, p. 163. (trans. BR)
Still today "... people understand the world as a large and complex machine that works smoothly and never runs down ..., but also one that is endowed with the anthropomorphic qualities of purposiveness, direction towards mature forms, constructiveness, and natural justice. There is, in this sense, a ghost in the machine." White, Peter A. (1992): The antropomorphic machine. Causal order in nature and the world view of common sense, in: British Journal of Psychology, 83 (1992), p. 90.

58 This coherence is not contradictory to the coherence based on the distinction of linear and circular movements. There were even some overlappings. The pre-modern concept lost its evidence in the history plotted by us by means of the four themes.

59 To take negative feedback systems, for instance, instead of classical machines as the basic paradigm leads to concepts like cybernetics, systems and evolutionary theory, transclassical logic etc. However outside of some institutionalised sciences, where such strenuous conceptual efforts are made, the machine paradigm is still operant.