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Chapter 1

Time as a variable

From Galileo's to Einstein's relativity

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1.1 Introduction

The concept of time and the concept of causality have always been at the centre of science: but how did these concepts evolve?

Galileo and Newton can be considered the theoreticians of "mechanical causality", on the basis of which all that we observe is determined by causes placed in the past. This type of causality is based on the description of a universe that moves from the past to the future: time follows an arrow in which past can never come back, future does not yet exist, and only the present moment is real. In this concept of time, the present is totally determined by past causes.

Over the last century, the concept of time has been revised. The starting point was the famous "Lorentz transformations" which linked time and speed, from which Einstein's special relativity was born (1905). Einstein developed special relativity in order to extend the validity of Galileo's relativity to all the physical phenomena, in particular to the electromagnetic ones. Special relativity is based on the fact that the speed of light is constant. Among its major consequences the concepts of space and time had to be redefined, and the equivalence between matter and energy. The concept of absolute time was abandoned, and it become relative to the speed of the system in which it was measured: this means that two events which are contemporary in a particular speed system may not be contemporary in another,

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this is a consequence of the fact that time flows in different ways according to different systems of motion (Einstein, 1916).
Quantum mechanics derives its equations from Einstein's special relativity, such as the energy/momentum/mass formula which links energy, speed and mass. This equation always has dual solutions: one in which time and energy move from the past to the future, and the other in which time and energy move in the opposite direction, from the future to the past. Using these equations, Paul Dirac, in 1928, demonstrated the existence of the positron, the anti-particle of the electron, and Feynman proved that each particle which moves in the usual retarded way, from the past to the future, has an associated anti-particle which moves in the anticipated way, from the future to the past (Feynman, 1949). Donald Ross linked the existence of emitters and absorbers of photons to the interaction of diverging waves, which propagate from the past to the future, and converging waves which, on the contrary, propagate from the future to the past.

1.2 The origins of the mechanical model in science: Newton's universe and the life machine model.

During the fifteenth and sixteenth centuries, the scientific revolution radically changed the concept of the universe which humanity had embraced during the Middle Ages, and opened the way to the understanding that we now have of the world.
The first signs of the scientific revolution can be traced back to the astronomical observations of Nicholaus Copernicus (1473-1543), which put the Sun at the centre of the universe and showed the contradictions of the geocentric system, in which the Earth was placed at the centre of the universe, based on the Aristotelian system. The Aristotelian system was introduced by Aristotle in the fourth century B.C., and perfected by Ptolemy in the second century A.D.. According to this system, the Earth is at the centre of the universe and the Sun, Moon, Mercury, Venus, Jupiter and Saturn turn around it in circular orbits, each using a different sphere. These spheres were contained within a greater sphere of the fixed stars, behind which was the sphere of God. The new system proposed by Copernicus, which represented a huge innovation in the astronomical field, was heliocentric, placing the Sun at

the centre of the universe, around which the planets Mercury, Venus, Earth, Mars, Jupiter and Saturn all orbit, while the Moon orbits the Earth and the stars are considered to be still.
Copernicus was followed by Johannes Kepler (1571-1630), who, thanks to astronomical tables, arrived at the formulation of the three laws of planetary motion, developing the Copernican heliocentric model into a scientific model.
The real change in scientific approach, however, can be found in the works of Galileo Galilei (1564-1642) who, using the telescope which had just been invented, was able to empirically prove the Copernicus' hypothesis, and provide the evidence that the Aristotelian-Ptolemaic cosmology was not true. In this way, Copernicus's hypothesis became the proven scientific model. The empirical approach of Galileo's work, and his use of mathematics, opened the way to the scientific revolution. The great contribution of Galileo can be found in the combination of scientific experiment and the use of mathematics. In order to use mathematics, Galileo studied fundamental properties which could be observed and measured.
In the same years during which Galileo was working on his ingenious experiments, Francis Bacon (1561-1626) was arriving at the formulation of the inductive method, deriving general conclusions from the observation of the experimental method. He became one of the major assertors of experimental methodology, courageously attacking the traditional schools of thought which were based on Aristotelian deductive logic. The Aristotelian method, starting from general laws, or postulates, deducts empirical consequences which have to be proved; Bacon's inductive method starts from empirical evidence to arrive at general laws. In order to produce objective knowledge, Galileo's and Bacon's scientific methods separated the observer from the observed.
This approach totally transformed the nature and purpose of science. Whereas previously the purpose of science had been to understand nature and life, science's purpose now involved the controlling and manipulating of nature. As Bacon said: "Objective knowledge will give command over nature, medicine, mechanical forces, and all other aspects of the universe". In this perspective, the aim of science becomes that of enslaving nature. We are now far away from the concept of "Mother Earth", and this concept will be totally lost when the organic concept of nature will be replaced by the mechanical concept of the world, which can be traced back to the works of Newton and Descartes.

Descartes (1596-1650) based his work on the idea that the “book of nature” had been written in mathematical characters. His aim was to reduce all physical phenomena to exact mathematical equations. He believed that nature could be described using simple motion equations, in which only space, position, and moment were relevant. “Give me position and movement”, he said, “and I will build the universe”. Among Descartes’ greatest contributions was his *Analytical Method of Reasoning*, according to which any problem can be decomposed into its parts, and then reordered. This method lies at the foundation of modern science, and has been of great importance, permitting the development of scientific theories and complex technological projects. Descartes’ vision is based on the duality between two reigns, separate and independent: the reign of spirit, or *res cogitans*, and the reign of matter, or *res extensa*. This division between matter and spirit has had profound consequences on culture, leading to the separation of body and mind which still puzzles science. According to Descartes, matter and spirit are created by God, who is the creator of the exact order of nature that we see, thanks to the light of reasoning. However, in the following centuries the reference to God was omitted and reality was divided into the human sciences, linked to *res cogitans* and the natural sciences, which were an expression of *res extensa*. Descartes’ vision described the material world as a machine which has no intentionality and no spirituality; nature functions according to mechanical laws, and every aspect of the material world can be explained on the basis of its position and movement. This mechanical vision was extended by Descartes to living organisms, in the attempt to organize a complete natural science. Plants and animals were considered simply as machines, whereas human beings were “inhabited” by a rational soul (*res cogitans*) linked to the body (*res extensa*) through the pineal gland, at the centre of the brain. The human body, on the other hand, was similar to the body of an animal-machine. This highly mechanistic vision of nature was inspired by the high precision that was being achieved at the time by the technology and art of clock-making. Descartes compared animals to “clocks with mechanisms and springs” and extended this comparison to the human body, comparing a sick body to a badly build clock, and on the other hand, a healthy body to a well constructed and perfectly functioning clock.

The scientific revolution reached its maturity in the works of Isaac Newton (1642-1728), who discovered the mathematical equations which govern mechanical motion, unifying the works of Copernicus, Kepler, Bacon, Galileo and Descartes. Kepler derived the laws of planetary motion from the astronomical tables; Galileo discovered the laws of falling bodies; Newton combined these results in a general formulation of laws which govern the solar systems, the planets, and also stones (and apples). He found that each body is attracted towards the Earth with the same force which attracts the planets to the Sun; he introduced the concepts of inertia and gravity, arriving at the famous laws which govern motion:

1. The law of inertia (already stated by Leonardo da Vinci and Galileo) which shows that bodies keep their movement until a force is applied to them.
2. The law of proportionality between force and acceleration, linking the force which is applied to a body with the mass and acceleration which is impressed, following the relation: F=ma.
3. The law of action and reaction, which shows that to each action there is a corresponding similar and opposite reaction.

The importance of these laws is their universality. They were soon found to be valid throughout the solar system, which was considered to prove the mechanical model which had been proposed by Descartes. In 1686 Newton presented his complete concept of nature and the world in the *Philosophiae Naturalis Principia Mathematica* (Mathematical principals of the philosophy of nature). This work is a set of definitions, propositions and demonstrations that for more than two hundred years have been considered the most exhaustive description of nature and the world. In the Principia Newton describes the experimental method which he adopted, which he derived from the combination of the empirical-inductive method described by Bacon and the rational-deductive method described by Descartes. Newton says that experimental results have to be resumed into theories, systematic interpretations, and deductions from theories have to be proved by experiments: in the absence of one of these two aspects, theories cannot be considered scientific. In this way Newton turned experimental methodology into the key element for the production of scientific theories and knowledge.

Newton's universe was the tri-dimensional space of the classical geometry of Euclid: an empty space independent from what takes place in it. Time was considered absolute and not linked to the material world: time flowed relentlessly from the past to the future, through the present. In this space and absolute time, material particles, small solid and indivisible objects, were governed by mechanical laws. Newton considered these particles to be uniform, and explained the differences between types of matter as more or less thick aggregations of atoms.

In Newton's mechanics, all physical phenomena can be reduced to the movements of elementary particles caused by their reciprocal attraction: the force of gravity. The effect of gravity on a particle or on any material object is described by Newton's mathematical equations of motion, which are at the base of mechanics. In this concept of the universe, empirical investigation could not extend to the elementary particles and the force of gravity: gravity and elementary particles were a creation of God, and could not be investigated.

In *Opticks*, Newton gave a clear description of how he believed God created the material world: *"I think that God first created matter in the form of solid particles, hard and compact, indivisible and mobile, made of such dimensions and shapes, and of such properties, to be the most adaptable to the purpose he had created them for; these particles are solid, harder than any other body, so hard that they can never be consumed or broken: no force can divide what God made at the moment of creation".*

In this way, Newton completed the vision of a gigantic cosmic machine, totally governed by mechanical laws of causality: everything originated from a precise cause, and could be determined using mathematical laws. Thus it would be possible to determine and calculate the future states of the universe, if the initial states were known.

During the seventeenth and eighteenth centuries this mechanical approach was used to explain even the smallest variations in the orbits of planets, satellites and comets, tides, and whatever was linked to gravity. The model was then extended beyond the boundaries of astronomy, and used to describe the behavior of solids, liquids, gases, heat and sound.

The mechanistic vision of reality is well summarized in the following words of P.S. Laplace (1814): "*We need to consider the present state of the Universe as a consequence of its previous states and as the cause of its following states. An intelligence which, for a specific instant, could know all the forces which move the objects which constitute the Universe, and could analyze these data, would embrace in a single equation all the movements of the Universe and of the atoms: nothing would be undetermined for the future and the past."* (Laplace 1795).

1.3 Thermodynamics and entropy: heat death

During the nineteenth century, the application of Newtonian mechanics to the description of heat lead to a new discipline: thermodynamics. This discipline, which can be traced back to the works of Boyle, Boltzmann, Claius and Carnot, studies the behavior of energy, of which heat is a form. Gases at the base of thermal machines were studied and the transformation of energy into work was analyzed; this lead to the discovery of three new laws:

1. The law of conservation of energy, which states that energy cannot be created or destroyed, but only transformed.
2. The law of entropy, which states that when transforming energy (for example from heat to work) part is lost to the environment. Entropy is a measure of the quantity of energy which is lost to the environment. When energy lost to the environment is distributed in a uniform way (ie where no differences in heat exist), a state of equilibrium is reached and it is no longer possible to transform energy into work. Entropy measures how close a system is to this state of equilibrium.
3. The law of disorder which states that within an isolated system entropy cannot diminish. When an isolated system reaches the highest level of entropy no further transformation can take place: the system has reached a state of equilibrium, known as heat death.

The principle of entropy (as expressed in the second law of thermodynamics) is of great importance, as it introduces into physics the idea of irreversible processes, such as that energy always moves from a state of high potential to a state of low potential, tending to a state of equilibrium. Sir Arthur Eddington introduced the expression "*the arrow of time*" (Eddington, 1927), showing that entropy forces events to move in one particular direction: from a situation of high potentials to one of low potentials, from past to future. Our experience continually informs us about entropy variations, and about the irreversible process that leads to the dissipation of energy and the heat death: we see our friends becoming old and die; we see a fire losing intensity and turning into cold ashes; we see the world increasing in entropy: pollution, depleted energy sources, desertification.

The term irreversibility refers to the fact that in physical processes there is a tendency to move from order to disorder, and it is impossible to restore the previous level of order in which all energy was available: mechanical energy dissipates in the form of heat and cannot be recaptured. If we mix together hot and cold water we get tepid water, but we would never see the two liquids separate spontaneously.

The third law of thermodynamics, derived from the second law, states that the dissipation of energy is an irreversible process, since dissipated energy cannot be recaptured and used again, and that the entropy of an isolated system (which cannot receive energy or information from outside) can only increase until a state of equilibrium is reached (heat death).

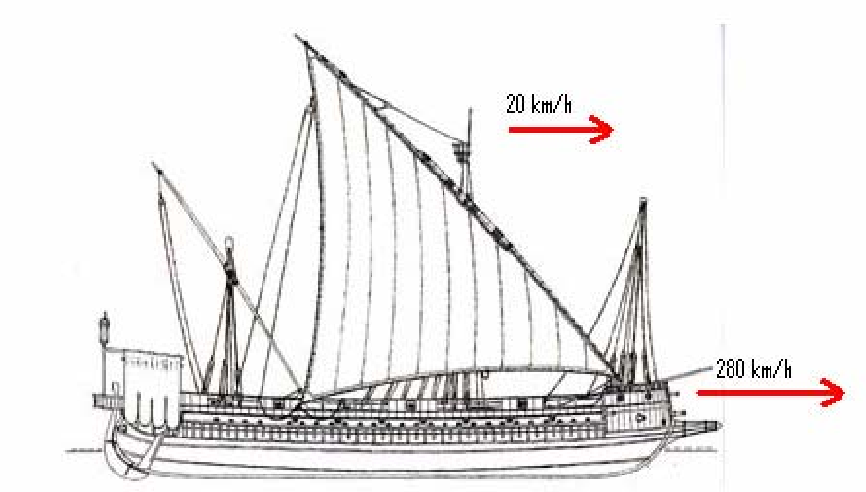
The term “entropy” was first used in the middle of the eighteenth century by Rudolf Clausius, who was searching for a mathematical equation to describe the increase of entropy.

Entropy is the combination of the Greek words “tropos”, which means transformation or evolution, and the word “energy”: it is a quantity which is used to measure the level of evolution of a physical system, but in the meantime it can be used to measure the “disorder” of a system. Entropy is always associated with an increasing level of disorder. In an isolated physical system, disorder (ie the homogeneous distribution of energy) increases leading to entropic heat death. Nevertheless, this seems to be contradicted by life: living systems evolve towards order, towards higher forms of organization, diversification and complexity, and can keep away from heat death. Jacques Monod tried to explain life as the result of improbable conditions (Monod, 1974). In this way life could be considered compatible with the laws of entropy, but its survival was a continual fight against the laws of physics, which made life highly improbable.

Entropy evolves only in one direction: towards death and the elimination of any form of organization and structure. In order to become compatible with entropy, biology explains life as the consequence of highly improbable events constituted by the incidental formation of genetic codes and positive genetic variations. Entropy leads to the concept of a universe in which life is extraneous, a universe governed by laws which ignore life. Jacques Monod describes this, saying: “If he accepts this message in its full significance, man must at last wake out of his millenary dream and discover his total solitude, his fundamental isolation. He must realize that, like a gypsy, he lives on the boundary of an alien world; a world that is deaf to his music, and as indifferent to his hopes as it is to his suffering or his crimes.”

1.4 Galileo’s relativity.

In his work "*Dialoghi sui Massimi Sistemi*" Galileo provides a very clear description of his principle of relativity. He describes an observer closed in the cargo of a ship, who observes the way how objects fall. Galileo proves that it is impossible for this observer to calculate the speed of the ship basing his calculations on the way objects fall, because all these objects share the same movement of the ship (the same inertial system). Galileo points out that for an observer on the coast the speeds on the boat would instead sum up to that of the ship. For example, if a ship is moving at 20 km/h:



and a cannon ball is fired at 280 km/h in the direction of the ship, the observer on the coast will see the cannon ball move at 300 km/h, 280 km/h of the speed of the cannon ball plus 20 km/h of the speed of the boat. If the cannon ball were fired in the opposite direction to the movement of the ship the resulting speed would be 260 km/h, 280 km/h of the speed of the cannon ball minus 20 km/h of the speed of the boat (speeds are subtracted because they move in opposite directions). On the contrary for a sailor on the ship sharing the same movement of the ship (inertial system), the cannon ball would always move at 280 km/h in any direction he would fire it. Therefore, if an observer on the seashore sees the cannon ball moving at 300 km/h and the boat in the same direction at 20 km/h he can conclude that the ball was fired at 280 km/h.

Galileo's relativity is based on the principle that when changing an inertial system, speeds are added or subtracted on the basis of their relative speeds. In Galileo's relativity, speeds are relative to the inertial system, while time flows in an absolute way for all the systems. It is important to underline that classical physics is based on Galileo's relativity.

1.5 Einstein's relativity

At the end of the eighteenth century Maxwell found that the speed of light did not add to the speed of the body which was emitting it, and Michelson and Morley proved experimentally that the speed of light was constant: it never adds to the speed of the body which is emitting it. The profoundly innovative researches of H.A. Lorentz, on electrodynamics and optics in moving bodies, lead to mathematical equations in which the speed of light is always constant.
In 1905, analyzing the results obtained by Michelson, Morley and Lorentz, Einstein found himself forced to invert Galileo's relativity according to which time is absolute and speed is relative; in order to describe the fact that the speed of light is constant, it was necessary to accept that time is relative. As an example, let us imagine, after 500 years, a sailor on a very fast space ship heading towards Earth at 20.000 km/s who shoots a laser light ray towards Earth (at 300,000 km/s). An observer on Earth will not see the laser light move at 320.000 km/s, as Galileo's relativity would predict, but it will see it move at 300,000 km/s (because the speed of light is a constant). According to Galileo's relativity, the observer on Earth would expect that the sailor on the space ship would see the light ray move at 280.000 km/h (300.000 km/h of the speed of light minus 20.000 km/h of the space ship) but, on the contrary, also the sailor on the space ship sees the laser ray move at 300,000 km/s. Einstein proved mathematically that what varies is time. When we move in the direction of light our time slows, and for us light continues to move at the same speed. This leads to the conclusion that approaching the speed of light time would slow down and stop, and if we could move at speeds higher than the speed of light, time would reverse.
In other words, events which happen in the direction in which we are moving become faster, because time slows down, but events which happen in the direction from which we are coming become slower, because time becomes faster.

In order to explain this situation, Einstein liked to use the example of lightning which strikes a railway simultaneously in two different points, A and B, far away from each other (Einstein, 1916). An observer sitting on a bench half-way would see the lightning strike the two points simultaneously, but a second observer on a very fast train moving from A to B (figure 1) passing next to the first observer at the moment in which the lightning strikes the two points would have already experienced the lightning striking point B, but would not have not experienced the lightning striking point A. Even if the two observers share the same point of space at the same moment, they cannot agree on the events which are happening in the direction in which the second observer is moving. Agreeing on the existence of contemporary events is therefore linked to the speed at which the observers are moving.

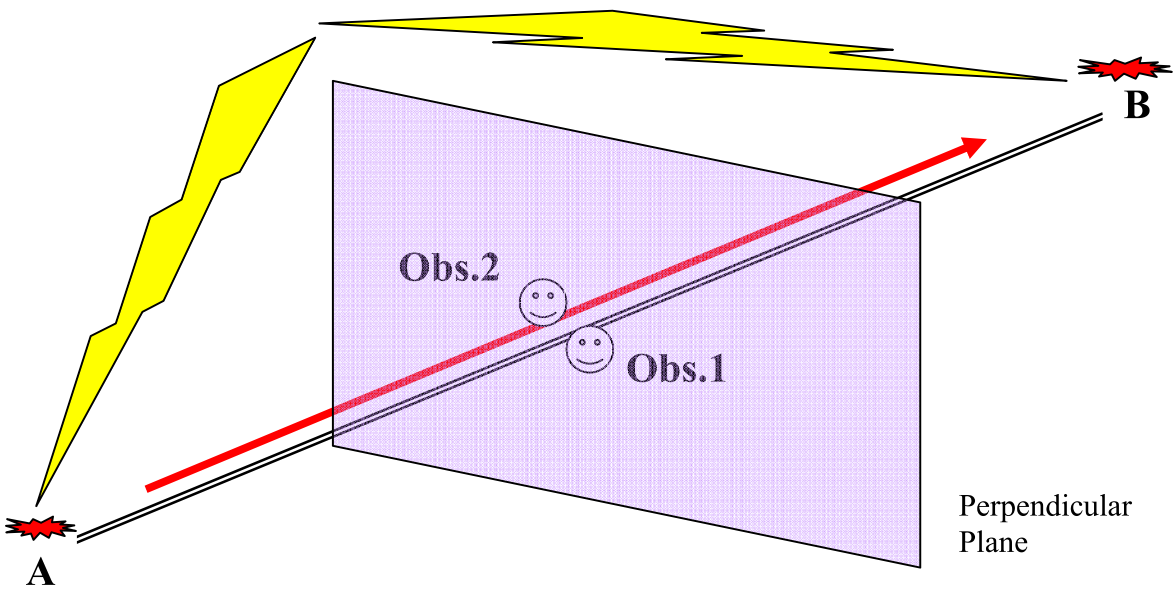


Figure 1

In other words, events which take place in the direction in which we are moving become faster, because our time slows down; but events which happen in the direction opposite to our movement become slower, because our time speeds up. It is important to note that time flows differently if the event is happening in the direction towards which we are moving, or in the direction from which we are coming: in the first case they become slower and in the second case faster. This example is limited to two observers; but what happens when we compare more than two observers moving in different directions at high speeds? The first couple (one on the bench and the other in the train) can reach an agreement only on the contemporary existence of events which happen on a plane perpendicular to the movement of the train. If we add a third observer moving in another direction, but sharing the same place and moment with the other two observers, they would agree only on events placed on a line which unites the two perpendicular planes; if we add a fourth observer, they would agree only on a point which unites the three perpendicular planes; if we add a fifth observer, who is not even sharing the same point in space, no agreement would be possible at all. If we consider that only what happens in the same moment exists (Newton's time concept), we would be forced to conclude that reality does not exist. In order to re-establish an agreement between the different observers, and in this way the existence of reality, we need to accept the coexistence of events which could be future or past for us, but contemporary for another observer. Extending these considerations, we arrive at the necessary consequence that past, present and future coexist.

Einstein himself found it difficult to accept this consequence of special relativity, according to which past, present and future coexist; but the unified time model was perfected by Minkowski, who coined the term "chronotopes" to describe the union of space and time. Since Einstein presented his theory of relativity, time has become a dimension of space: space is no longer limited to 3 dimensions. As we can move in space, so we can also move in time: space now has 4 dimensions, and is therefore named space-time.

Another important consequence of the theory of relativity is that mass is a form of energy, and even a stationary object has energy in its mass. The relation between mass and energy is expressed by the famous equation $E=mc^2$, where *c* is the speed of light, *m* the mass and *e* the energy. The equivalence between mass and energy opened the way to quantum mechanics, where mass is no longer associated with a material substance, but seen as a type of energy. Particles are therefore now studied according to relativity, where time and space are united in a four-dimensional continuum. Atomic particles are now considered dynamically to be forms of time-space: their space form makes them appear as objects with mass, while their time form makes them appear as waves with energy. Since the introduction of relativity, matter and its activity are two aspects which can no longer be separated: they are two forms of the same space-time unity.