Friedel Weinert

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Evolving Conceptions of Time in the Light of Scientific Discoveries

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Preface

The present volume originates from lectures and seminars, which I gave at Victoria University in Wellington (New Zealand), at the University of Bradford (UK) and at international conferences, organized by the International Society for the Study of Time (ISST). They are held every 3 years and I attended the meetings in Monterey, California (2007), and Costa Rica (2010). The following pages reflect my long-standing interest in the philosophy of time, and develop themes, which I first explored in talks, which I gave at Sydney University, the University of Western Ontario, and in various published papers on the notion of time.

I benefited from a British Academy Overseas Conference Award (2007) and from two research fellowships. The first draft of this book was completed at the Unit for History and Philosophy of Science, University of Sydney, where I was a visiting fellow from June to September 2009. I would like to thank the members of the Department for their hospitality. The final draft of the book took shape at the Rotman Institute of Philosophy, University of Western Ontario (Canada), where I was a research fellow from May to July 2012. I would like to thank the members of the Institute for their hospitality and the stimulating intellectual atmosphere, which the Institute provides.

I was fortunate to received constructive criticism from several readers. Meir Hemmo, from the University of Haifa, read Chap. 3. Claudio Calosi (University of Urbino) and Roman Frigg (London School of Economics) both read the whole manuscript. Thanks to their generous and expert advice I was able to improve and clarify the ideas discussed in this book. Finally I must express my gratitude to Angela Lahee, my editor at Springer Verlag in Heidelberg, for her unwavering support and her enthusiasm for a book on time.

I hope the reader will enjoy reading the book as much as I enjoyed writing it.

Friedel Weinert

Contents

Chapter 1
Evolving Conceptions of Time in the Light of Scientific Discoveries

> The concept of time is perhaps one of the most integrating in human knowledge. It appears in many fields, including philosophy, biology and, most prominently, in physics, where it plays a central role. It has interested Man of all Ages, and the finest minds from Saint-Augustine to Kant and Einstein have paid attention to its meaning, and the mystique shrouding its most notorious property: that of flowing only forward, its irreversibility.
>
> José Angel Sánchez Asiain, Forword, in J.J. Halliwell et al. (1994), xiii.

1.1 Introduction

Our earliest ancestors must have had a dim awareness of time, since their very existence was heavily dependent on the cycle of seasons. They will have been aware of the rhythm of day and night and no doubt of lunar cycles. Their preoccupation with daily survival and the hunt for food and shelter may not have granted them much time for thoughts of a more abstract nature but one may speculate that in quiet moments by the fireside on starry nights they may have succumbed to reflections about the nature of time. No written records of these musings exist but cave drawings and large stone structures, like Stonehenge, testify to the curiosity of our earliest ancestors about the universe. The Greeks, however, left numerous written documents about their preoccupation with the cosmos and the nature of time. They demonstrate that time is one of the most fundamental notions, which is dominant in both human existence and human endeavours to understand the surrounding world. Many thinkers have grappled with the notion of time and their collective efforts have produced some influential models of time (Chap. 2). Although these philosophical models establish important insights into the notion of time, and are therefore of considerable value as guidelines of investigation, they cannot be divorced from scientific discoveries about time (Chaps. 3, 4) so that our evolving conceptions of time have to be considered in the light of scientific discoveries. New discoveries in cosmology

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about the evolution of the universe have led to radical new views about the notion of time. When these ideas are considered and our views of the history of time reckoning are extended to the present day, three striking features, which will structure the contents of this book, stand out.

1. Most considerations of time, up to the 21st century establish a link between time and cosmology (Chap. 2). Cosmology is the study of the large-scale structure of the universe, to which the Greeks made significant contributions. The particular cosmological feature, which struck early observers, was the periodic regularity of planetary motions. As we shall see, this feature is clearly present in the views of Plato and Aristotle, as well as Ptolemy. In Greek cosmology the universe is a closed system. The 'fixed stars' constitute the outer boundary of the cosmos beyond which the deities reside. The Earth is modeled as a stationary sphere near the center of the universe, and all the planets and stars perform circular motions around the 'central' Earth. Their preoccupation with the eternal regularity of celestial motions predestined the Greeks to consider the *passage* of time and its measurement. Modern cosmology has moved to different preoccupations, especially to the question of the origin of the universe and its overall history and its eventual demise. Modern cosmology is more concerned with the question of the *arrow* of time at least insofar as this concerns the observable expansion of the cosmos and the question of its eventual fate—will the universe expand forever or will its expansion grind to a halt and then enter a phase of recontraction? All these processes depend on certain regularities, which are required for the measurement of the *arrow* and the *passage* of time. Talk of the direction or anisotropy of time may thus refer either to an experience of a one-directional, forward movement of events in our galactic vicinity, which will be characterized as the *passage* of time; or to the global movement of the whole universe, pointing like an *arrow* from an initial beginning in the Big Bang to its eventual end, either in a contraction of the universe (Big Crunch) or the complete disappearance of all energy gradients (Heat Death). Time, of course, cannot be measured directly; regular events are needed to measure time. But the anisotropy of time could conceivably be experienced in the absence of such regularities. Imagine a universe, in which only random sounds can be heard or in which occasional light flashes appear from different directions. If you are the unfortunate inhabitant of such a lonely universe, you will be at a loss to establish a regular pattern between the intervals of the sounds or flashes. You could not tell how long the intervals last between the flashes and the sounds. Nevertheless, you could count the sounds and flashes you experience, say up to 100, which would give you a basic 'before-after' relationship between the series of observed sounds and flashes. Hence you could determine the passing of time by the irregular events you perceive although you would not be able to measure the passage of time. The measurement of the passage of time requires some regularity, often of a periodic kind. Such a periodic regularity requires regular intervals between events, as the Greeks observed in the orbits of the planets. However, regularity is not a

sufficient condition; the regularity must also be invariant. This requirement became particularly clear with the Special theory of relativity. Invariance means that an observed regularity must not depend on a particular perspective. A regularity is invariant if it is the same from different temporal and spatial perspectives. The physics of a tennis match is invariant in this sense since it is the same whether it is played in Andalusia or Zimbabwe, whether it was played on a Victorian court in 1875 or in Flushing Meadows in 2005. Greek astronomers stipulated that the planetary motions were perfectly circular, which implies both regularity and invariance. The regularity of planetary motions was observed to be the same irrespective of the spatial or temporal perspective of the observer.

2. The Greeks also highlighted the second feature in human views on time: stasis *versus* flux (Chap. 3). This feature can most conveniently be located in the debates of Heraclitus and Parmenides. The *Parmenidean* view can be characterized as the thesis that reality, at a fundamental level, is a timeless, unchanging, being. Stasis is fundamental and the perception of change and the passage of time are a human illusion or conception. Flux is a mere appearance (See Callender 2010). The passage of time is a product of the human mind such that time would disappear with the disappearance of humans. The Parmenidean view denies that time exists in the physical universe but allows for the existence of *human* time. The *Heraclitean* view emphasizes the dynamic aspect of flux, of the changing nature of events, of temporal becoming. According to this view, as long as there are physical events, there is *physical* time. Hence flux is fundamental and stasis is only an appearance. Physical time only depends on the 'before-after' relationship between events in the universe and occurs irrespective of human awareness. But for the measurement of physical time, humans require physical time to be regular and also independent of particular perspectives. If physical time is to be understood as a 'before-after' relation between events in the physical world, then *human time* can be understood as a conceptual representation of physical time. As such it is a mental construct, since it depends on human awareness of change and succession. The Heraclitean view regards human time as an abstraction from physical time. Some writers conceive of human time as *mental* time (Augustine 1961; Lucas 1973; cf. Gunn 1930) but this characterization is too psychological, since it does not include the conventional and social aspects of human time reckoning. Human time is expressed in calendars: the division of the year in 12 months and 52 weeks, the division of the day in 24 h, the beginning of the year and the day. It comprises both conventional and natural units of time. It comprises the distinction between past, present and future. Human time is a product of both natural units of time—periodic, regular and invariant processes in nature, like the waltz of the planets around the sun—and conventional units of time—the symbolic representation of time according to our calendars, to which no particular physical event may correspond (like the end of the year).

As this book is concerned with 'evolving conceptions of time in the light of scientific discoveries', these early Greek speculations appear to be out of place.

Surprisingly, interpreters of modern physical theories have re-emphasized this contrast between flux and stasis. Modern commentators take their cue from the results of physical theories—the theory of relativity, cosmology or quantum mechanics—and *infer* a particular view on the nature of time (being or becoming, stasis or flux).[1] It is important to realize that these are *conceptual* inferences, i.e. that they do not follow deductively from the principles of the respective theories. That is to say that certain features of these theories are taken to lend support to a certain view of time. It is the prevailing view today amongst physicists and philosophers that modern physical theories imply a *static* timeless view of the universe. This view is often called the *block universe*. Many commentators lean towards a Parmenidean view, which is no longer based on metaphysical speculations but on particular features of scientific theories. This book is an attempt to show that these physical theories are compatible with a Heraclitean, dynamic view of physical time. Hence the title of the book: *The March of Time*. This Heraclitean view is also an inference from certain features of physical theories. Hence the question of whether there exists physical time or only human time is empirically underdetermined to a certain extent. Two incompatible views of time (stasis, flux) are compatible with the results of physical theories. However, this situation need not end in a stalemate. It is the author's contention that a certain dynamic view of time is more compatible with the overall results of modern theories than a static view.

3. One important consequence of the emergence of modern science is the discovery of laws of nature, which may be understood as quantifiable structural relations between events, objects, properties and systems in the physical universe. These structural relations can be expressed in the language of mathematics. The German astronomer Johannes Kepler (1571–1630) was probably the first scientist to formulate mathematical laws of planetary motions. The laws of motion often employ the parameter t, which stands for clock time. It is an essential feature of many fundamental laws that they are time-reversal invariant. Technically, this means that a physical law, L, which includes a parameter t, allows physically possible models with either $+t$ and $-t$ as temporal parameters. Let L state a relationship between some fictional parameters, say, $\theta = \varphi t^3$, then time-reversal invariance means that both $+t$ (always producing a positive result for θ, if φ is a positive constant) and $-t$ (always producing a negative result for θ) are both permissible and physically possible processes according to the equation. This characterization marks the time-

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[1] These debates sometimes take on a life of their own. For instance, there are discussions about the semantic properties of temporal language or the attention turns to an ontological debate about realism or anti-realism about time or space–time or metaphysical debates about presentism *versus* eternalism. These debates are not the focus of this book. Whilst the discussion will touch on some of these debates, for instance the discussion between Newton and Leibniz, the main focus of the book's material is the question to which extent a Heraclitean or Parmenidean view of time is compatible with the results of scientific theories. The more metaphysical ramification will not be pursued but can be gleaned from Savitt (2001).

reversal invariance of laws. A different sense of time-reversal invariance refers to the solutions of the equations. A good illustration of time-reversal invariance or temporal symmetry in this sense is to picture a film of a pendulum—an ideal pendulum, which does not suffer damping—that oscillates with a certain frequency, υ. A viewer would not be able to tell whether the film was running backward or forward in time. The same is true of an animation of planetary motion. As a matter of fact, it is the case in our solar system that all planets orbit the sun from west to east. But an observer who was ignorant of this fact would not be able to tell which of two films—one showing the planets moving in the familiar direction and the other in the opposite direction—was a correct representation of reality. But even if observers did know the true motion of the planets around the sun, on seeing the film running in reverse, they would only be able to conclude that the planetary system shown was not the familiar solar system but that it was a physically possible planetary system elsewhere in the universe. For the particular direction of orbits depends on special initial conditions but the planetary laws allow both systems. Now let the viewer be shown a slow-motion film of a bullet leaving a pistol shaft or a cup falling from the top of a table and breaking on impact. In these cases, if the film was shown running in reverse, this viewer would be in no doubt as to the true sequence of events. S/he would judge the reverse scenario as physically impossible (especially if s/he was asked to judge intuitively without employing any previous knowledge of statistical mechanics). The reason for this verdict is that these cases display a fundamental asymmetry. This contrast between the time symmetry of fundamental laws and the ubiquitous asymmetry of physical events around us is the third feature of modern views on time (Chap. 4). It too divides researchers into proponents of a Parmenidean view versus proponents of a Heraclitean view. The latter view will be defended in the following pages.

The story of time, which is the subject of this book, will not be told in chronological sequence; rather it will be structured according to these three features: Chap. 2, *time* and *cosmology*; Chap. 3, *stasis* and *flux* (or being and becoming), and Chap. 4, *symmetry* and *asymmetry*. The author hopes that the focus on these three themes, in view of the scientific discoveries, will throw new light on the nature of time.

Chapter 2
Time and Cosmology

> Our theory of clocks has great influence on our understanding of time. (J. R. Lucas, *A Treatise on Time and Space* 1973, Part I, Sect. 10)

Running through the whole history of time reckoning is a deep connection between time and cosmology. It is essential for the measurement of time, since it provides periodic regularity. The early Greeks established the association of time with periodic regularity on a planetary scale. Regularity, however, is not a sufficient condition for the objective measurement of the passage of time. A further condition is needed: invariance, the importance of which came to the fore with the Special theory of relativity. The measurement of time is here understood as the measurement of less regular intervals by more regular intervals of events, and the improvement in accuracy, which can thereby be achieved through the method of triangulation. In this volume time is meant in a physical sense, which is based on some regular, material events in the physical universe; it is not meant in a metaphysical sense, according to which there exists some entity called TIME in the physical universe over and above its matter, motion and energy. Equally, when the discussion switches to the 'direction' of time, what is meant is the direction of processes and events *in* time, not a direction of Time itself.

2.1 Greek Astronomy

> (…) if we seek to examine Time, we find ourselves examining Reality. (Gunn 1930, 369)

The intellectual labour of the Greeks produced a first coherent cosmology: the Aristotelian-Ptolemaic theory of geocentrism. According to this view, the Earth resides motionless at the 'centre' of the universe. This universe was essentially identical with the existence of the then known six planets. The planets, which included the sun, were understood to be carried around the central Earth on circular orbs, in known periods, from west to east. The fixed stars, beyond the planetary spheres, also circled the stationary Earth in a 24 hour-rhythm from east to west.

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The planets were the ‘wandering stars’ because their movements could be observed against the background of ‘fixed’ stars, which did not seem to change their positions in the stellar constellations over long periods of time. In the history of astronomy Plato’s cosmology, as presented in the *Timaeus*, is usually neglected, while Aristotle’s cosmology figures more prominently. Aristotle conceived of the cosmos as a two-sphere universe (Aristotle 1952a, b; cf. Weinert 2009, Chap. I). The region between the Earth and the moon was the *sublunary* sphere; the region beyond the moon to the fixed stars was the *supralunary* sphere. The sublunary sphere was the area of asymmetry, change and flux. The supralunar sphere, in which the planets circle the Earth, was characterized by perfection, permanence and symmetry. This cosmic division reflects the fundamental distinction in Greek metaphysics between Parmenidean stasis and Heraclitean flux. As the planets’ orbits were located in the supralunar sphere, their journey around the stationary Earth was supposed to be circular, for the circle was a perfect geometric figure in Greek culture. Whilst the sublunary sphere was characterized by changing events, by decay and renewal, the planets moved around the central Earth with perfect periodic regularity. The Greeks knew the order of the planets, although they placed the sun where in today’s Copernican worldview the Earth is located and they knew the orbital periods of the planets fairly accurately. Unlike Aristotle, who stipulated that the Earth sits motionless at the centre of the universe—a view, which was later refined by Ptolemy–Plato seems to have attributed a diurnal motion to the Earth (Taylor 1926, 449–454; Cornford 1939, 120–134). Plato was not the only Greek who bestowed a diurnal rotation of the Earth on its own axis. In the 4th century B.C. Heraclides of Pontus proposed that the daily rotation of the stars was produced by the daily rotation of the Earth on its own axis. Aristarchus of Samos (310–250 B.C.) went further and placed the sun at the centre of the universe and gave the Earth a circular orbit around it. But this view had little impact on subsequent developments, since it seemed to contradict the perceptual evidence. To a Greek observer it seemed obvious that ‘the heavens’ moved and that the Earth stood still. A powerful argument against the motion of the Earth on its own axis, which prevailed until the work of Copernicus (1543), was that under the force of the rotation—similar to the experience on a spinning wheel—buildings would crumble and violent winds would blow from east to west, stopping birds from flying eastwards.

2.2 Plato and Aristotle

Whilst Plato’s cosmology had little impact on the subsequent history of astronomy, his views on time were more influential. They mark a clear example of the association of time with cosmic regularity, which persists to the present day. As is well-known Plato (427–347 B.C.) drew a distinction between the changing world of our daily experience and an underlying realm of unchanging forms. The visible world is the world of becoming and change; but it is a shadowy image of an eternal world of unchanging, permanent forms. According to Plato there can be no exact science of the natural world, because it is subject to change and flux. Physics only tells a likely story but mathematics deals with timeless forms—for instance geometric objects, like circles and triangles—and they alone can be the object of rational understanding (Cornford 1937, Prelude). And yet there is time. Time, in Plato's view, is the 'moving likeness of eternity'. But, significantly, Plato adds that this image of eternity moves according to number, by the will of the demiurge:

> But he took thought to make, as it were, a moving likeness of eternity; and, at the same time that he ordered the Heaven, he made, of eternity that abides in unity, an everlasting likeness moving according to number – that to which we have given the name Time. (*Timaeus* 37D; quoted in Cornford 1937, 98; see also Taylor 1926, Chap. XVII; Benjamin 1966; Whitrow 1966; Jammer 2007)

But as the sensible world is subject to irregular fluctuations and oscillations, a measurable passage of time cannot be identified in this realm. Time depends on periodic regularity of motion, which is to be located in the movements of the planets.

> (…) Time came into being together with the Heaven, in order that, as they were brought into being together, so they may be dissolved together, if ever their dissolution should come to pass; and it is made after the pattern of the ever-enduring nature, in order that it may be as like that pattern as possible (…) (*Timaeus* 38B, C; quoted in Cornford 1937, 99)

Firstly, then, Plato identifies time with regular physical events, like the motion of celestial bodies; secondly, such orbital motions mark off periods of time, due to their regularity. It takes a planet a certain amount of time—from 87 days (Mercury) to 164 years (Neptune), and 284 years (Pluto)—to return to its previous position. These orbital periods can be used to define periods of human time: the calendar year (orbit of the Earth) or the month (lunar cycle). 'Plato's view of time is inseparable from periodic motion', (Cornford 1937, 103), for in this way time can be 'the moving image of eternity'. The changing events on Earth are too irregular, in Plato's view, to constitute physical time; the underlying reality of eternal forms simply exists in a timeless sense of pure being. The planets are therefore an ideal instrument of time (*Timaeus* 38C–39E). Their observable motion is periodic, regular and, according to Greek cosmology, everlasting; hence invariant.

Aristotle (384–322 B.C.) criticized Plato for his theory of forms and his theory of time. Aristotle objected that time cannot be identified with celestial motion: since motion is measured in time, time cannot be measured by motion. Motion can be fast or slow and change, which accompanies motion, has a location in space but time as such cannot be perceived, although we are conscious of the passing of time when we discern change and movement. Aristotle granted that time is dependent on change or motion and awareness of time depends on an awareness of 'before' and 'after' in change. The relation between time and change is reciprocal: Without change, there can be no recognition of time; and without time, there can be no measurement of change. 'The time marks the movement, since it is its number, and the movement the time' (Aristotle 1952a, iv, 220b). But Aristotle did not provide a theory of time; rather he sketched a theory of the measurement of time. In Aristotle's view, time becomes quantifiable change from 'before' to 'after' in the course of events; hence Aristotle associated regular motion with measurement and magnitude. He argued that regular change was a necessary condition of the measurement of time. Whilst there are many particular movements, which may change and cease, there is one type of regular movement—the eternal circular motion of celestial objects—which provides the perfect measure of time. He regarded time as a numbering process, associated with our perception of a 'before–after' relationship between events in motion. Motion is restricted to qualitative (alteration), quantitative (change in size) and local motion (change in place). Time is quantifiable change from 'before' to 'after', thus implying measurement and magnitude. Aristotle furnishes a definition of the measurable duration of events, rather than a theory of time, since Aristotle remains silent on the question of the nature of time (cf. van Fraassen 1970, 11–17; Whitrow 1989, 42; Benjamin 1996, 12–15; Kronz 1997; Jammer 2007).

But is Aristotle right in his view that time cannot be identical with motion because motion can be slow or fast and it is measured in time but not *vice versa*?[1] It is true that many motions would be unsuitable for an identification of physical time: the motion of particles in a liquid, the motion of gas molecules in a container, the motion of pedestrians in a city, the motion of cars on a motorway are all too irregular to qualify. But if care is taken to distinguish between *physical* and *human* time, some regular physical events will be needed to identify physical time. Experience tells us that less regular motion can be measured by more regular motion. A person's heartbeat could be used to measure the movement of pedestrians in the street: how long it takes them to cross it, how long it takes them to move from its northern to its southern end. An obvious disadvantage is that heartbeat is irregular so that such measurements will be inaccurate. But heartbeat could be replaced by a more regular clock, say a water clock. So gradually—by a process of triangulation—the precision of clocks would improve until fairly reliable clocks become available. The best clocks at the disposal of Aristotle's contemporaries would have been sundials and water clocks (Clepsydras, Fig. 2.1), which were already known in Egypt in 1600 B.C. Nevertheless, the Greeks argued that the measurement of time should be based on celestial motion, since it was regular and periodic; it constituted physical time. Aristotle, however, has a point when he refuses to identify circular celestial motion with time. For there are several notions of time: physical time, human time, social time, psychological time and they cannot all be identified with celestial motion. And subsequent centuries replaced the orbit of planets with more robust processes to associate them with physical time. Human time is an abstraction from the observation of diverse physical processes, which give rise to the division of the year and the day, according to our familiar calendars.

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[1] As we shall see, John Locke (*Essay* BK XIV, Sect. 21) also recommended a distinction between duration 'in itself' and 'the measures we make use of to judge of its length.'

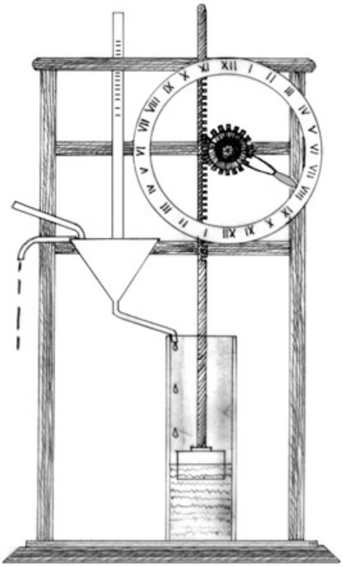

Fig. 2.1 Clepsydra, Wikimedia Commons

In order to grasp the distinction between physical and human time, it is important to distinguish *natural* and *conventional units of time*. Natural units of time are based on periodic processes in nature, which recur after a certain interval. They may be quite imprecise, like the periodic flooding of the Nile, on which the ancient Egyptians based their calendar year; or more regular, like celestial phenomena. Some basic units of time, like the day and the year, are based on natural units of time. For instance, the equatorial rotational period of the Earth is 23 h 56 min and 4.1 s; that of Uranus is 17 h (Zeilik 1988, 508). The tropical year—the time that the Earth needs for one revolution around the sun—has a length of 365, 242,199… days or 365 days, 5 h, 48 min and 46 s (see Moyer 1982; Clemence 1966). But the calendar year has 365 days and 366 in leap years, which gives the calendar year an average length of 365.2425 days. As calendar years cannot have fractional lengths, there will always be a discrepancy between the tropical and the calendar year. This difference led to the replacement of the Julian calendar by the Gregorian calendar (1582). The Gregorian calendar will remain accurate to within one solar day for some 2,417 years. One difficulty with the day and the year, as just defined, is that these units of time are not constant, due to slight irregularities in the motion of the Earth. Historically, this discrepancy has led to calendar reforms and redefinitions of the 'second' from a fraction of the rotational period of the Earth around the sun to atomic oscillations.

Whilst physical time is based on such natural units, human time is based on conventional units of time. The 7-day week, introduced by the Romans, the subdivision of the day into 24 h, of the hour into 60 min and of minutes into 60 s, the division of the year into 12 months and the lengths of the months into 30 or 31 days (except February), again introduced by the Romans, are all conventional units of time. They are conventional because they respond to human social needs about time reckoning although there may be no physical processes, to which they correspond. To give an example, the beginning of the year (1st January) is purely conventional, since there is no natural event, which would single out this particular date. Equally the beginning of the day at midnight is a convention. Note, however, that not all such conventions are arbitrary. The equinoxes, the summer and winter solstices correspond to particular positions of the Earth with respect to the sun. Already the Babylonians introduced the 7-day week and named the days of the week, like the Egyptians, according to the sun and the known planets: moon, Mars, Mercury, Jupiter, Venus and Saturn (Wendorff 1985, 118). The division of the year into 12 months (4000 B.C.) was inspired by the 12 orbits of the moon around the Earth in one tropical year. But this creates a problem of time reckoning because the time between lunar phases is only 29.5 Earth days (Zeilik 1988, 152; Wendorff 1985, 14), but the solar year has 12.368 lunar months. As a consequence, the length of the month is now purely conventional and no longer related to the lunar month. The division of the day into 2 × 12 h is explained by geometrical considerations. During the summer only 12 constellations can be seen in the night sky, which led to the 12 h division of day and night. According to the sexagesimal system, there are 10 h between sunrise and sunset, as indicated by a sundial, to which 2 h are added for morning and evening twilight (see Whitrow 1989, 28–29; Wendorff 1985, 14, 49). When the year and the day are set to start also depends on conventions and social needs. In ancient Egypt, for instance, the year began on July 19 (according to the Gregorian calendar), since this date marked the beginning of the flooding of the Nile (Wendorff 1985, 46). In the late Middle Ages there existed a wide variety of New Year's days: Central Europe (December 25); France (March 21; changed to 1st January in 1567); British Isles, certain parts of Germany and France (March 25) (Wendorff 1985, 185; Elias 1988, 21f).

Despite these aspects of conventionality, it must be emphasized that the conventional units of time must keep track of natural units of time. For otherwise, conventional units of time will fall out of step with the periodicity of the natural units. The measurement of time is inseparably connected with the choice of certain inertial reference frames, like the 'fixed' stars, the solar system, and the expansion of galaxies or atomic vibrations (Clemence 1966, 406–409). It was one of the great discoveries of Greek philosophy to have realized that there exists a link between time and cosmology. The existence of conventional units of time thus presupposes the existence of natural units of time. The existence of physical time can be justified by a consideration of the consequences of idealist and empiricist notions of time (cf. Schlegel 1968, Preface, Chap. I; Rugh and Zinkernagel 2009).

2.3 The Need for Physical Time

> Time and Space are among the fundamental physical facts yielded by our knowledge of the external world. (Gunn 1930, 215)

What happens when physical time is neglected can be gleaned from a consideration of Saint Augustine's famous reflections on time and by the attempts of the British empiricists to grapple with the notion of time.

2.3.1 Saint Augustine (354–430 AD.)

For Saint Augustine time emerges with the creation of the material world by a Deity. Saint Augustine rejects as nonsensical the question whether time existed before God's creation of the universe. God exists in a timeless manner. Time is co-existent with the creation of material events but not co-eternal with God's existence (Augustine 1961, Bk. XI, Sect. 14). At first, Saint Augustine associates time with an awareness of a 'before–after' relationship between physical events. These material events come into being with the creation of the universe. As will be discussed in Chap. 3, Saint Augustine partly embraced what was later to be called a 'relational view' of time (see Box I). This is essentially the view that physical time depends on a 'before–after' relationship, a succession of events in the material universe. Saint Augustine also rejects the Platonic view that physical time is be identified with celestial motion because he refers to a statement in the Bible, according to which Joshua made the sun stand still so that a battle could be won (Augustine 1961, BK. XI, Sect. 23). He does not specify which events he has in mind; in particular he does not specify whether the 'before–after' relation between events is of a regular or irregular nature. Saint Augustine's reflections start with the postulation of physical time through the creation of material events. Then his reflections turn to the question of the measurement of time. But when he asks himself how time is measured, surprisingly he does not refer to physical clocks, which were available at his time: water clocks, shadow clocks, sun dials. He slips into psychological language and makes the human mind the metric of time. We remember the past, we are aware of the present, we anticipate the future. There is, however, a certain problem with the awareness of the present. Saint Augustine arrives at the view that 'the present is without duration' because he entertains a mathematical notion of time, in which each interval of time can be subdivided into ever smaller intervals. Consider the time it takes to utter a phrase like 'Saint Augustine'. A speaker needs a certain amount of time to pronounce this name, so that this phrase can be further subdivided into past and future segments. As s/he speaks, the sounds seem to emerge from the future only to recede irretrievably into the past. Perhaps then the present is not the time it takes to utter the phrase 'Saint Augustine' but occurs when a particular syllable is spoken. But even the utterance of a syllable takes time and this interval can be further subdivided into past and future. As long as an event has duration it can be further subdivided into future and past moments. By this kind of mathematical reasoning, Saint Augustine concludes that the present has no duration. It is a metaphorical knife edge. Despite this conundrum time seems to be measurable.

Box I: ***A brief Introduction to the Philosophy of Time***

It is convenient to distinguish three influential philosophies of time, to which the discussion will return throughout.

- The *realist view* (I. Barrow, I. Newton) is the view that time is a physical property of the universe, over and above other properties, and that time would exist even in an empty universe. This view can be expressed in the slogan that the ‘universe has a clock’, since according to this view some master clock exists which measures the ticking of time across the whole universe, even if no physical events occurred in this universe. In modern discussions it reappears as the block universe, often accompanied by an idealist view of time.
- The *relational view* (G. Leibniz, E. Mach, partly Saint Augustine) is the view that time depends on the succession of physical events in the universe, such that time would not exist in an empty universe. This view can be expressed in the slogan that ‘the universe is a clock’ since according to this view there is no master clock and clocks depend on the existence of regular, periodic processes in the universe. This view is a version of the Heraclitean view of flux and becoming.
- The *idealist view* (I. Kant, partly Saint Augustine and, surprisingly, many physicists and philosophers) is the view that time is a property of the human mind. The passage of time in the physical universe is an illusion or a human construction, and hence time depends on the existence of human observers. A complement of this view is the so-called block universe, i.e. the view that physical reality is a timeless, unchanging being. This view is a version of the Parmenidean view of stasis.

> We can be aware of time and measure it only while it is passing. Once it has passed it no longer is and therefore cannot be measured. (Augustine 1961, BK. XI, Sect. 16)

The future has not yet arrived and the past has gone. So how do we measure the present time, if it has no duration? Time is coming out of what does not yet exist, passing through what has no duration and moving into what no longer exists (Augustine 1961, BK. XI, Sect. 21). What measurable period could be used as a yardstick to measure temporal intervals? Some of his Greek predecessors offered the periodic regularity of planetary motion as a metric but Saint Augustine is as dissatisfied with this answer as Aristotle was. The movement of bodies is always measured in time, but time is never measured by reference to the movement of bodies, including the sun (Augustine 1961, BK. XI, Sects. 23–24). The measurement of bodies in motion presupposes a notion of time. ‘It is by time that we measure the course of the sun’ (Augustine 1961, BK. XI, Sect. 23). Secondly, bodies (including the sun) move more or less quickly or remain at rest but their motion and rest are still measured by way of time. This answer is of course

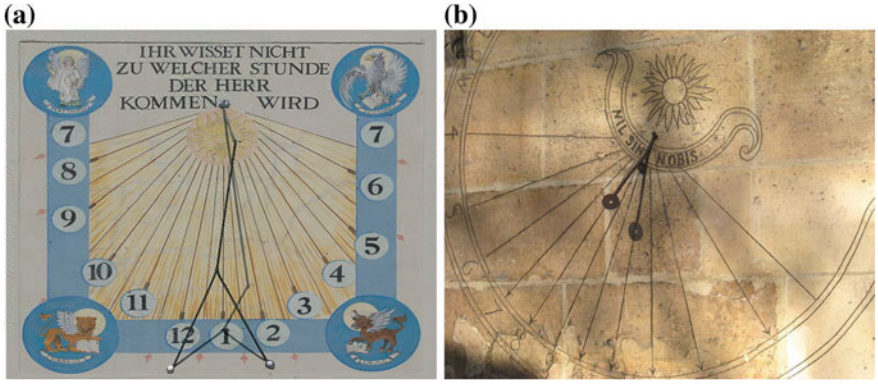

Fig. 2.2 Sun dials, Wikimedia Commons

inaccurate, since the Greeks already employed the relative regularity of physical processes to construct sundials, shadow clocks and water clocks as time pieces to measure less regular intervals; and they regarded the motion of the planets as circular and uniform (Fig. 2.2a, b). But Saint Augustine does not consider these possibilities. This neglect leaves the mind as the metric of time. It is the human mind, which measures time and its ‘flow’. As time is not objective, the human mind measures the impressions, which the passing of external things leave on it. Events flow from future to past, through the present and leave traces on the human mind. It is these impressions, which the mind measures. A long past is a long remembrance of the past; and a long future is a long expectation of the future (Augustine 1961, BK. XI, Sect. 28). The human mind becomes a metric of time: it has an expectation of future events, it is aware of the passing of present events and it remembers past events.

Saint Augustine argues from objective beginnings of physical time to time as the extension of the mind (Augustine 1961, BK. XI, Sect. 26). The conclusion is that the mind can be aware of time and measure it only while it is passing (Augustine 1961, BK. XI, Sect. 16). It is only in individual minds that time is measured, which makes time a subjective experience (cf. Lucas 1973, Pt. I, Sects. 1, 2 for a modern defense of mental time).

Thus Saint Augustine makes an implicit distinction between the ‘before–after’-relation between material events and the ‘past–present–future’ relation, which depends on human awareness.

Consider an analogy with sound. A group of observers sits on a hill above a tennis court in the distance. They can see the players on the court but as sound travels more slowly than light they experience a curious effect. They watch the two players serve the ball before they hear the sound. So on Saint Augustine’s analysis of the measurement of time, when they see player *A* serve the ball, the sound still lies in the future although its arrival is anticipated. Then the sound arrives and is perceived as the sound waves pass by the observers. The sound then recedes into the distance beyond their earshot; it is in their past and they only remember it.

Events pass from the future into the past but they leave an impression on the mind, and it is this impression, which the mind measures. We do not say ‘past time is long’ because the past no longer exists. We say that a long past is a long remembrance of the past. And a long future is a long expectation of the future (Augustine 1961, BK. XI, Sect. 28).

Saint Augustine’s conception has severe limitations:

1. Although Saint Augustine admits that the awareness of time requires a ‘before–after’ relation between events and physical time is co-existent with the creation of the material world—the measurement of time occurs in the mind and therefore possesses no objectivity. But Saint Augustine cannot evade the need for physical time, since he admits that there is a succession of events in the physical world (Augustine 1961, BK. XI, Sect. 27). This succession of events is objective although Saint Augustine does not consider it worthy as a candidate for a metric to measure the duration of time between two events. Saint Augustine suggests that the mind can serve as a metric thus rejecting several other possible metrics. As mentioned, during Saint Augustine’s time water clocks, shadow clocks and sun dials existed, which could have provided a rough but objective measure of the duration of events. The choice of a metric is conventional but the occurrence of material events is not as they are separated by intervals between an earlier and a later event (see van Fraassen 1970, 77). Saint Augustine treats time as an extension of the mind, which made him the founder of psychological time. But psychological time falls victim to the vagaries of psychological states. Thus, Saint Augustine’s notion becomes idealist and subjective at the same time, since time is measured in individual minds as a result of impressions left on them through passing events. But his notion of time also contains relational elements since he begins his reflections by the observation that we are only aware of time where there is change in the physical world. This change affects the human mind and the past-present-future relation as categories of the mind; it gives rise to a subjective measurement of time.
2. Human time only exists in individual minds, which constitute metrics of time. This thesis reduces time to psychological time. But psychological time suffers from two defects: first, it lacks *regularity* since the way an individual perceives the duration of a particular event depends on their psychological states; second, it lacks *invariance* since the same individual cannot compare the assessment of duration on two different occasions, nor can two individuals compare their respective evaluation of elapsed time on the same occasion. Psychological time is not invariant across different perspectives. But both regularity and invariance are important features of a measurable passage of time and have important philosophical consequences.
3. According to Saint Augustine the present time is mathematically divisible into infinity so that any present moment, however, short, can always be subdivided into smaller units. But this is not a statement about physical time. Saint Augustine conflates the present as a physical interval—a period of some duration—and as a mathematical instant—a duration-less point (Lucas 1973,

Pt. I, Sect. 4; cf. Newton-Smith 1980, Chap. VI; Denbigh 1981, Chap. 3, Sect. 3). There could exist a shortest possible time interval: for some time physicists have speculated that there might exist a ‘chronon’, a unit of time which is determined by the time it takes a light signal to cross the diameter of an electron; more recently the suggestion has been made in the area of quantum gravity that the shortest possible moment of time is defined by Planck time. This is a much shorter interval but it would still make time discrete (cf. Smolin 2006).

2.3.2 *David Hume (1711–1776) and John Locke (1632–1704)*

In Saint Augustine’s reflections we are faced with a curious mixture of a relational view and an idealist view of time. The relational view of time was developed by G. W. Leibniz in the 17th century and it is based on the need for physical time. The idealist view of time was developed by I. Kant in the 18th century in opposition to both Leibniz’s relational view and Newton’s realist view of time. As we shall see Kant’s idealist view of time is beset by the same difficulty as Saint Augustine’s view of the measurement of time. Kant, despite his avowal that time exists only in the mind, implicitly acknowledges the need for physical time in his employment of the notion of causality. But these difficulties are not restricted to idealism; they also afflict the views of the British empiricists. As is well-known the British empiricists take the mind to be a *tabula rasa*, on which the external world leaves impressions, which by cognitive processes are transformed into ideas. But the basic tenet of British Empiricism is that there can be no succession of impressions without a succession of perceptions, which themselves are caused by the succession of real, perceived events. British Empiricism presupposes a succession of events in the physical world, without which no mental impression of objects in the physical world could be formed. Both David Hume and John Locke base their reflections on time on this basic tenet. Thus Hume opens his *Treatise of Human Nature* (1739) with the statement that ‘all the perceptions of the human mind resolve themselves into two distinct kinds’: impressions and ideas. Their difference lies in the degree of liveliness and force, with which they are perceived; their difference is one of ‘feeling’ (sensation) and ‘thinking’ (reflection). For Hume ‘our impressions are the causes of our ideas’ (Hume 1739, Bk. I, Section I). The order of events is then that impressions strike upon our senses, producing perceptions of hunger, heat, pain, pleasure etc.; and these impressions then give rise to ideas (copies of impressions) in our minds (Hume 1739, Bk. I, Section III).

Consequently, both space and time are abstract ideas—the first being characterized by extension, the second by duration. Hume defines time as a succession of perceptions in the human mind. Although Hume accepts that without a succession of impressions and ideas there can be no notion of time, he does not accept a notion of physical time:

> Whenever we have no successive perceptions, we have no notion of time, even though there is a real succession in the objects. (Hume 1739, 35)

Hume seems to fall prey to his own empirical presuppositions. He sees impressions as the causes of ideas, and from this basic tenet of Empiricism he concludes that time 'is always discovered by some perceptible succession of changeable objects' (Hume 1739, 35; italics in original). By tying the notion of time to *perceivable* successions, Hume 'refuses to time any reality save that of a succession of ideas'. But Hume does not seem to realize that this 'mental synthesis' presupposes an awareness of objective change (Gunn 1930, Sect. III.8; Kronz 1997, Sect. 5). Hume implicitly acknowledges the need for physical time, irrespective of human perceptions, because 'perceivable successions of changeable objects' are simply a subset of changeable objects. A perceivable succession presupposes a succession of changeable events. The events and objects affect our senses, and thus lie at the root of our impressions.

It is to John Locke's credit that in his *Essay Concerning Human Understanding* (1689) he shows awareness of this basic difficulty in British Empiricism. This awareness makes Locke's reflections on time more sophisticated than Hume's but ultimately he fails to overcome the difficulty. Locke, like Hume, locates the notions of duration and succession in the flow of ideas in human minds. Ideas themselves have their sources in sensations or reflections. The ultimate source of our knowledge is experience and the experience of 'external sensible objects' (sensation) is one source of our knowledge. But the mind can reflect on these ideas, originating from sensations, and make them 'the object of mental operations' (Locke 1964/1690, Bk II, Chap. I). After this empiricist introduction Locke proceeds to apply his ideas to the notion of time. He makes a distinction between *duration* and *time* (Locke 1964/1690, Bk. II, Chap. XIV; cf. Gunn 1930, Sect. III.5). The perception of duration derives from a succession of ideas in the mind. The perceiver is only aware of the train of ideas when s/he is awake but not during hours of sleep. When 'that succession of ideas ceases' in moments of unconsciousness, 'our perception of duration ceases with it'. Of duration, then, Locke furnishes a very psychologistic account, for 'we cannot perceive that succession (of ideas) without constant succession of varying ideas during our waking hours'. Yet Locke is aware, like Saint Augustine, to whom he refers, that the idea of duration, arising from reflection on the succession of ideas in the mind of the perceiver, gives rise to a consideration of measure. The mind needs to

> get some *measure* of this common duration, whereby it might judge of its different lengths, and consider the distinct order wherein several things exist, without which a great part of our knowledge would be confused and a great part of history rendered useless. This consideration of duration, as set out by certain periods, and marked by certain measures or epochs, is that, I think, which most properly we call *time*. (Locke 1964/1690, Bk.II, Chap. XIV, Sect. 17)

Thus Locke distinguishes between the passage of time (duration) and the measurement of time, and reserves the notion of time to measurable duration of external events. Locke recognizes the need for both human time, which for him resides in the flow of ideas, and physical time, which resides in objective physical change. But Locke grants no priority to physical time, and bestows more significance on human time (duration) than on physical time. Just like Aristotle before him, he denies that the idea of succession arises from the observation of motion. We have to distinguish carefully 'betwixt duration itself' and the measure of duration for our measures of duration are a matter of choice.

> For the freezing of water, or the blowing of a plant, returning at equidistant periods in all parts of the Earth, would as well serve men to reckon their years by, as the motions of the sun; and in effect we see that some people in America counted their years by the coming of certain birds amongst them at their certain seasons, and leaving them at others. (Locke 1964/1690, Bk.II, Chap. XIV, Sect. 20)

Our choice of measure is a matter of convention. More importantly, we have no guarantee of the equality of any pairs of duration, 'for two successive lengths of duration, however, measured, can never be demonstrated to be equal' (Locke 1964/1690, Bk. II, Chap. XIV, Sect. 21). Locke points out, as Newton did at the same time, that the motion of the sun suffers from irregularities. But even the 'two successive swings of a pendulum' cannot be known to be equal.

> Since then no two portions of succession can be brought together it is impossible ever certainly to know their equality. (Locke 1964/1690, Bk. II, Chap. XIV, Sect. 21)

In view of such apparent uncertainty, Locke gives preference to human time. The ideas of succession and duration are formed 'by reflection on the train of our own ideas' (Locke 1964/1690, Bk. II, Chap. XIV, Sect. 27). However, this lapse into psychologism and focus on mental time, at the neglect of physical time, suffers from the same defects as Saint Augustine's psychological time. Mental time is essentially private, which makes it impossible to compare two temporal intervals, which succeed each other. Individual observers cannot know, in principle, whether their 'measurements' of the duration of external events is regular and invariant. Thus Locke's objection to the measurement of physical time also applies to his mental time. Compare this situation to the use of a mental yardstick to measure some spatial length. A joiner is repairing a piece of furniture and needs a short piece of wood. No meter is to hand and he can only rely on his intuition. He has some suitable pieces of wood in his van but he must choose their lengths from memory. His task is impossible. To remember the duration of events, in the absence of any clocks, is equally difficult. There is no regularity in memories and they are dependent on particular perspectives or psychological states; hence they are not invariant. To secure regularity and invariance, there is a need for physical time. But how can the difficulties with the measurable passage of time, emphasized by Aristotle and Locke, be overcome? In the history of time reckoning this problem has been solved by the method of triangulation. We measure less regular processes by increasingly more regular processes, and eventually arrive at fairly accurate time pieces. Locke emphasizes himself that the 'revolutions of the sun' are not the only measure of duration. In his own time his contemporaries began to use the pendulum 'as a more steady and regular motion than that of the sun or (to speak more truly) of the Earth' (Locke 1964/1690, Bk. XIV, Sect. 21). Although two successive swings of a pendulum cannot be compared in order to see whether they are equal what can be compared are the oscillations of a pendulum against, say, the rotations of a spinning sphere. Locke acknowledges as much when he speaks of the relations of time.

> Thus, when anyone says that Queen Elizabeth lived sixty-nine and reigned forty-five years, these words import only the relation of that duration to some other, and mean no more but this, that the duration of her existence was equal to sixty-nine, and the duration of her government to forty-five annual revolutions of the sun; and so are all words, answering, *How long?* (Locke 1964/1690, Bk. II, Chap. XXVI, Sect. 3)

In the end, then, Locke refers the measurement of time to cosmological processes, like the ancients. Since the Copernican Revolution the dual mobility of the Earth has served humanity as a yardstick for the measurement of the passage of time. We have to turn to Kant's cosmology to witness the first appearance of an arrow of time.

2.4 Kant's Cosmology

Before Kant (1724–1804) developed his idealist view of time, he proposed an evolutionary view of the cosmos. His idealist view of time is, as we shall see later, objective rather than subjective. Kant had inherited the Copernican worldview, first proposed in the modern age by Nicholas Copernicus (1543) and later refined by Kepler, Galileo, Descartes and Newton, according to which the sun was the centre of the solar system and the planets orbited the sun in elliptical orbits. But when Kant published his *General History of Nature and Theory of the Heavens* (1755) the extent of the universe was no longer confined, as Copernicus had still assumed, to the solar system and the fixed stars on the horizon. Kant's treatise is the first systematic attempt to give an evolutionary account of cosmic history (Whitrow 1989, 153). Kant's evolutionary history is limited to the physical universe, since he explicitly excludes living organisms from his evolutionary considerations. Kant depicts the order of nature as an unfolding, ongoing process and distances his view from the Biblical story of a six-day creation process.

> The Creation is never finished or complete. It did indeed once have a beginning but it will never cease. (Kant 1755, Seventh Chapter, 145; cf. Toulmin and Goodfield 1965, 130)

According to Kant the cosmos reveals a dynamic history and is no longer split into two spheres: the realm of eternity, perfection, and symmetry as against the realm of temporality, imperfection and asymmetry. Kant conceives of the whole cosmos as an ordered structure, in analogy with the solar system. The solar system is only part of a larger structure, the Milky Way, which is our home galaxy. But the universe plays host to other galaxies, which may only appear as 'small luminous patches' in the telescope (Toulmin and Goodfield 1965, 129–131). This whole hierarchical structure is governed by dynamic laws, similar to the ones, which Kepler had formulated for the solar system. Kant argues that the whole cosmos consists of ordered systems, like our solar system, and that the smaller systems can be understood as embedded in larger systems within galaxies. And the galaxies themselves form larger systems, which are known as clusters.

Furthermore this cosmic order was the result of the action of mechanical laws, which moulded the original chaos into the observable order of nature. The mechanical laws work in a regular, predictable fashion. The work of blind mechanisms, which drove the mechanical evolution of cosmic history, does not, in Kant's view, throw serious doubts on philosophical proofs of a divine creator (Kant 1755, Preface). Kant assumes that the Deity is the first cause, who sets the whole machinery in motion, thus leaving an 'agreement between my system and religion'. The implication is, however, that creation is not the act of a single moment (Kant 1755, Seventh Chapter, 145). Kant proposes the idea of a successive extension of 'creation' through the infinite universe. Kant thought that Nature underwent formations of order, out of chaos. The importance of this theory of cosmic evolution for the notion of time is that it throws serious doubt on the Biblical chronology of 6,000 years. Bishop James Ussher (1581–1656), for instance, had calculated the creation of the world as occurring on October 23, 4004 B.C. But Kant's position implies that the gradual establishment of order out of chaos had taken a vast period of time.

> There had perhaps flown past a series of millions of years and centuries, before the sphere of ordered Nature, in which we find ourselves, attained the perfection which is now embodied in it; and perhaps a long period will pass before Nature will take another step as far in chaos. But the sphere of developed Nature is incessantly engaged in extending itself. Creation is not the work of a moment. (Kant 1755, Seventh Chapter, 145)

Working within a Newtonian paradigm, Kant relates the creation of order out of chaos to an infinite time scale:

> This infinity and the future succession of time, by which Eternity is unexhausted, will entirely animate the whole range of Space to which God is present, and will gradually put it into that regular order which is conformable to the excellence of His plan. (…) The creation is never finished or complete. It has indeed once begun, but it will never cease. It is always busy producing new scenes of nature, new objects, and new Worlds. (…) It needs nothing less than an Eternity to animate the whole boundless range of the infinite extension of Space with Worlds, without number and without end. (Kant 1755, Seventh Chapter, 145)

Although Kant paints a picture of an evolutionary universe, it did not include organic nature. Kant speculated that the whole mechanical world would be understood by reference to mechanical laws before 'a single weed or caterpillar' could be explained from mechanical causes (Kant 1755, Preface, 29). Kant's evolutionary account of cosmic history does not include the evolution of species. This inclusion had to wait 104 years until Darwin published his *Origin of Species* (1859) (Weinert 2009, Sect. II.1).

According to some commentators, Kant seems to have believed in a cyclic cosmology, each cycle ranging from a Big Bang to a Big Crunch (Toulmin and Goodfield 1965, 134), an idea, which has been resurrected in modern cosmology (Penrose 2010). He certainly postulated a 'Big Bang' scenario, from which the present order of Nature evolved according to mechanical laws. It seems that our world has attained 'perfection'—a common assumption amongst Enlightenment philosophers—but other worlds are still evolving towards perfection. According to Kant's cosmic expansion hypothesis, the formation of the universe is marked by a basic *asymmetry*, since mechanical laws work on the original chaos to produce the current, ordered state of the world. But it is not clear from Kant's statement whether he subscribed to a cycle of cosmic evolution and cosmic destruction. Rather, Kant seems to recognize that decay and destruction are built into the fabric of nature. He envisages that 'whole worlds' and 'whole world orders' will decline but he also holds that the phoenix of nature will create new worlds and new world orders.

> Millions and whole myriads of centuries will flow on, during which always new Worlds and systems of Worlds will be formed, one after another, in the distant regions away from the Centre of Nature, and will attain perfection. (Kant 1755, Seventh Chapter, 145; cf. Kragh 2007, 78–83)

Thus Kant does not seem to envisage that the whole universe will expand, grind to a halt, and re-contract to collapse into a Big Crunch. Rather, regions of the universe will fall into decline to be replaced by other regions elsewhere in the universe, where ever productive nature will install new orders. As we shall see later, these speculations are surprisingly close to the views of Ludwig Boltzmann and modern cosmology. This pattern of decline and renewal, this destruction of old worlds and the ever present operation of mechanical laws, invests the cosmic evolution with an arrow of time. But Kant did not only provide an evolutionary account of cosmic history, he also developed his own theory of space and time. His views on time became very influential and were taken up by proponents of the Special theory of relativity. Kant develops this view in his *Critique of Pure Reason* (1781). It stands in stark contrast with his view on an evolutionary cosmos, which clearly implies a physical notion of time. But in his later work, Kant embraces an idealist view of time, which, in contrast to Saint Augustine's view, is objective in nature. Still, Kant does not escape the difficulties, which accrue, when the need for physical time is neglected in one's view of time, as will now be discussed.

2.5 Time and Causality

> Space and time expand with the universe because they are the universe. (Shallis 1983, 98)

If the universe expands, there must be a succession of events, and this succession may serve as a criterion for the direction of time. Both Kant and Leibniz establish a link between the anisotropy of time and the causal succession of events, a topic,