Enantiomorphy and Time

ENANTIOMORPHY AND TIME

A CHALLENGE FOR REDUCTIONISM

TOWARDS

ORIENTATION OF TIME

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Contents

Preface

> "Would it have been worth while
> If one, settling a pillow or throwing off a shawl,
> And turning toward the window, should say:
> 'That is not it at all,
> That is not what I meant, at all."
>
> — from The Love Song of J. Alfred Prufrock
> by T. S. Eliot.

Before leaving for Cambridge in the autumn of 1996 I decided to write a graduation thesis on causation. During that autumn I took part in a reading group of the book Time's Arrow and Archimedes' point by Huw Price. Also I followed the courses on time by D. H. Mellor. This made me quit the subject of causation and study time. Back in Utrecht I finished a paper that was focused exclusively on criticizing Price. It was judged insufficient for attaining a degree and I decided to leave the subject.

Presumably it is a bad habit to be a bad loser, but the present work is a result of that habit. After some months I felt that the paper was worth an additional effort: I was sure to have laid bare some flaws in Price's book. I set off reading several standard works, such as Smart's collection, attempting to find a new lead for this paper, and worked on it every so often since then. The puzzles of Kant and Leibniz quickly surfaced. Zeno's puzzle had already played a part in the original paper. Of the other authors, Earman made me understand most how intricate the matter was, Horwich best illustrated its width and Zeh showed its complicated face in physics. Many other authors illuminated again other things. This is an opportunity to thank them all.

Having to write the paper once again was hard work. Nevertheless I am grateful to Jos Uffink for forcing me to do so, as well as for his merciless comments on various drafts. I feel the paper and me have both gained drive from it. Further I want to thank Igor Douven for his enthusiasm and criticisms. His remarks were more valuable than he expected them to be. I regret not having learned to discuss the subject of this work with interested friends. I want to thank Maaijke Mevius for making clear that this is a mistake.

I feel that due to this paper I learned to separate personal sentiments from intellectual enterprises. In the beginning I had many preconceived ideas, but gradually I have stopped nursing and fostering some of them. For studying time this is a first requirement and I hope the present paper satisfies it.

Introduction

Time is omnipresent and the peculiar orientation of processes in time is something we observe every day. This becomes apparent when the hilarious reactions to a film played backwards are considered. Children that graciously jump out of a swimming pool, leaving the water without a ripple, and spilled wine jumping back in a glass that, at nervy command of some people at a party, jumps into someone's hand, such events are intuitively impossible and show that the orientation of processes is deeply embedded in common sense. In the same way the distinction between past and future orientations of time is part of common sense. The word 'future' refers to a particular end or location in time, it is not shorthand for 'a time which such and such conditions occur'. It is to a defence of such common intuitions that this work is dedicated.

This work focuses on the orientation of time as a concept of physics. This concept will be subjected to philosophical investigations. That is, the present work will deal with questions that are usually classified as philosophical. This is not to say that it covers all or most of the philosophical questions concerning the orientation of time. The temporal opposition of hope and regret, the human destiny of growing old and dying, the eternal moment of mystics, such things will not be dealt with. Time is a difficult subject and even in a restricted conception intuition is so permeated with it that investigation turns into confusion lightly. An investigation into the orientation of time within physics will be hard enough. In physics two different conceptions of time can be considered, time as a geometrical notion within spacetime and time as a parameter to characterize processes. The orientation of time is sometimes associated with spacetime and sometimes with the laws governing processes in spacetime. In this work orientation will be considered as applying both to spacetime and to processes. It will be explained what the orientation of processes consists in and further that we cannot do without such a concept.

Processes as described by physics may be *asymmetric* in time, meaning that they contain no intermediate state around which the past and future part are mirror images. Most processes we encounter in nature are asymmetric in this sense. Really there is no reason to get excited about such an asymmetry. However, it appears that in nature certain types of physical processes always show a particular asymmetry in the same temporal orientation, for instance that differences in temperature tend to level out in future time orientation. Temporal asymmetry in this sense does call for an explanation. Further, it is sometimes said of processes that they are *irreversible*. In that case the reversal processes are disallowed by laws of nature, that is, such processes cannot exist in opposite temporal orientation. Similarly a theory is sometimes called noninvariant under time reversal, when the processes that it governs are irreversible.

The orientation of time is often reduced to some asymmetry of processes or to some irreversibility of processes or time reversal noninvariance of theories.

In *reductionism* towards orientation of time it is held that any property of processes pertaining to a particular orientation can be explicated in terms of properties that do not pertain to orientation. If for instance the orientation of some asymmetric process in time can be explained by other properties of the process that do not in any way make reference to orientation, then the orientation *of that process* is said to be reducible. Similarly, if the particular orientation of time that is called future can be equated with the orientation of an asymmetry of certain processes and if these asymmetries do not themselves pertain to orientation, then the orientation *of time* is said to be reducible. So there are two sorts of reductionism towards orientation, one reducing the orientation of time and one reducing that of processes. For any attempt at reducing orientation it is essential that the concepts or properties employed in the reduction do not themselves make reference to orientation. Asymmetry and irreversibility are the usual candidates for such concepts.

Apart from these two candidates I will consider a property of processes that has not been considered in this context in the literature, namely enantiomorphy. Examples of spatial enantiomorphs are the chiral molecules of sugar or yogurt, right and left gloves and the booklet you are now holding. Usually enantiomorphy is only predicated of spatial objects. It will in this paper be argued that oppositely oriented processes, that is, a process and its reversal, relate in the same way as spatial enantiomorphs, for instance left and right gloves. The orientation of processes, as separate from the orientation of time, emerges naturally from this as the analogy of the orientation of a glove, that is, its being left or right. Clearly enantiomorphy in time and the orientation of an enantiomorph process are related to asymmetry and irreversibility of processes in time. By keeping distinct several questions concerning these notions I hope to resolve some confusions not uncommon in present literature. Most notably I will argue that because of the enantiomorphy of processes reductionism with respect to orientation of time fails.

Another area of confusion concerns explanations of the temporal asymmetries observed in nature, such as the leveling out of temperature differences alluded to above. Explanations from three different parts of physics (thermodynamics, electrodynamics, cosmology) will be discussed. The attempts at explanation will appear particularly vulnerable to a distinction in questions to be drawn on the basis of a sharp distinction between the features of asymmetry and enantiomorphy. The reductionism of Reichenbach and many different attempts at explaining temporal features of processes will seen to be defective in the light of this distinction. Special attention will be given to the attempts by Price to symmetrize physics and time as much as possible. It will be argued that he overplays his hand. Without reference to orientation certain facts about enantiomorphy are inexplicable. Even Price will sometimes have to refer to orientation to give satisfactory explanations in all cases. Note that the time asymmetry allegedly present in quantum mechanics will not be dealt with, nor those in quantum cosmology or in quantum field theory.

The main question posed in this work is whether reductionism towards orientation of time is tenable. The answer will be negative. It will be shown that asymmetric processes in time are enantiomorphs, like hands in space are. Just like the orientation of a hand, its being left or right, cannot be reduced to intrinsic properties of the hand, because left and right hands have all intrinsic properties in common, the orientation of a process, its being either of the reversals, will turn out to be irreducible, because oppositely oriented processes have all intrinsic properties in common. A distinction between the two orientations of a process in an otherwise empty universe will therefore have to employ orientation as a basic property. Similarly the orientation of time itself, whatever that is, cannot be reduced to properties of processes simply because such properties do not allow for a distinction of orientations. The challenge for reductionists is therefore to do without the indispensable concept of orientation.

The outline of this work is as follows. First reductionism and its major problems will be characterized. Chapters II to IV concerning orientation, asymmetry and irreversibility are intended to perform this task. Secondly, it will be proved that processes in time are enantiomorphs. Chapter V on enantiomorphy serves this purpose. Thirdly, the consequences of this fact will be elaborated on. Three issues will be dealt with in particular. The first is that reductionism fails to accommodate orientation, or put bluntly, that orientation is irreducible. The second is that explanations of the orientation of processes cannot do without the notion of orientation. The third is that particular explanations concerning asymmetry invite confusion over the separate notions of orientation and asymmetry. The three issues will be laid out mainly in chapter VI. In chapters VII to IX the problems emerging from them will be identified in several explanations of physics. In these chapters it will also be shown that Price falls prey to these problems, in particular that he confuses the notions of asymmetry and orientation. The paper will be summarized in chapter X. Some suggestions for improvement will be presented as well.

The plan of writing has now been outlined. But before I turn to the actual tasks I want to present some philosophical puzzles. These are intended to prepare for the various issues that are of relevance in this work and to connect them with major philosophical issues of earlier days. But they are added to raise curiosity. It is hoped that they sharpen the reader's attention for the problems at hand. Only at the end of chapter IX and partly in chapter X will the puzzles be employed in an argument, mainly against Price but in broader perspective against all authors that deny orientation its place among the elements of reality. Until these chapters the function of the puzzles may remain somewhat vague.

I

Puzzles

In this chapter I will present three puzzles. The first of these is taken from two different publications of Kant[1] and deals with the existence of spatial enantiomorphs as well as their relation to space and each other. The second originates from Zeno of Elea and concerns the nature of movement, or of change in general. Its import is that movement is in fact nonexistent. The third originates from Leibniz and can be found in the Leibniz-Clark correspondence[2]. It deals with the ontological status of absolute space. The argument of Leibniz purports to defend a relational view. The relevance of these puzzles and the respective interpretations will be presented in later chapters.

I.1 The hands of Kant

If two objects are identical with respect to all their intrinsic properties, i. e. properties that do not require the existence of anything else, one can be put in place of the other without there occurring any difference[3]. Now consider an example of a spatial enantiomorph and its mirror image. Kant himself considered opposite yet otherwise identical scelene[4] triangles on a sphere or, closer to daily observation, a hand and its mirror image. Of such pairs of objects the one can never be put in place of the other and consequently there must be some intrinsic difference between both. If however we tried to point out this difference exclusively in terms of intrinsic properties, we would fail. The puzzle is that a left and right hand or oppositely oriented triangles are clearly different but that no basis can be found for the difference in the hands and triangles themselves. It is this puzzle that lies at the basis of all three publications Kant dedicated to the subject.

The first of these publications appeared in 1768[5]. In it Kant argued that the existence of spatially different but otherwise identical objects, such as hands, was reason to postulate the existence of absolute space. The existence of a single hand in space is assumed and it is then observed observed that this hand would still be either left or right. It is then noted that there is no intrinsic property of a single hand that corresponds to its being left or right, that is, the fact that the hand has a particular shape, either left or right, cannot be expressed in

[1] Kant (1768) [26], (1783) [28].

[2] Smart (1964) [50].

[3] Scholastic discussions on the transformation of wine into the blood of Christ by changing none of the properties of wine but just its substance will here be left aside.

[4] These are triangles of which no side is equal to any other side.

[5] Frederick (1998) [13], pp. 27-36.

terms of intrinsic properties. Surely one way to distinguish between both hands is by referring to some other handed object. But this does not remove Kant's worry. The point is that although for us mirror images can be distinguished, there seems to be no difference between the mirror images on their own terms, that is, internally. It is concluded that the single hand must bear some relation to something else for having a definite shape, and this something else is finally argued to be absolute space.

But in order to solve this puzzle in his 1783 argument[6], Kant does not invoke absolute space anymore. He there appeals to our intuition of space as a means to conceive the objects but also as constituting the objects in reality. He writes

> "These objects [e. g. the hands] are not representations of the things as they are in themselves and as a pure understanding would know them, but sensible intuitions, i. e. appearances, the possibility of which rests on the relation of certain things, unknown in themselves [Dinge an Sich], to something else, namely our sensibility. Now of this sensibility space is the form of outer intuition..."

So according to Kant the distinction between mirror images is real and ultimately resides in space itself. On the other hand spatial features are added to the objects by us as their mode of existence and a means to represent them. This may seem ambivalent, but can be understood properly when it is realized that in Kant's transcendental philosophy much of the world structure, including space and time, is in fact projected onto the world by us. In the move between 1768 and 1783 one can recognize a development of Kant's philosophy towards transcendentalism.

In the two arguments Kant advances different solutions to his own puzzle. For later purposes it is important to keep them distinct. In the following it will be argued that the 1768 argument solves the puzzle less conclusively than the 1783 argument. In fact it seems that Kant has reconsidered his own solution and found it wanting. The 1768 argument solely explains the fact that we are able to *determine* of a single hand whether it is left or right whereas oppositely oriented hands have the same intrinsic properties. This argument is about the definability and determination of handedness. That is, it supplies a distinction between left and right hands on the epistemological level using the existence of absolute space. The 1783 argument however is also concerned with the fact that the hands themselves *exist* as different objects whereas there seems to be no ontological basis for this difference. The solution Kant there offers provides a difference between left and right hands on both ontological and epistemological level. In the following I will elaborate on this subtlety and its consequences.

It appears that the two solutions Kant presented for his puzzle, one solely on epistemological and one also on ontological level, can be confused lightly. In the introduction to Problems of Space and Time Smart gives a modernized version both of Kant's 1783 puzzle and his eventual solution[7]. He begins by

[6]Smart (1968) [50], pp. 124-5.
[7]Smart (1968) [50], p. 7.

supposing that the only object in the universe is a hand. According to Kant, says Smart, this hand would be either left or right. But there is no way to define this difference or determine its actual handedness[8]. Then Smart writes:

> "...he [Kant] concluded that spatial properties have to be grasped by intuition and elude definition in terms of relations."

The rephrased conclusion is in perfect agreement with the 1783 argument. It contains the idealism typical for the later Kant. But I am dissatisfied with the reformulation of the puzzle itself. In fact Smart is literally spelling out the problem and argument Kant advanced in 1768 and which was aimed at establishing the existence of absolute space. This argument should not at all end with an idealistic conclusion[9]. Spelling out my dissatisfaction in precise terms will help to discern the solutions of the 1768 and 1783 arguments. Both are of relevance to this paper.

Let me first focus on the puzzle considered only as an ontological problem, that is, how it comes about that two objects with the same intrinsic properties can *exist* as different things. This aspect of the puzzle is typical for the argument Kant advanced in 1783. It remains even if we imagined other objects or substances in the universe by means of which the handedness is definable. For in that case it is still unclear how these other objects or substances make distinct *for the hand itself* its otherwise identical mirror image. Unlike the inner sensibility introduced by Kant, which bears an immediate relation both to the hand as it is presented to us and to the hand as it is to itself, the presence of other objects or substances doesn't connect ontologically to the hand and its shape. Because in 1768 Kant did not address the ontological aspect of his puzzle, he must have taken for granted that if these other things are present, they somehow cause an internal difference in the hand[10]. But such an assumption, bridging the gap between definability and existence, needs to be argued for separately. Kant's puzzle is therefore deeper than he himself thought earlier.

Note that both the substantivalist, someone who takes spacetime to be a substance existing independently, and the relationist, someone who takes spacetime to be constituted of the relations of objects in space, have the same problem. The problem for both is to link the presence of something, space substance for the substantivalist and other handed objects for the relationist, with the reality of handedness. This part of the puzzle concerns both. Kant has solved it by appealing to an inner sensibility of which space is the outer form. That is, space

[8] Note that addition of any amount of indistinguishable objects would not make the handedness definable, as such objects cannot be arranged to make a handed composition. The emptiness of the universe does not single out the exact feature that disallows handedness to be definable. However, the empty universe is the simplest setting in which the problem occurs and I take Smart to choose the setting for convenience.

[9] All throughout the articles by Frederick (1991) [13]), Van Cleve (1991) [4] and Kemp Smith (1991) [29] the same distinction of realism and idealism in the arguments of Kant can be found. Also one may consult all Kant's arguments in [26], [27] and [28].

[10] This kind of move might be compared with Mach's reply to Newton's bucket argument. In this reply the internal property of inertia is made dependent on the presence of other objects in the universe, e. g. the fixed stars.

according to him is simply the form the sensibility gets when projected onto the world and giving shape to it. The relationist might join in with this and add that the inner sense of space on its turn is directed by the arrangement of objects around us. The substantivalist might reverse Kant's solution and stipulate that our sense of space is simply derived from the space stuff in the world, which on itself causes the reality of handedness. Either way their problem is solved, but the solutions are different.

The reformulation of Smart does bring to light the epistemological problem. This problem Kant in fact addressed in both articles, and it is also solved both by introducing absolute space and by postulating some spatial sensibility. In the 1768 argument Kant purported to show that Newton's absolute space, not Leibniz' relationism, was to be adopted[11]. In Smart's reformulation the puzzle of Kant is thus linked with the modern debate of substantivalism vs. relationism. Substantial space, like the sensibility alluded to by Kant or the presence of other handed objects that the relationist resorts to, makes the handedness real. So for a substantivalist the handedness of hands in an otherwise empty space is real while for a relationist it is not. In more precise terms, following Nerlich in his Hands, knees, and absolute space and Earman in his On the other hand, the argument is this[12].

R_1 A hand can only be left or right by virtue of intrinsic properties.

R_2 A lone hand does not differ from its mirror image by intrinsic properties.

$\Rightarrow$ R A lone hand is neither left nor right.

But according to Kant the handedness of objects is real anyhow, irrespectively of the presence of other objects. A relationist position therefore faces a serious problem[13].

As Smart suggests, a relationist can argue that handedness of objects in empty space is simply unreal. Apart from a strong intuition about handedness which may be bound up with the overfull universe we live in, there seems to be nothing against this relationist tenet. Also Remnant[14] takes this position. Earman and Sklar, who both defend relationism as well, avoid it by denying R_2, as will be seen in chapter V. But for now we will stick to the position of Remnant and Smart. The conclusion must be that a relationist and a substantivalist can both solve Kant's puzzle. A relationist needs to hold that in empty space a hand is both left and right, or neither left nor right. For a substantivalist the difference between left and right is genuine. With these solutions to the epistemological

[11]Kant has always remained an adversary of relationism and in light of this the misrepresentation of Smart is understandable. In his 1783 argument however he is definitely not an absolutist anymore. According to Kemp Smith (1991) [29], p. 45 "[the 1783 argument] is made to yield. . . a *directly opposite conclusion.*"This conclusion is that space is subjective instead of objective.

[12]Nerlich (1991) [34] and Earman (1991) [11].

[13]Note that the possibility of an intrinsic property of being left or right is not considered here. I will return to this possibility in section V.3.

[14]Remnant (1991) [39].

problem we will leave the puzzle. How it links in with time is the subject of later chapters[15].

I.2 The arrow of Zeno

Zeno was a pupil of Parmenides. Following his teacher, he maintained that the world was an unchanging and eternal unity. The changes and divisions in daily observations are in this perspective illusions, as the real world does not show such imperfections. Zeno argued for this by presenting several reductios ad absurdum, taking the opposite position as point of departure. Because these reductios concentrate on mathematical entities it is plausible that they were aimed at the Pythagoreans. Usually the reductios are not considered to be only apparent paradoxes, due to solutions by Aristotle, Russell and many others. Some of the paradoxes deal with divisibility of space and time in points and moments respectively. For instance Zeno argued that all finite lines have equal length because all consist of infinitely many points. The other paradoxes deal with movement. The paradox of the arrow is one of the latter kind. Closest to the lost text of Zeno himself stand the comments by Aristotle. For a philosophical background one may consult Lee[16].

The arrow paradox is quite simple and one may overlook its pervasiveness. Consider an arrow which has been released from a bow and assume with Zeno's adversaries that time is built up of moments, not of infinitesimal stretches of time. At every such moment the arrow is occupying a definite part of space, caught between its endpoints. At any other moment the arrow is occupying a different part of space, because it has moved. However, at each moment separately we cannot say the arrow is moving. Rather at every moment it is hanging perfectly still. There is nothing in the state of affairs at one instant that corresponds to, or even suggests, its moving. Now because the process of the arrow flying from bow to target is built up of nothing else but instantaneous states, there is nothing in the process that corresponds to movement either. Thus for someone accepting moments as the elements of time, movement is nonexistent.

[15]The following summarizes how the definability, conceivability and reality of handedness (D, C and R respectively) relate. Smart's formulation of Kant's puzzle presupposes that real handedness of an object is always definable (R →D). Then it is noted that in empty space (E) handedness is not definable (E → –D) and thus not real (because –D → –R). But according to Kant it must be real anyhow (R), which amounts to contradiction. Kant solves this by introducing a sensibility to cause the prior conceivability of handedness (C), which makes it both definable (C →D so that no longer E →–D) and real (C →R). This latter step, projecting the inner sensibility outside us, is typical for Kantian philosophy.

For the substantivalist the emptiness of the universe does not cause undefinability because space itself can be used in the definition (E → D). Space also makes the handedness real (E → R) and by our observations of it conceivable (R → C). For the relationist the handedness is simply not real as long as the universe is empty (E →–D →–R). Kant's intuition is ignored, so that no contradiction emerges. In case other handed objects exist this makes for definability (D), which on its turn makes handedness conceivable (D → C) and, following Kant, real (C → R).

[16]Aristotle [1], Salmon (1975) [43] and Lee (1936) [30].

Before we turn to a possible solution let me summarize the structure of the argument. The assumption is that time is a series of moments. First it is noted that a state of affairs at one moment, when part of a process of moving, does not contain any element that corresponds to the movement itself. Secondly, in accordance with the above assumption, it is stipulated that the process of moving is nothing more than the series of these states. Thirdly, it is stressed that a process cannot somehow possess any other properties than those contained in its states. From these three premisses it follows that the process of moving contains no element that corresponds to movement either. Schematically, the argument is as follows.

z_1 A state contains no element of change.

z_2 A process is a succession of states.

z_3 A process cannot contain any element not contained in one or more of its states.

$\Rightarrow$ z A process contains no element of change.

For reductionism towards orientation Zeno's paradox will pose a particular problem. In several parts of the present work it will show up to do this.

How, if at all, can the paradoxical conclusion z be avoided? Both premisses seem plausible a priori. With respect to the first, Zeno would argue that a factual state description is determined completely by the nature and distribution of matter. The first premiss therefore hinges on the point that velocity cannot be included in such a state description. It is something over and above matter, something bound up with the behaviour of matter in time. With respect to the second premiss, unless we adopt some holistic picture of processes and states as their parts, nothing can be said against it. So to avoid the conclusion either we have to argue for some sort of holism, or we have to include velocity or in any case a time dependent notion in the state description. Salmon, in order to solve the reductio, undertakes the latter[17]. Note that this solution fits in with physics. In classical mechanics for instance the notion of instantaneous velocity is commonly used. A state is usually characterized not only by the distribution of matter, but also by the velocities of several parts of matter. With this additional feature of states the process of a flying arrow obviously contains an element of movement even though it is built up of such states.

But, it can be asked, movement in what spatial direction? Should we say the arrow is moving in the direction of the arrow's point or rather to its feather, that is, forward or backward? Recall that in order to solve Zeno's paradox we have introduced the notion of velocity in ontology. We cannot dispose of the above question by stipulating that there is no such thing as velocity anyhow and that a velocity assignment is only a convenient tool in theorizing, fully based on convention. In the standard solution to Zeno's paradox velocities inherent in states cannot be mere illusions created by the arrow being at different positions

[17]Salmon (1975) [43].

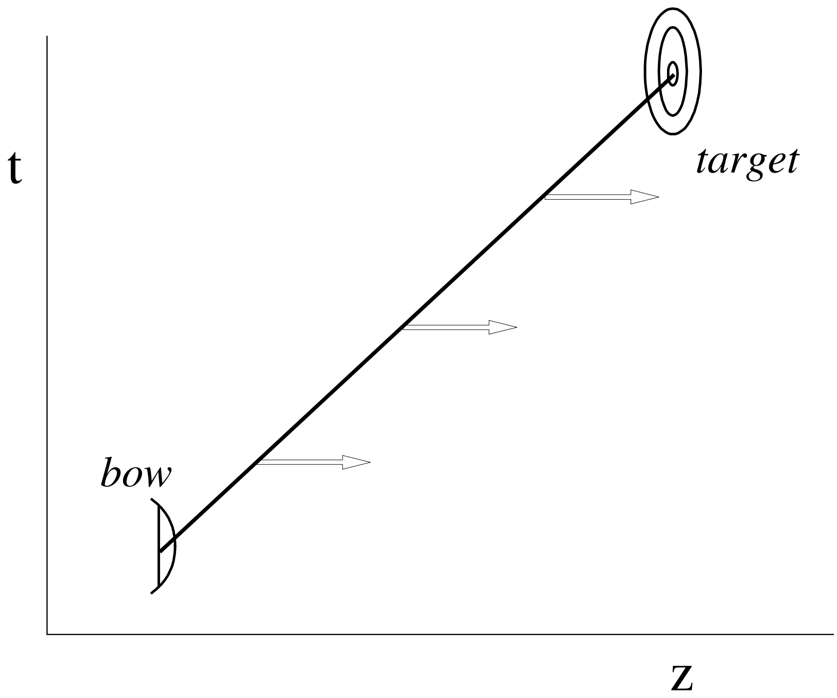

Figure I.1: The arrow with a velocity that accords with the observation of it by us, with the order in which it is first at the bow and then at the target.

on different times, they have a reality of their own. Thus the above question is sensible once we adopt the standard solution to Zeno's paradox. To illustrate it, the two figures I.1 and I.2 show the processes of a flying arrow with two possible velocities associated with them.

The common answer presumably is that the spatial direction of the velocities in the state descriptions is defined by the order in which the states happen to be observed by us. This velocity assignment is depicted in figure I.1. In formulas, velocity is then defined as

$$v \;=\; \lim_{\Delta t \to 0} \frac{z(t+\Delta t) - z(t)}{\Delta t} \tag{I.1}$$

We say that the arrow is moving in the forward direction if the arrow hits the target later than that it jumped from the bow, that is, if $z(t{+}\Delta t)$ is further from the bow than $z(t)$ so that the numerator in equation (I.1) is positive. Note that due to Zeno's paradox there must be an objective fact to the spatial direction of $\vec{v}$. But in that case we adopt a particular kind of temporal orientation inherent in all states of the process of the flying arrow: The velocities themselves are such

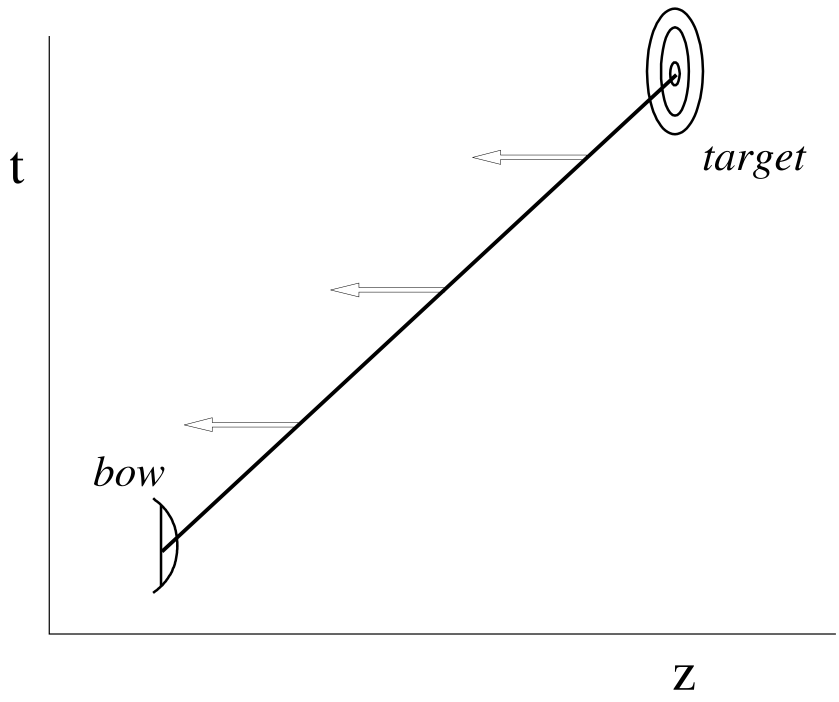

Figure I.2: The arrow with a velocity that accords with the observation of it by someone having an opposite temporal perspective, with the order in which it is first at the target and then at the bow.

as to accord with the order in which we happen to observe the process. For reductionists towards orientation this is not acceptable, because they want to avoid any reference to orientation, and in particular also reference to orientation in a definition of velocity. A reductionist will accept both processes shown in the figures as valid possibilities.

A few things must be noted. First, once we tie loose the direction of the arrow's velocity from the observed order of states it becomes an unobservable feature of the process. Then there is no way to discern the processes of an arrow flying forward or backward, or the two processes in figures I.1 and I.2. For both processes the arrow jumps from (or into) the bow before it hits the target if we use the word 'before' in its everyday sense, and the value of velocity or the curve along which the arrow flies are not different for either process. It can therefore never be maintained that there is empirical evidence for the velocity having either of spatial directions. Moreover, it cannot be maintained that because of this the distinction between the processes in figures I.1 and I.2 is only of description, as Reichenbach does [18]. Finally, there seems to be a trivial way to merge the forward and backward processes. The instantaneous velocity vector might be redefined to point both forward and backward, thus expressing the value of velocity and the curve along which the arrow moves but not its being forward or backward. It will be seen in section IV.2 that such an assignment is problematic.

How do the puzzling facts on Zeno's paradox link in with temporal asymmetry? In the preceding section I questioned the origin of the difference between objects that are mirror images. It was seen that this difference is linked to the way the object is situated, or represented, in space. The suggestion of the puzzle of Kant obviously is that a similar difference can be found between processes that are mirror images. In this section I introduced a solution to Zeno's paradox in which time dependent features, such as velocities, were incorporated in state descriptions. The solution was seen to introduce a notion of orientation inherent to the states of a process or to allow different ways to represent a process in time. A further suggestion is that the two ways of representing may be related to the different ways of situating a process and its mirror image in time. Yet how precisely the hands of Kant and the arrow of Zeno relate is the subject of subsequent chapters. In section IV.2 these issues will be considered in particular.

I.3 The Creation of Leibniz

Eventually the points of the above puzzles will provoke an argument concerning temporal orientation. This argument shows many similarities with an argument due to Gottfried Leibniz, which emerged as a reaction to the introduction of absolute space by Isaac Newton. It was first conceived in the famous correspondence of Leibniz with a contemporary of Newton and him, Samuel Clark, which is partly reprinted in Smart[19]. For sake of completeness I will briefly present the argument of Leibniz here.

In the argument Leibniz adopts his principle of sufficient reason: an occurrence for which no fully determining reason can be cited is impossible. Physically this means that everything should have a completely determining cause, on theological reading it means that God will never do anything without reason. According to Leibniz the existence of absolute space implies a violation of the principle of sufficient reason. First he notes that space on itself is absolutely uniform and remarks:

> "...without the things placed in it, one point of space does not absolutely differ in any respect whatsoever from another point of space."

[18] Reichenbach (1956) [37], pp. 31-2. In another context (pp. 43-7) Reichenbach suggests that the direction of causation of the backward and forward processes differ, when he deals with counterfactual statements.

[19] Smart (1964) [50].

Then he imagines God in his act of Creation, placing the heavenly bodies in space after a certain order between them, and concludes:

> "... (supposing space to be something in itself, besides the order of bodies among themselves) that 'tis impossible there should be a reason, why God, preserving the same situations of bodies among themselves, should have placed them in space after a certain manner, and not otherwise; why everything was not placed the quite contrary way, for instance, by changing East to West."

That is, Leibniz points out that there can be no reason for God to create the world like this rather than rotated relative to absolute space. On the supposition that absolute space exists, the principle of sufficient reason is violated in creation. The only way to avoid this is to deny the existence of absolute space[20].

To this argument one can object that the principle of sufficient reason need not be accepted on the theological level. But the argument can just as well be performed without introducing any supernatural being, leading to the conclusion that there can be no physical cause or reason for the spatial orientation of the world. In reply to this one can deny the principle of sufficient reason completely. In that case the existence of absolute space can be maintained, because a property that has no reason or cause is not considered problematic anymore. Denying Leibniz principle however is quite radical. It is part of both philosophy and physics that things or facts have reasons.

Let us imagine that the substantivalist maintains Leibniz' principle. The above argument can then be raised against him. In a form that is concerned with explanations it reads as follows.

- S$_1$ Different positions in empty space cannot be distinguished by any property.
- S$_2$ Otherwise identical universes that occupy different positions in otherwise empty space, are different.
- $\rightarrow$ Otherwise identical universes at different positions are different but cannot be distinguished by any property.
- S$_3$ Universes that cannot be distinguished by any property, cannot be taken apart in different explanations.

$\Rightarrow$ S Different positions of otherwise identical universes are inexplicable.

The argument of the present work will be presented in this latter form. It will eventually be seen that authors who want to reduce the notion of orientation, allow for universes that are different yet cannot be distinguished either. Moreover, such reductionists will not simply deny Leibniz' principle concerning orientation. Reductionism will thus be confronted with the same problem that Leibniz confronted substantivalism with. But this argument will be advanced only in chapter IX.

[20] Leibniz continues by presenting an analogous argument against absolute time, asking why God did not create the world a year sooner.

II

Orientation

In An Attempt to add a little direction to the problem of the direction of time Earman aims to disentangle the plethora of problems concerning the direction of time[1]. In the course of this article he presents a series of definitions. I will in this chapter reproduce the definitions that are put to use in later chapters. The first main point in Earman's article is that the direction of time need not be connected to irreversibility, contrary to the position taken by reductionists such as Reichenbach and Gold, who seem to dominate the literature. The second main point of Earman's article, namely that considerations concerning entropy are not as crucial to time's directionality as is usually supposed, will only be dealt with indirectly. In general, Earman's article focuses on time as a geometrical notion.

II.1 Spacetime properties

Earman starts off with expressing a problem that has attracted nearly no attention in the literature, namely whether all physically possible spacetimes can be assigned a consistent temporal orientation. Temporal orientability is defined as follows.

Definition 1 *A relativistic spacetime $\langle M, g, \Gamma \rangle$ is said to be temporally orientable if there exists a continuous, nonvanishing vector field on M which is timelike with respect to g.*

where the triple $\langle M, g, \Gamma \rangle$ defines a manifold M with geometric structure g and affine connection Γ. The geometric structure g in curved spacetime is given by

$$ds^2 \;=\; g_{\mu\nu} dx^\mu dx^\nu \tag{II.1}$$

which for a spacetime in which curvature is zero becomes

$$ds^2 \;=\; (dx^2 + dy^2 + dz^2) - (c\,dt)^2 \tag{II.2}$$

Whether a vector is timelike or not is determined by the geometric structure $g_{\mu\nu}$, in particular the lightcone structure.

Definition 2 *Let $\langle M, g, \Gamma \rangle$ be a relativistic spacetime. A vector $V \in M_x$ [starting from x] is timelike (respectively light-, spacelike) if V lies inside (on, outside) the light cone through x, denoted C_x.*

[1] Earman (1973) [8].

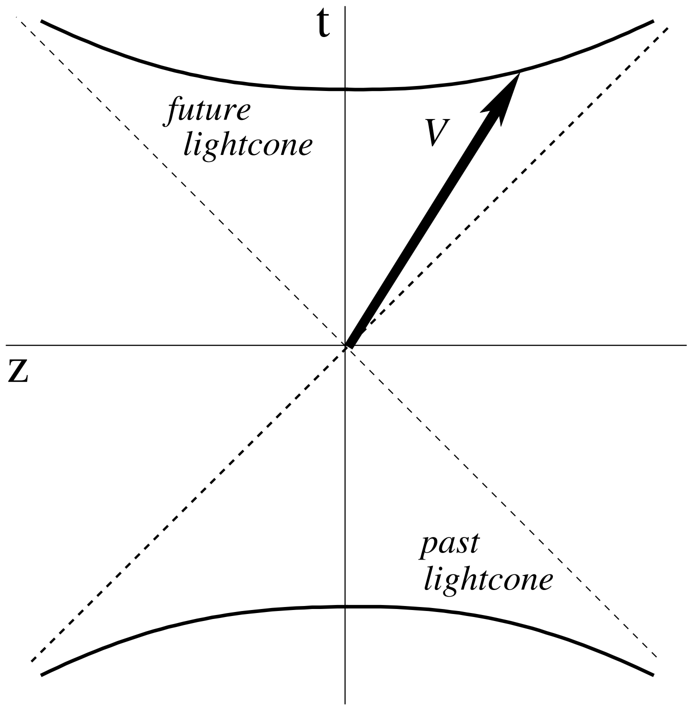

Figure II.1: Past and future lightcones in 1+1 spacetime. The curved lines represent points with equal timelike distance to the origin.

The light cone C_x at some point x on the manifold is defined as the set of all vectors from x that have negative length. Such a light cone relative to x separates the set of all points in the manifold with a negative distance to x into two subsets, of points that lie respectively to the past and to the future of x. These separated sets are called temporal lobes and will be denoted with C_x^p and C_x^f. In figure II.1 the mentioned notions are illustrated in a spacetime diagram of two dimensions, a $1+1$ spacetime.

Consider a function that assigns to every point on the manifold one of its temporal lobes, say C_x^f. Such a function is called an orientation O of the manifold when it satisfies the following definition.

Definition 3 *Let $\langle M, g, \Gamma\rangle$ be a relativistic spacetime. The function $O : x \mapsto C_x^f$ is an orientation of that spacetime if and only if there exists a continuous, nonvanishing vector field F on M such that $\forall x : F(x) \in O(x)$.*

So the orientation of time of a manifold is given by a function O that males the assignments of temporal lobes in a sense agree for all points on the manifold. Recall that the temporal lobe C_x^f of x was a subset of the manifold given by all points exclusively to the future of x. Precisely when the vector field according to which some manifold is orientable lies inside all temporal lobes, the assignment of temporal lobes is an orientation.

Because the laws of general relativity do not rule out non-orientable spacetime topologies and because for any non-orientable spacetime it is impossible to define an orientation O, the answer to the question whether all spacetimes allow for an orientation is negative. It thus makes sense to ask whether this universe is in fact orientable and how we can find out about this. But whatever the answers to these latter questions, at the moment it is only important to keep in mind the notions of orientability, orientation and light cone structure, because they will be used in later chapters. It will simply be assumed that spacetimes are orientable and allow for a definition of orientation in them.

Using the orientation function O it is possible to specify a temporal order, i.e. a transitive relation $E(x, y)$, between points on a timelike curve.

Definition 4 *Let $\langle\langle M, g, \Gamma\rangle, O\rangle$ be a temporally oriented spacetime, where O is the time orientation. Define the relation $E(\ ,\ )$ on $M \times M$, where $E(x, y)$ is interpreted to mean that x is earlier than y, by requiring that $E(x, y)$ holds just in case there is a differentiable $\sigma : [0, 1] \to M$ such that $\sigma(0) = x$, $\sigma(1) = y$ and $\frac{d\sigma(t)}{dt} \in O(\sigma(t))$ for every $t \in [0, 1]$.*

Of this order it can be asked whether it is irreflexive, or consistent, like the common 'earlier than' relation. This is the case if and only if we rule out closed timelike curves, obviously because on such curves two distant points are both earlier and later than eachother. If the time order is indeed consistent it can be asked whether it is possible to define a global time function.

Definition 5 *The time oriented spacetime $\langle\langle M, g, \Gamma\rangle, O\rangle$ has a global time function if there is a smooth map $t : M \to I$ such that $t(x) < t(y)$ whenever $E(x, y)$, where $I \subset \Re$. Spacetimes with orientation and time function is denoted $\langle\langle M, g, \Gamma\rangle, t\rangle$.*

Such a time function is only possible if the manifold is connected. Moreover, a time function implies the possibility of a consistent orientation, so that $\langle\langle M, g, \Gamma\rangle, t\rangle$ is indeed shorthand for $\langle\langle M, g, \Gamma\rangle, O, t\rangle$. It can also be asked whether the spacetime that our world is made of, has orientation or not. That is, whether there is a sense in which every point on the manifold can be assigned the same unique orientation, either by time itself or by particular features of the processes taking course along timelike curves. While most of the earlier questions are usually ignored, it is here that the bulk of the discussion on time's directionality comes in. If time has no orientation, where does our sense of being oriented in time come from? And if it does, which of both orientations does it have?[2]

One particular manner for time to have orientation should be mentioned separately, namely that of time being anisotropic. Many authors use this notion,

[2] With the definitions given this is a sensible question to ask. But one may seriously doubt whether the answer is epistemically accessible to us, and even whether there is a difference between worlds or spacetimes having opposite orientations at all.

but there is no consensus about its precise definition. I will therefore present two different views on anisotropy and show that they are the extreme choices of a variety of meanings for this notion. At the one end we find Horwich and Earman. Horwich characterises anisotropy as[3]

> "…an *intrinsic* dissimilarity of the past and future directions: a difference that would be manifested in some time asymmetry within our laws of nature."

It seems Horwich echoes Earman in his article Irreversibility and Temporal Asymmetry, who writes[4].

> "…time is anisotropic…if there are fundamental laws of nature that are not invariant under time reversal."

In his Attempt to add a little direction to the problem of the direction of time Earman gives a more formal definition of anisotropy as a metrical property of spacetime, which limits the laws capable of bestowing anisotropy of time to those that govern spacetime itself[5].

On the other side of the debate on anisotropy we find Grünbaum and Black. Grünbaum maintains that time is anisotropic if and only if it is possible to[6]

> "…structurally distinguish the opposite directions of earlier and later."

With a structural distinction between opposite directions Grünbaum means any invariance under time reversal of any process in spacetime. That is, if turning around one process in time already makes a difference, Gruünbaum talks of a structural difference. NOte that any asymmetry of a process will do for a structural difference. Black adopts a comparable but even more liberal view on anisotropy[7]. He accepts our sense of temporal orientation as a criterion to distinguish earlier and later as well[8]. Both for Grünbaum and for Black the mere fact that time has orientation, here meaning that there is a physical criterion to uniquely atttach one temporal lobe to every point in spacetime, that is, the fact that a function O is definable, suffices to establish the anisotropy of time. In contrast, for Horwich and Earman but also for Reichenbach the anisotropy of time only ensues if this criterion is based on physical laws. It is important to keep in mind this difference whenever in the literature the question about temporal orientation is posed as one about anisotropy.

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[3] Horwich (1987) [23], p. 37.

[4] Earman (1967) [7], p. 543.

[5] Earman (1973) [8], p. 29).

[6] Grünbaum (1963) [18].

[7] Black (1967) [3], p. 182-93.

[8] The criticisms of Earman on Black in the first article (Earman (1967) [7]) therefore seem beside the point. The discussion of these criticisms however I postpone to the end of the next section.

II.2 Reductionism

A very influential strategy in answering questions about temporal orientation is what Earman calls reductionism. The first reductionist dogma is to deny orientation, sometimes called anisotropy, to time itself. Time, according to a reductionist, cannot be oriented in its own right and does not come equipped with an orientation O. Usually the motive for adopting reductionism is relationism, the position denying the existence of time per se and therefore of any property of time. Time, according to a relationist, is in fact nothing more than the relations of the states of some changing system, and if nothing existed there would be no time either. Grünbaum's stipulation that time is anisotropic if and only if opposite temporal directions are distinguishable by a property of physical processes, is best understood as part of such a relationist attitude. Reichenbach motivates his requirement of lawlike distinction of temporal orientations with the same relationism[9]. But other motives are imagineable. One might for instance argue that basing temporal orientation in time itself is unsatisfactory, because time as a substance is so elusive. Further, a substantivalist like Friedman will not adopt orientation of time, because he requires symmetry between spacetime theories and theories using other notions. Orientation plays no role in these other theories.

The second reductionist dogma reads that time is oriented if and only if processes in time show particular features. This tenet is contained in the first because the first entails that orientation must somehow depend on processes. Yet the first does not say with what features of processes orientation is associated. Features of processes usually associated with orientation are temporal asymmetry and irreversibility, but the precise definitions of these features vary amongst the authors. In general asymmetry is associated with orientation based on factlike features whereas irreversibility appears when the features are lawlike. The positions of Grünbaum and Reichenbach respectively illustrate such versions of the second dogma. Note that this tenet can again be derived from relationism because for a relationist time is defined in terms of relations between states and processes. But again other motives for adopting the second dogma are possible, for instance that temporal orientation without empirical consequences is loose talk. With respect to both reductionist dogmas, it therefore seems that relationism entails reductionism but is not implied by it.

Earman reacts to reductionism by negating the first and a particular version of the second reductionist dogma. The resulting position he calls the *time direction heresy*, heretic because reductionism is so pervasively and dogmatically professed in the literature. A denial of the first reductionist dogma is best understood by reading the previous section in substantivalist perspective. If we assume that spacetime is a substance, we can attach to every point a timelike vector denoting the orientation of time. But in the literature such a blunt assertion of orientation is highly uncommon. Note that in denying the first

[9]Note that Horwich and Earman, who like Reichenbach associate orientation with some lawlike distinction, allow for an orientation of time itself and therefore disagree with the first reductionist thesis.

dogma Earman implicitly denies relationism, notwithstanding the fact that a relationist reading of the previous section is perfectly possible.

The second point of Earman's heresy is a denial of the strong bonds between temporal orientation and irreversibility. Earman convincingly disputes the bonds of orientation with several kinds of irreversibility. Yet it is not said that Earman denies the bonds of orientation with any kind of feature of processes. Whereas the first reductionist dogma entailed the second, as the precise feature associated with orientation was left unspecified, the second point of Earman's heresy does not entail the first. Many other features of processes may be associated with orientation. In short Earman's heretic points are the following.

TDH$_1$ If it exists, a temporal orientation is an intrinsic feature of spacetime and cannot be reduced to nontemporal features.

TDH$_2$ The existence of a temporal orientation does not hinge as crucially on irreversibility as the reductionist would have us to believe.

It must be noted that THD$_2$ is not formulated with ultimate clarity. This is because Earman is at once attacking many different positions both on irreversibility and on its relation to orientation. On the whole the heresies are intended not so much to convince readers but mainly, as it seems, to refresh the discussion.

The next two chapters will deal with temporal asymmetry and irreversibility respectively. These are of crucial importance to all reductionist accounts and in fact to all literature on the subject. After each of them I will briefly discuss the criticisms of Earman.

III

Asymmetry

In the previous chapters temporal asymmetry of processes was already mentioned a few times. I will here formalize this asymmetry. The formalization is part of specifying what reductionism amounts to, because asymmetry was one of the features associated with orientation in the second reductionist dogma. Further, the characterization of asymmetry will be of use in the discussion on enantiomorphy of processes. At the end of the chapter two reductionist authors basing orientation on asymmetry will be considered, namely Grünbaum and Black. Both have already been mentioned because they called the particular orientation they adopted anisotropy. It will be seen that Earman's criticisms on both authors is mistakenly directed against them, because Earman has another notion of anisotropy than Grünbaum and Black. This illustrates the remarks made at the end of II.1, that anisotropy is used in a variety of meanings in the literature. But first I will make precise the notion of asymmetry itself. The explication is partly inspired by an explication of relationism by Forbes[1].

III.1 Definition of processes

Because processes cannot be described in terms of properties of spacetime, I will from now on concentrate on state space theories rather than on spacetime theories. In connection to this it may be noted that according to relationists the latter are in fact convenient abbreviations of the former. Where in the previous chapter time was dealt with as a geometrical notion, it will now be used as a parameter. To make this transition smoothly the following definition of processes is proposed.

Definition 6 *Let $\langle\langle M_R, g, \Gamma\rangle, t\rangle$ be an isolated spacetime region with a global time function t. A process is a mapping $p : I \mapsto \mathcal{S}$ of the time parameter $t \in I$ to a state description S(t), where I is some interval given by the selected region M_R and $\mathcal{S}$ the state space.*

The orientation in which t increases, is not in any way privileged. The interval I is conventionally taken $[0, 1]$. A state description is in most cases given by an n-tuple of positions and momenta at a particular instant t, $S(t) = (r_1, \ldots, r_n; p_1, \ldots, p_n)$, where $(r_i, t) \in M_R$. Sometimes other specifications of a state are allowed, like colour or temperature, that is, such qualities may be part of a state description as well. Because the global time function attaches a t to every point x on the region of the manifold M_R, defining hypersurfaces

[1] Forbes (1997) [12].

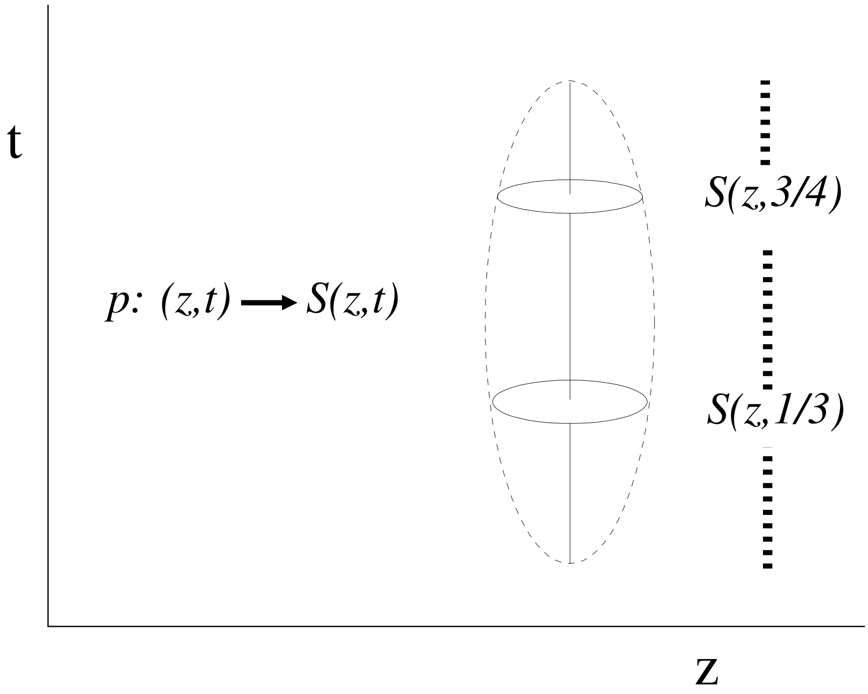

Figure III.1: The representation of a process as an object in spacetime, as a function of spacetime points (z, t).

of equal time $H_\tau = \{x \in M_R | t(x) = \tau\}$, the parameterized process has a geometrical interpretation. It is a particular sequence of labeled hypersurfaces points $x = (z, t)$. That is, the process presents itself in spacetime as a mapping $p : (z, t) \mapsto S(t)$ and may be viewed as a geometrical object in this respect. For present purposes the representation using time is more convenient, but it is important to keep the geometrical picture of processes in mind. Figure III.1 illustrates the notion of a process.

We can further specify processes by restricting the sequence of states $S(t)$ to a particular form. This restriction may be based on a distinction by Earman between kinetically and dynamically possible series of states. Where DEFINITION 6 characterizes at least all kinetically possible processes, the following only allows dynamically possible ones, that is, processes obeying a physical law.

DEFINITION 7 *Let $\langle\langle M_R, g, \Gamma\rangle, t\rangle$ be an isolated spacetime region with a global time function, $t \in [0, 1]$. A law obeying process is a mapping $p : I \mapsto \mathcal{S}$ of the time parameter t to a state description $S(t)$, with the evolution $p = \{S(t) | t \in I\} \in \mathcal{L}$, the set of possible solutions to L within state space $\mathcal{S}$.*

The law L is intended to be some forwardly and backwardly deterministic law that, given a state $S(t) = S_i$ at a fixed t, completely fixes all subsequent and preceding states[2]. In that case the process p is completely fixed by the law and condition $S(t) = S_i$, which can in principle be applied at any H_τ.

DEFINITION 8 *A process p for which it holds that* $\forall t \in I$, $\exists! S(t) \in \mathcal{S} : \{S(t)|t \in I\} \in \mathcal{L}$ *and* $S(0) = S_i$ *is denoted* $p = (S_i, L)$.

For present purposes a process is meant in the sense of DEFINITION 7. Standard examples can be taken from classical mechanics, e. g. the moving balls in biljarts or tennis.

III.2 Mirror asymmetry

The most easy definition of asymmetry uses the negation of symmetry. As a naive first attempt, symmetry of a process may be described by the following.

DEFINITION 9 *A process* $p = \{S_t|t \in [0,1]\}$ *is temporally symmetric iff* $\forall t \in [0, 1/2]$ *it holds that* $S_t = S_{1-t}$.

This definition states that symmetry holds for the process when the states that lie symmetrically around $S_{\frac{1}{2}}$ are qualitatively identical. But a simple example can prove the proposed definition to be problematic. Consider a perfectly elastic ball falling from some height, bouncing and then returning to its initial position. Most authors call such a process temporally symmetric[3]. But strictly speaking it is not! If we consider the ball's velocity, the two halves of the process are certainly not the same. There is a clear difference between the ball having velocity downward and upward, so that states lying around $S_{\frac{1}{2}}$ are not pairwise identical. This is illustrated in figure III.2, in which the ball shows velocities in different directions before and after the bouncing.

So if velocity is defined to accord with our observations, then the states around $S_{\frac{1}{2}}$ are not pairwise identical. But as argued in section I.2 the velocity of the ball need not be in line with the order of our observations. One may argue that a process is temporally symmetric if and only if the states around $S_{\frac{1}{2}}$ can be made pairwise identical, by swapping the spatial directions of velocities. In the example this means that the velocities of the ball in the two halves of the process must both be turned upward (or downward). Figure III.3 illustrates this different representation. But then another problem surfaces: Whatever the order of observations in figure III.3 the velocity of the ball will only match the observations in one half of the process. So the two halves of the process must be considered in opposite order. One may say that whereas in figure III.2 the velocities are spatially different yet similarly oriented in time, they are spatially identical but oppositely oriented in time in figure III.3.

[2] In order to avoid a structural difference between the two temporal orientations beforehand it is assumed that a law L is either deterministic in both orientations or not at all. See chapter VII of Earman's A Primer on Determinism [9] for more on this.

[3] cf. Reichenbach (1956) [37], Price (1996) [36], Zeh (1989) [58] and Davies (1977) [5].

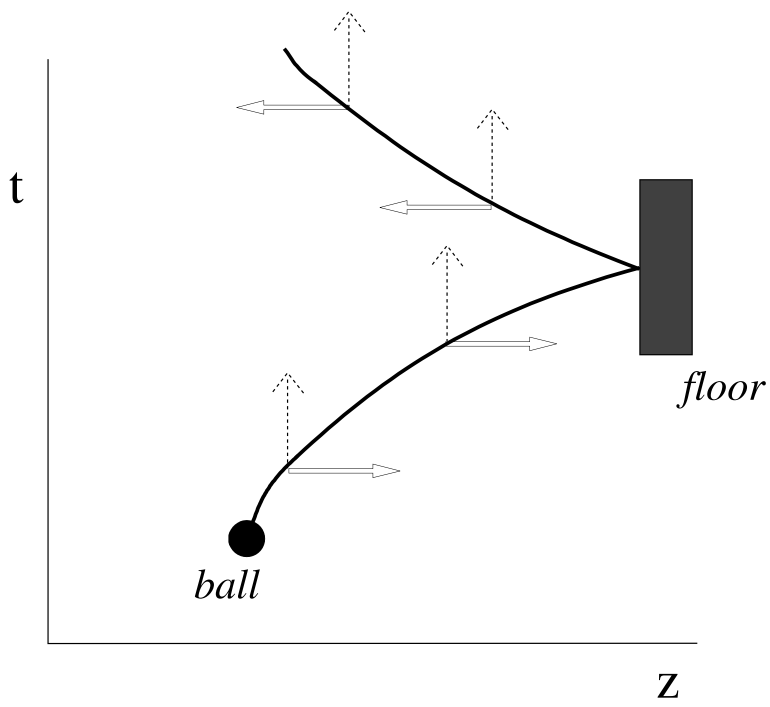

Figure III.2: A ball bouncing against the floor, having opposite velocities before and after the bouncing.

Let us try to find an analogy of these facts for spatial objects. Of a three-dimensional object we say it is symmetric when there is some surface that separates it either into two mirror image parts. For some objects these mirror image parts are exactly identical and can be put in place of each other, for instance with a typical table. For other objects these parts cannot be put in place of each other, for instance with a typical chair. The symmetrical halves of a chair in fact relate in the same way as left and right hands do. Examples of objects in two dimensions that are symmetrical in the way tables are and in the way chairs are, are given in figures III.4 and III.5 respectively. DEFINITION 9 hinges on symmetry of the kind shown in figure III.4, the table symmetry, because the strict qualitative identity of the two mirrored parts of the process is required. In contrast, the two symmetrical halves of the chair or the two halves of the object in figure III.5 can be said to be oppositely oriented in space. The idea is to formulate a definition of symmetry that better accords with the second kind of symmetry, of a symmetry that holds between, what we call, enantiomorphs.

When we can base our definition on symmetry in the sense of chairs, we must require the two parts of the process to somehow be mirror images in

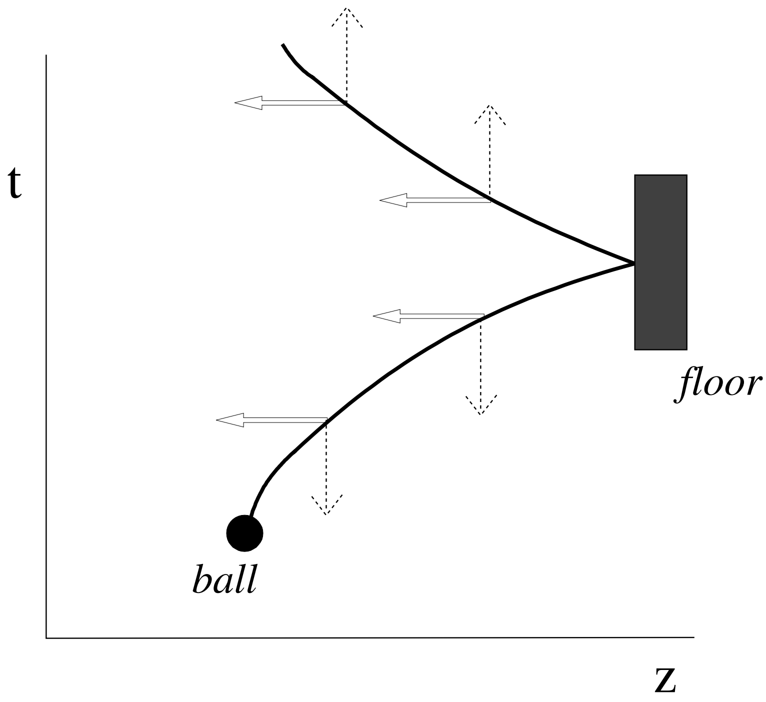

Figure III.3: A ball bouncing against the floor, having spatially identical velocities before and after the bouncing.

time. Consider first one half of a symmetric chair. Again, this half cannot by simple translation and rotation be mapped into its mirror image, and is therefore an example of an enantiomorph. But there is a way to transform the half as to turn it into its mirror image, namely *by taking it inside out*. A much clearer example is given by a right handed glove which, taking it inside out, is turned into a left handed one. The orientation of the surface of the glove, which defines the threedimensional object, is reversed in such a transformation. It is in fact the reversal of the orientation of every part of the surface that makes the righthanded glove turn to lefthanded, or the half of the chair to its counterpart.

Now consider again the process given by $p = \{S_t, t \in [0,1]\}$. Analogous to the chair this process may be called symmetric when the halves given by $p = \{S_t, t \in [0,1/2]\}$ and $p = \{S_t, t \in [1/2,1]\}$ are mirror images. As we learn most clearly from the gloves, mirror images will have something to do with reversing the orientation of every part of the process, that is, the states. The nature of this reversal and mirroring will be dealt with extensively in the section IV.2. For now let us simply denote the operation of mirroring processes with $\mathbf{M}[\cdot]$ and of reversing states with $\mathbf{T}[\cdot]$. Then we can define a process $p = \{S_t, t \in [0,1]\}$ to

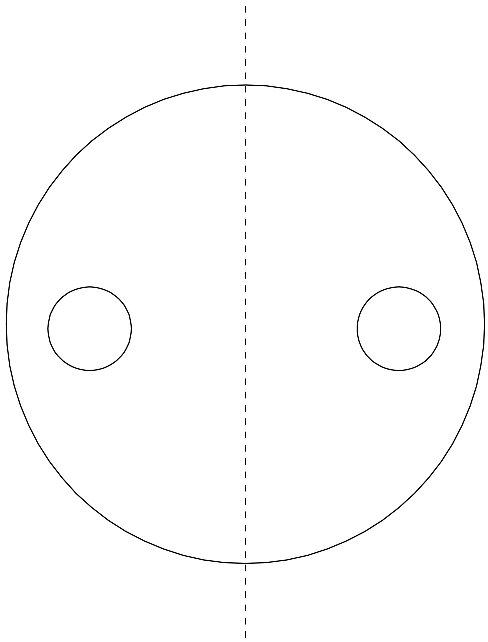

Figure III.4: Symmetrical object with identical symmetric halves.

be temporally symmetric if and only if $\{S_t, t \in [0, 1/2]\} = \mathbf{M}[\{S_t, t \in [1/2, 1]\}]$.

On the supposition that mirroring processes and reversing states connect in the way suggested by the glove example, namely $\mathbf{M}[\{S_t, t \in [0, 1]\}] = \{\mathbf{T}[S_{1-t}], t \in [0, 1]\}$, the definition suggested above is equivalent to the following.

DEFINITION 10 *A process $p = \{S_t | t \in [0, 1]\}$ is temporally symmetric, or* TS (p) *for short, iff $S_t = \mathbf{T}[S_{1-t}]$ for all $t \in [0, 1/2]$.*

The problem of the bouncing ball example can be resolved completely by using this latter definition. Taking $\mathbf{T}$ to reverse the orientation of velocity in the state description, the process of bouncing is then symmetric according to DEFINITION 10. Depending on what time reversal operator is chosen, that is, depending on whether $\mathbf{T}$ swaps velocities or reverses the orientations in time associated with the velocities[4], the process in either figure III.2 or figure III.3 is symmetric.

The definition of temporal asymmetry used in this work is DEFINITION 10. To start with the simplest case, a single process p is temporally asymmetric, or TA(p) for short, iff it does not satisfy DEFINITION 10, i. e. not TS(p). More

[4]Recall from the arrow paradox that the velocity assignment is not fixed by empirical data. In section IV.2 the precise form of the reversal operator will be considered.

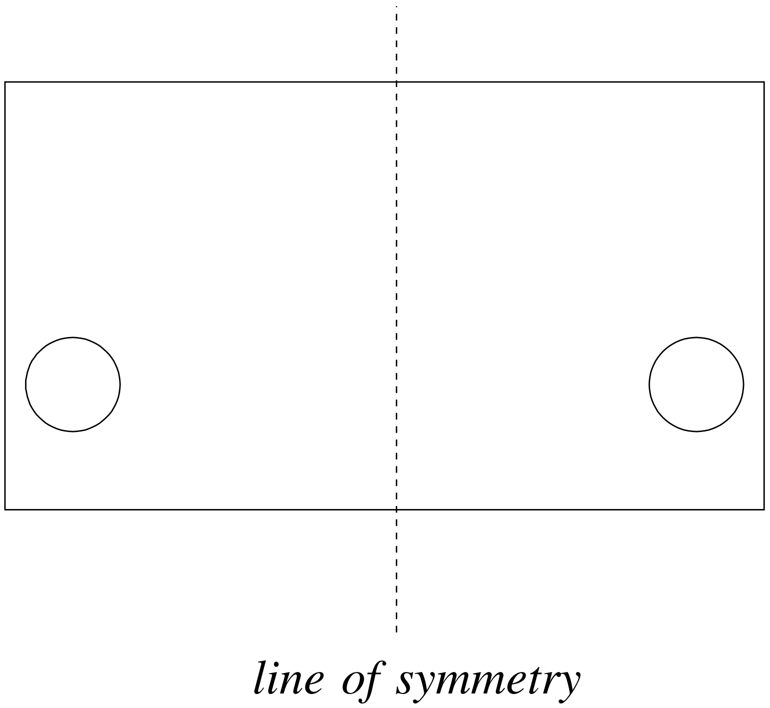

Figure III.5: Symmetrical object with oppositely oriented, symmetric halves.

general asymmetries concern sets of processes $\mathcal{P}$ in a single spacetime. I consider sets of processes $\mathcal{P}$ which are such that if $\{S(t)|t \in I\} \in \mathcal{P}$ then, for all $I' \subset I$ it holds that $\{S(t)|t \in I'\} \in \mathcal{P}$. Usually $\mathcal{P}$ is confined to some $\mathcal{L}$ and restricted by conditions $\mathcal{S}_i$. The set of all processes occuring in a deterministic universe for instance is determined, ideally speaking, by the laws of physics and one of the states of the universe. Now a set $\mathcal{P}$ is said to be strictly temporally asymmetric, STA($\mathcal{P}$), iff no $p \in \mathcal{P}$ satisfies TS(p). This occurs for instance when the L only allows TA processes as solutions in the domain of possible S_t. A set $\mathcal{P}$ is said to be weakly temporally asymmetric, WTA, iff there exists at least one $p \in P$ for which TA(p).

III.3 Oriented asymmetry

The temporal asymmetries under consideration are all about the identity of states and their reversal in general. This will now be narrowed down to the identity of states with respect to one particular feature f, which will be called temporal symmetry *of feature* (TS$_f$). The notion of TS$_f$ is much wider than TS, because many processes are TA in general yet TS with respect to the particular feature inquired into. For instance, the process of a flying arrow is TA because the positions of the arrow differ at the temporal ends, but while the arrow's mass remains unchanged it is TS in that particular feature. Further, in this section I will define the orientability of a process. Both the temporal asymmetry of feature and the orientation of a process will subsequently be used in a definition of the oriented temporal asymmetry of a set of processes. This latter notion is of particular importance to the present work.

In order to formalize temporal asymmetry of feature, let $f(S_t, p)$ denote some typifying feature depending on the elements in the state descriptions $S(t)$, and possibly also on the process p to which the states belong. Here S_t denotes any set of elements from $S(t)$, the full state description. Note that the parameter t is itself not among those elements. The function f then assigns numbers to all states $S(t)$ of some process p. Symmetry with respect to this function is defined as follows.

DEFINITION 11 *A process* $p = \{S_t | t \in [0, 1]\}$ *is temporally symmetric with respect to* $f(\ ,\ )$*, or* $\text{TS}_f(p)$ *for short, iff* $f(S_t) = f(\mathbf{T}[S_{1-t}])$ *for* $t \in [0, \frac{1}{2}]$.

Temporal asymmetries of feature can now be characterized using the normal TA's in the above paragraph. It can be that there is no $f(\cdot)$ with respect to which p (or $\mathcal{P}$) is (weakly or strictly) TS, or that there is at least one $f(\cdot)$ with respect to which p (or $\mathcal{P}$) is (weakly or strictly) TA. I will not explicitly consider cases of the former. The latter is exemplified in a process for which $A \in S_t$ holds and $f(A)$ increases monotonically with time. Conditional features $f(S_t, p)$, which explicitly depend on the process of which the states are considered parts, are also incorporated in the set of possible features, but any asymmetry of a process can be characterized without employing conditional features. The notion of conditional features will be explained below.

The last notion to be specified concerns the orientation of temporal asymmetry with respect to some feature. The setting is an orientable spacetime region M_R in which the processes $p \in \mathcal{P}$ defined on the global time parameter t are TA. It can then be asked whether some p is orientable, that is, whether there is some $f(S_t, p)$ that defines a consistent orientation over all states of p. In other words, a process is orientable if and only if its endpoints can be distinguished unequivocally. The following definition is proposed.

DEFINITION 12 *A process p is orientable if and only if* $\exists f(S_t, p)$ *that is monotonically increasing over the process.*

Note that orientability is stronger than simply $\text{TA}_f(p)$, because in the case of a simple $\text{TA}(p)$ the $f(S_t, p)$ need not be monotonically increasing. On the other hand any TA of a process can be used to define a feature that is monotonically increasing over the process. Conditional features are particularly suited for this. They allow for reference to the process as a whole, so that global characteristics of a process can have impact on the value of the feature for every state separately. A conditional feature can always be constructed in such a way that it is continuous and $\forall t' \neq t : \ f(S_{t'}, p) \neq f(S_t, p)$, and therefore monotonically increasing. Using conditional features any TA process is orientable.

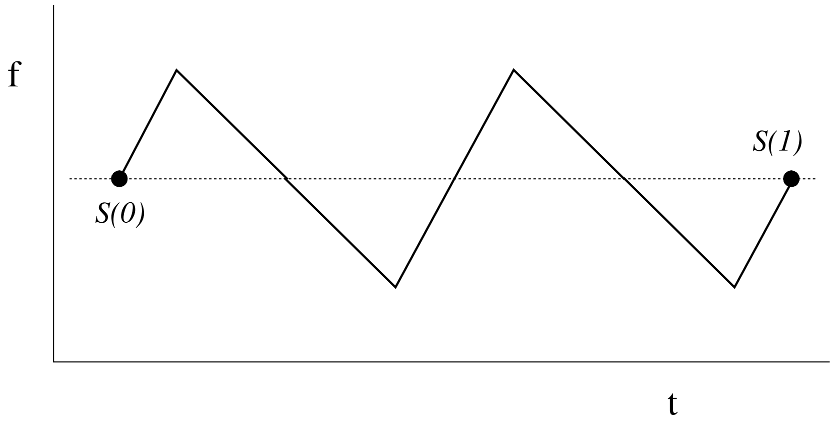

Figure III.6: A process that is only asymmetric with respect to conditional features $f(S_t, p)$.

The following example illustrates how conditional features can be of use. Consider the asymmetric process of figure III.6. Clearly the feature $f(S_t)$ depicted is asymmetric. But it is hard to distinguish its endpoints unequivocally because the value of f at the endpoints is the same. Now let us construct a conditional feature for this process, e. g. the function g that increases in the direction in which, along the domain $t \in [0, 1]$, the absolute value of $|\frac{df}{dt}|$ is larger for positive values of $\frac{df}{dt}$ than for negative values of that expression. The constructed conditional feature g is monotonically increasing and continuous and can therefore be used to define the orientation of the process in figure III.6. We can now propose the following distinction. If a process is orientable exclusively by using conditional features, the orientability is called global. If it is orientable using an $f(S_t)$ not depending on p the orientability is called local. Any TA process is orientable in one of these ways[5].

A set $\mathcal{P}$ in an orientable region M_R of spacetime is oriented if and only if there is some feature $f(S_t, p)$ according to which all $p \in \mathcal{P}$ are orientable, and according to which the orientation of all p lies in the same temporal orientation. Formally orientation can be expressed as follows.

DEFINITION 13 *Let M_R be an orientable spacetime region with a global time function t. A set of processes $\mathcal{P}$ defined on the time parameter t of this region*

[5] One can say every TA process is locally orientable because any property of any $f(S(t), p)$ can be expressed locally using a Taylor expansion. But most of such mathematical tricks to express the orientability locally will be hard to interpret physically, and this can be reason to discard them as local again.

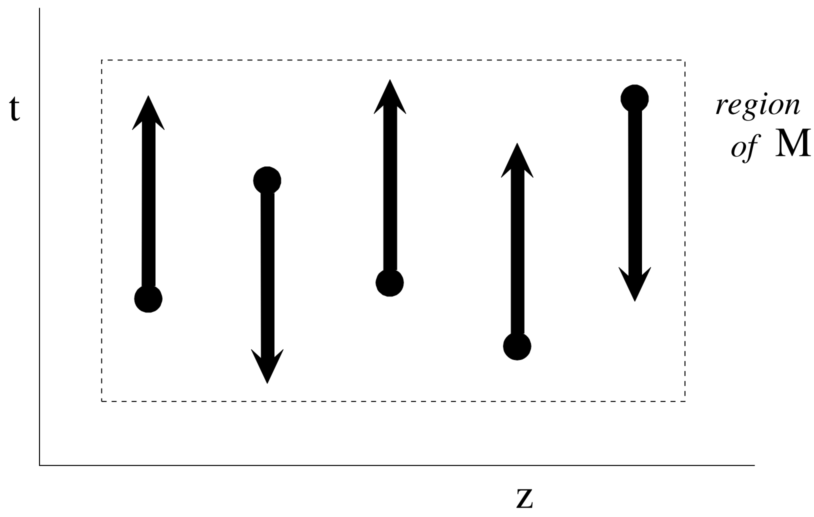

Figure III.7: A set $\mathcal{P}$ in which all p are asymmetric and thus orientable.

M_R is oriented temporally asymmetric in some feature, or OTA_f *for short, iff* $\exists f(S_t, p)$ *such that* $\forall p \in \mathcal{P}:\ \text{TA}_f(p)$ *and* $\forall t < t\prime:\ f(S_t, p) \leq f(S_{t\prime}, p)$.

The set $\mathcal{P}$ being oriented is stronger than property than the orientability of all $p \in \mathcal{P}$. If for instance in all processes the objects change from red to blue it is not yet said that they do so in the same temporal orientation. That is, one can imagine a world with a few separated processes all showing a change from red to blue, thus being asymmetric in this respect, without these changes all occuring towards the same end of spacetime. This is shown in figures III.7 and III.8. The first figure shows a set $\mathcal{P}$ in which all p are orientable, that is, asymmetric, and the second figure shows a set $\mathcal{P}$ that is itself oriented. It is also possible that the orientation of particular parts of a process is opposite to the orientation of the whole, for instance when using badly chosen conditional features such as the above.

Three remarks must be made. First note that the occurrence of an OTA for some $\mathcal{P}$ hinges on a comparison of orientations of the $p \in \mathcal{P}$. Once the orientation of p is consistent one can speak of an OTA. Yet it is questionable if the features in which a process can be orientable allow for a comparison as it is made in for instance the 'smaller than' relation. If all objects change from red to blue in the same temporal orientation, it can still be hard to identify this orientation everywhere, because different shades of blue may differ more among themselves than certain shades of red and blue. For present purposes it is assumed that such a comparison can be made. Secondly, note that orientation comes in global and local kind as well, depending on whether the orientating f is a function of p. Contrary to global orientability, global orientation is not

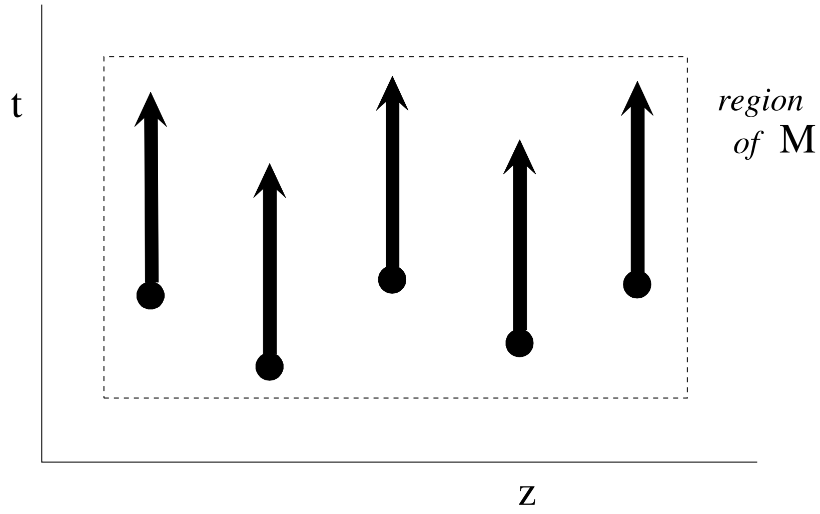

Figure III.8: A set $\mathcal{P}$ that is oriented temporally asymmetric.

trivial. Whereas the temporal ends of some process may easily be distinguished when it is asymmetric, it is not at all trivial to single out, by some criterion, the end that lies towards one particular extremity of spacetime. Thirdly, if M_R is connected the set of processes $\mathcal{P}$ can be considered as one process. In that case orientability of all $p \in \mathcal{P}$ entails that the set of processes $\mathcal{P}$ is OTA.

III.4 Anisotropy as asymmetry of processes

The aim of reductionism was to reduce the orientation of time to some kind of temporal asymmetry or irreversibility. Earman criticizes the strong bonds between irreversibility and orientation in his Attempt to add a little direction to the problem of the direction of time[6], championing the heresy of TDH_2. In that article he also criticizes attempts to reduce orientation to an asymmetry of some kind, more or less repeating the points he had made in an earlier article[7]. These attempts, but mainly the criticisms Earman levels against them, will be discussed in this section. It will be argued that the Earman's arguments are beside the point. The intention is both to illustrate reductionism, in particular the reductionism focusing on the temporal asymmetry presently at issue, and to put in perspective the heresies by Earman.

To some reductionists the existence of an OTA_f in the universe suffices to say that time is oriented, or in other words, anisotropic. Obviously the anisotropy *of time* is in reductionist positions merely a way of speaking, shorthand for particular characteristics of processes taking course in time. In the present section two of such reductionists will be discussed, namely Grünbaum and Black. Grünbaum holds that the omnipresent OTA with respect to entropy, in his words a 'de facto irreversibility', is enough for anisotropy[8]. It is noticeable that Grünbaum uses irreversible where I use asymmetric. In the following this must be kept in mind. For Black anisotropy is already established by the OTA present in human language and life[9]. Black seems to have a position much like that of Grünbaum, even though he does not explicitly refer to irreversibility and even though he does not openly support reductionism. Grünbaum and Black will therefore be treated together. It will be seen that the criticisms Earman levels against them are deficient for the same reason.

Earman discusses both authors in the article Irreversibility and Temporal Asymmetry[10]. First he deals with Black, who has dedicated one chapter of Models and Metaphors to the problem of anisotropy. In the chapter Black argues that time is anisotropic, literally not the same in both orientations, because we can distinguish between temporal orientations. That is, in language and experience the distinction between temporal orientations is manifest and unequivocal. This comes out in the fact that temporal relations such as 'earlier than' are complete, where 'complete' means that of two timelike separated events one is earlier than the other independently of conventions or the position of the observer. Relations like 'earlier than' clearly distinguish temporal ends and the completeness of these relations takes care that the distinction is not dependent on circumstances, but actually attached to time itself[11].

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[6] Earman (1973) [8].
[7] Earman (1967) [7].
[8] Grünbaum (1963) [18].
[9] Black (1962) [3].
[10] Earman (1967) [7], p. 543-9.
[11] It is not completely clear from Black's text how literally this 'attaching to time itself' is to be interpreted. Possibly Black is not a reductionist. But for the present purpose this is not important.

But Earman disagrees with Black. Presumably he feels that the particular anthropocentric perspective is too weak a basis for anisotropy. To evade it he argues as follows. First, he takes Black to hold the following[12].

B$_1$ If time is isotropic, the relation of 'earlier than' is incomplete.

B$_2$ The relation of 'earlier than' is complete.

$\Rightarrow$ B Time is anisotropic.

He then criticizes Black on the first supposition, arguing that really the isotropy of time cannot have such an influence on the community of observers we happen to be part of. That is, Earman argues that the isotropy of time cannot cause the community of observers to contain only members that have our particular perspective and that Black is mistaken in holding this. If Black indeed held this, I think Earman would be correct. But in my opinion Black never intended to claim anything about the connection between isotropy and the type of community of observers in the universe. Rather he proposes the following.

B'$_1$ If the relation 'earlier than' is complete, then time is anisotropic.

Statement B'$_1$ is logically equivalent to B$_1$ and thus yields the same conclusion B, but it avoids the suggestion of any connection between isotropy and the community of observers. With B'$_1$ Black says nothing about isotropy and its mysterious influence on the type of community of observers. He does not claim that in a universe with isotropic time there necessarily is disagreement about the 'earlier than' relation. Rather he takes the agreement among observers as a *sufficient reason* to assume anisotropy.

Earman can still object against the Black's reasoning. He may argue that the completeness of the 'earlier than' relation is not a sufficient reason for anisotropy, taken as a separate notion, at all. However, in my opinion Black intended to *define* anisotropy as depending on criteria that enabled us to distinguish temporal orientations. Such criteria encompassed both time in physics, as given by laws of nature, and daily experience. This is brought out in the following passage.

> "On the view that time is 'isotropic', there is nothing in the Universe that *could* distinguish the one [temporal direction] from the other."

By contrast Earman takes anisotropy to be defined in itself as determined by the laws of nature, as can be read in section III.1, and he interprets Black in this manner as well. That Earman takes Black to connect anisotropy only with time in physics, determined by laws of nature, becomes clear from a passage in the 1973 article. There he paraphrases the supposition of Black as the following[13].

> "... if all the laws of physics were time reversal invariant, the relation of chronological precedence would be an 'incomplete' relation...."

[12] Earman (1967) [7].
[13] Earman (1973) [8].

In sum then, Earman misrepresents Black in taking him to advocate B_1 which, unlike $\mathrm{B'}_1$, can never be understood as a definition of anisotropy. And as far as Earman considers $\mathrm{B'}_1$, he misunderstands this definition as a false implication.

In the 1967 article Earman also criticizes Grünbaum[14]. Grünbaum takes the relations 'earlier' and 'later' to be incomplete, or in his own words *extrinsic*, if the universe is not in some sense irreversible. According to Earman the universe not being irreversible is in turn entailed by its isotropy. So Grünbaum seemingly maintains that isotropy entails the incompleteness of 'earlier than', that is, Grünbaum maintains precisely B_1. Against this Earman argues that really the incompleteness of 'earlier than' has got nothing to do with irreversibility, just as he argued against the connection of isotropy and incompleteness directly in discussing Black.

Earman seems to forget however that for Grünbaum the denial of irreversibility means much more than that there is no process that has lawlike asymmetry in the universe. For Grünbaum it means the lack of *any* TA and thus the impossibility to distinguish the temporal ends of the universe period. In case this notion of irreversible is used, Grünbaum is correct in maintaining that reversibility of the universe entailed the incompleteness of 'earlier than', simply because in a reversible universe there can be no difference between orientations at all. Moreover, Grünbaum would only agree that isotropy entailed the universe being reversible under this much more stringent notion of reversible. This is because for Grünbaum, just as for Black, isotropy is *defined* by the impossibility to distinguish temporal orientations and not, as for Earman, given by the weaker notion that laws cannot distinguish between these orientations. In sum then, Grünbaum can maintain B_1. The requirements are that isotropy is defined as the lack of any TA process in the universe, and that incompleteness of the 'earlier than' relation follows from nothing less than such a lack of TA processes.

Nevertheless Earman's criticisms have intuitive appeal. One feels that it cannot be correct that time is anisotropic simply for the fact that some global or human dependent OTA occurs. Even though the arguments of Black and Grünbaum are not mistaken, it is questionable whether they characterize anisotropy, in another word, orientation, correctly. Earman in his 1973 article eventually arrives at this when distinguishing between literal and metaphorical anisotropy. He takes literal anisotropy to reside in the metrical structure of time itself. An OTA of processes, it is argued, seems to have very little to do with this. Earman associates such OTA's with the metaphorical sense of anisotropy. Consequently Earman reads Grünbaum as merely discussing the latter. Because Grünbaum is a reductionist this metaphorical anisotropy indeed seems what he actually means[15]. Unfortunately Black is left out of consideration, but I think a similar objection can be raised against him. Both Grünbaum and Black are concerned with a derived notion of anisotropy. But such an objection is much more in line with TDH_1 than with TDH_2, which seemed to direct the criticisms advanced above.

[14]Earman (1967) [7].
[15]Earman (1973) [8], p. 29-31.

By contrast, Earman proposes a very stringent notion of anisotropy, which is strongly connected to the geometrical structure of spacetime. He distinguishes this anisotropy from the notion of orientation. Orientation can be assigned to time without spacetime having these particular properties. In the next chapter we will return to reductionism towards orientation in this latter sense, and reserve the term 'anisotropy' for the strict notion Earman proposes.

IV

Irreversibility

This chapter is devoted to an account of time reversal and irreversibility. The characterization of irreversibility may be seen as the second part of explicating reductionism, as irreversibility was one of the features of processes associated with orientation in the second reductionist dogma. But the notions developed in this characterization will also be used in later chapters, most notably in the chapter on enantiomorphy. This certainly holds for the notion of reversal, that will be spelled out in the first section. Its explication will provoke a section on the time reversal operator, as it is being used in reversing a process. Further, two sections are devoted to two related yet different notions of irreversibility. The first of these concerns processes, the second concerns noninvariance of theories under the operation of time reversal. Therefore the second strongly relates to the precise form of the time reversal operator **T**, depending again on the theory in which it functions. Finally, the heresy TDH_2 is made explicit.

IV.1 Reversal of processes

Before dealing with irreversibility I will specify what is meant with the reversal of processes. This will be attempted using an analogy of a process laid out in time with the word change written on paper. It will be concluded from this analogy, and from the discussion concerning asymmetry of the previous chapter, that in a reversal of a process not only the order of states but also the states themselves need to be altered. This will again be argued from figures IV.2 and IV.3. With these figures two possible ways of altering the states will be discerned.

Reichenbach distinguishes descriptions of processes in positive and negative time[1]. If for instance an object is changing from red to blue in positive time, then in negative time it changes from blue to red. Note however that the process itself still lies in the same temporal orientation, it is only our perspective on the process that has altered. One may compare this to a word, say change in figure IV.1(a), which can be read both from left to right and conversely. The word as it is written on paper remains the same whatever the direction of reading, with the c leftmost and the e rightmost. The separate letters in this word can be considered separate states and one can further compare the word being allowed in English vocabulary to the process being allowed by a law of nature.

In terms of the definitions in the previous chapters, for a description in negative time both the time function on some region of spacetime and the as-

[1] Reichenbach (1956) [37], pp. 30-2.

(a)

(b)

(c)

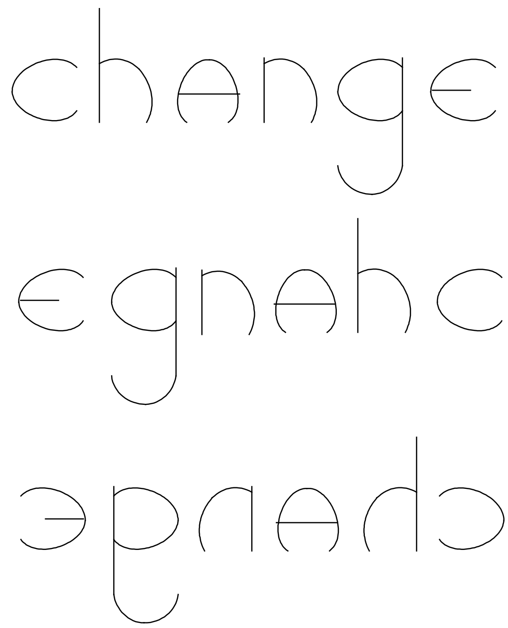

Figure IV.1: The word change written in different ways as analogon for different ways in which a process can be situated in spacetime.

signment of states by the mapping p are reversed, so that every hypersurface in the region is associated with the same state as before the conversion of positive into negative time. Formally this can be expressed as follows. Let $x \mapsto t$ be the time function on spacetime and $t \mapsto S(t)$ a process in so-called positive time. A conversion of t into $1 - t$, called negative time, in both mappings then results in the same assignment of states to hypersurfaces: $x \mapsto t' = (1 - t)$ and $t' \mapsto S(1 - t')$ so that $x \mapsto S(1 - (1 - t)) = S(t)$. A conversion of this kind is sometimes called passive as it leaves unaltered the process itself. Reichenbach held that the difference between processes in positive and negative time is only one of description.

The time reversal of a process is obtained by leaving out either the reversal of the time function or of the assignment of states to it, resulting in something like $x \mapsto t \mapsto S(1 - t)$. Reichenbach puts it as follows.

> "We can now use the converse description [the description in negative time] and give it a different meaning: we regard it as a description in positive time."

Indeed this is precisely what the assignment of states to hypersurfaces according to $x \mapsto S(1-t(x))$ does. Under this operation the process of an object changing from red to blue in some temporal orientation turns into a process of an object changing from blue to red in the very same orientation. In terms of the analogy with words, the order of the letters on paper is altered in a reversal, the order of reading has nothing to do with this.

But taking a closer look at the analogy, one can still ask what a reversal looks like. It seems that for change there are two possibilities, which are given in figure IV.1(b) and IV.1(c) respectively. Figure IV.1(b) is arrived at by reversing the order of letters, much in the same way as that the reversal of some process is constructed by reversing the order of states. Nothing else is done in that reversal. Figure IV.1(c) is constructed by, in addition to a reversal of the order of letters, reversing the orientation of the letters, or if you like, altering the letters themselves. Note that the intrinsic properties of the letters do not change in either reversal. In figure IV.1(c) the letters are only *mirrored*. Now which one is correct?

The analogy with words may help to get clear on the question, but it is obviously not suited to yield the answer. The question is whether, in construing the reversal of a process, the state description itself needs to be mirrored or in some way altered as well. Two considerations may be advanced to answer this question. First, by carefully drawing the analogy between space and time, it was in section IV.3 suggested that identical but oppositely oriented halves of a symmetric process were such that the corresponding states in these halves mutually differed. The states lying symmetrically around $S_{\frac{1}{2}}$ were only pairwise identical after transforming either with $\mathbf{T}$. The same reasoning can now be applied to an entire process, to the effect that the construction of its identical but oppositely oriented counterpart involves operating on the states of the process with $\mathbf{T}$.

A similar consideration with the same conclusion stems from figures IV.3 and IV.2. Consider the reversal of a movement from $z(a)$ to $z(b)$ in which the velocity is directed towards $z(b)$. Such a velocity is intuitively associated with an order of the states *from* $t(0)$ *to* $t(1)$. Now the reversed process obviously shows a movement from $z(b)$ to $z(a)$. But what happens with the states the process consists in? In case we do not alter the velocity assignment, the states will have to be associated with a different orientation, namely *from* t_1 *to* t_0. Then the states must be changed in what may be called their orientation in time, as is shown in figure IV.2. A more common solution is to change the velocity assignment in the state description, that is, towards $z(a)$ and not towards $z(b)$ anymore, as is shown in figure IV.3. Note however that altering absolutely nothing causes trouble. For then the movement itself, considered *from* t_1 *to* t_0, will disagree with the velocities, being directed towards $z(b)$. One can say such a process is in conflict with a law, in fact kinematically impossible, like egnahc does not occur in a dictionary.

It seems that the mirror image of a process is the correct time reversal of a process, like the mirror image in figure IV.1(c) is the reversal of figure IV.1(a). That is, in a reversal something of the states in a process will have to be altered

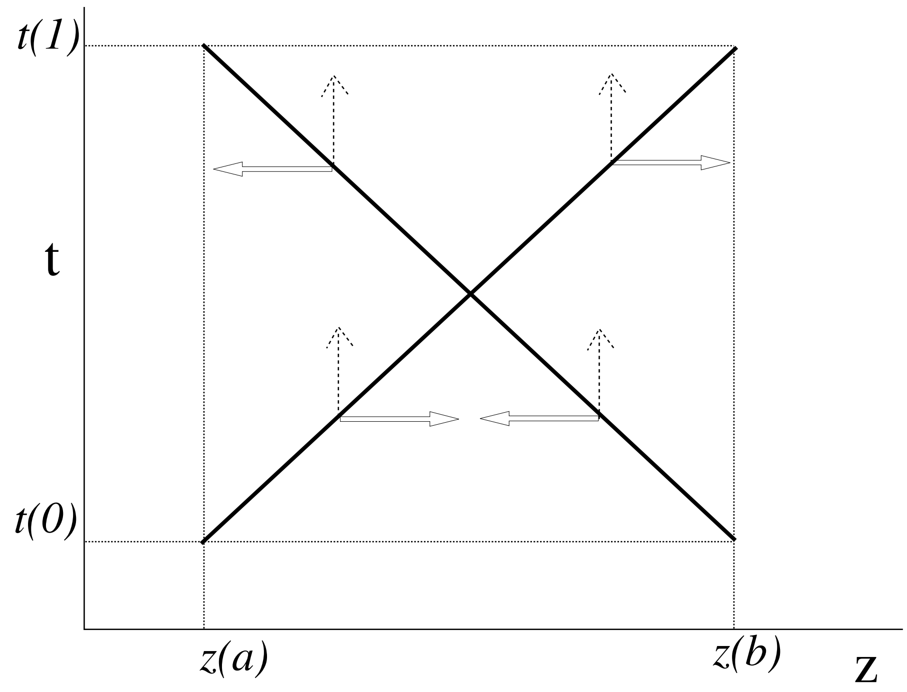

Figure IV.2: A process p and its reversal $\mathbf{R}[p]$ with velocities as they are usually taken, that is, with different spatial directions in the two reversals.

over and above reversing the order of states. It is a possibility to reverse the spatial directions of velocities in the state descriptions, but it is also possible to alter the orientation of states in time, as was shown in the figures IV.2 and IV.3. I will explain what this amounts to in the next section, in which I will deal with the precise form of the time reversal operator $\mathbf{T}$. For now it is only important that the operation performed on the state description in a reversal is $\mathbf{T}$ and that in a time reversal either the time function t or the mapping p has to be altered, but not both. I will here define reversal by altering the latter.

Definition 14 *Let the process $p : [0,1] \mapsto \mathcal{S}$ be a mapping from a time function t to state descriptions $S(t)$. The time reversal of p is a mapping $\mathbf{R}[p] : [0,1] \mapsto \mathcal{S}$ from t to the state descriptions $\mathbf{T}[S(1-t)]$, which are thus relabeled and oppositely oriented in time.*

Contrary to the processes described in positive and negative time, a process and its reversal are in general different. Actually any TA process differs from its reversal in that it is oppositely oriented. But it is not yet said that TA processes are irreversible, that is, impossible in the opposite orientation.

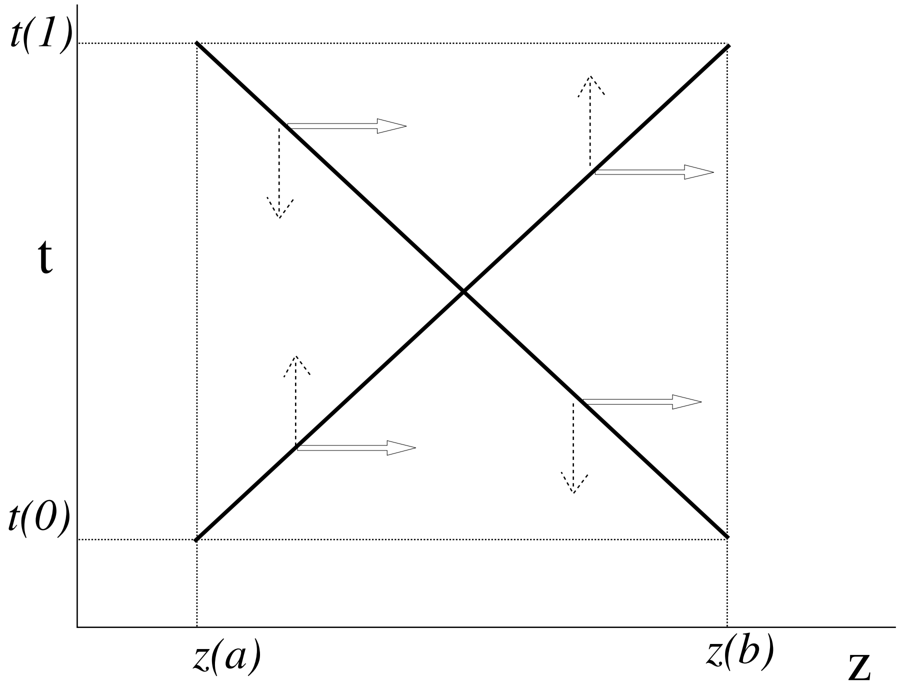

Figure IV.3: A process p and its reversal $\mathbf{R}[p]$ with velocities that have not been changed in spatial but in temporal orientation.

IV.2 Time reversal operator

Before turning to the notion of irreversibility, it will be useful to consider the time reversal operator in more detail. The aim of this small excursus is to clarify two different views on time reversal, connected to two different kinds of operators $\mathbf{T}$. The central question is how precisely a state in some process differs from the corresponding state in the reversal process.

The possibility that the operator $\mathbf{T}$ reverses just the orientation associated with the states and not the spatial directions of the velocities, as is shown in figure IV.2, has not been considered in the literature. In reversing the process p of figure IV.2 the operator $\mathbf{T}$ is always taken to reverse the spatial orientation of the velocity. I can see two reasons to change the velocity assignment rather than to swap its orientation. First one can hold that velocity is intrinsic, but happens to be such as to express the intended movement of the object in *our* temporal orientation. That is, one can hold that the only candidate for a reversal process must nevertheless have its velocities on a par with a particular perspective *due to the particular nature of change*. As this entails a genuine orientation for virtually all processes, very few authors will acclaim that. Both the blatant adoption of orientation and the reference to human particularities are not approved of in physics and philosophy.

The majority of authors will advance another reason, namely that velocity reflects the movement we happen to see, whereas nothing real or existent corresponds to the velocity being backwardly or forwardly oriented. The opposite spatial orientation of velocity is taken in the reversal *by convention*. This latter position seems tenable. But I want to confront the position with Zeno's paradox and with a puzzle that proponents of any kind of **T** operator will have to answer. Zeno's paradox, as was already argued, provides reason to consider velocity as an intrinsic property of the arrow at all stages of its process and thus as element of the state descriptions. The puzzle provides reason to adopt the notion of orientation of states, or at least of state descriptions, that contain elements pertaining to change. This puzzle will now be dealt with.

Let the state of a ball be as in figure IV.4, namely $S(t) = \{z, v\}$. It is then asked to predict the process of which the given state is an intermediate one. To fully appreciate the problem, predict the process before and after having turned this booklet over π radials. It is easily seen that the prediction depends on the perspective taken. The thing to note here is that, whatever kind of **T** is adopted, one is in need of extra information on the perspective in which the velocity is to be considered in order to predict the process. Authors that assume a reversal operator swapping the orientations of states are in need of additional information because the intrinsic property of velocity $v \in S(t)$ simply needs an orientation to be unequivocal. Those authors that assume velocity assignments to be fixed by convention make implicit use of their own perspective to predict unequivocally.

Without associating an orientation to those elements in a state description denoting change, the state description may be called incomplete. Any state description involving elements that express change, such as the v in $S = \{x, v\}$, must therefore be furnished with an extra element that fixes in what orientation of time the elements of change are to be considered. That is, if it is maintained that in deterministic physics process are fixed by laws and suitable conditions, any state description that functions as such a condition must be extended with the orientation O in which the properties in the state description pertaining to change are to be understood. So $S = \{x, v\}$ must be written $S = \{x, v, O\}$, where O is the orientation of v. Only when an orientation is added explicitly to state descriptions these descriptions fix processes unequivocally. I therefore hold that rejecting the possibility of a reversal operator **T** that only swaps the orientation of states in time because there are no such things as an orientations of states, is flawed.

In sum, the paradox of Zeno shows that velocity must be taken as an intrinsic property of the arrow and that different velocity assignments can be chosen. In the same way the above puzzle shows that orientations are properties of states. It will be discussed later whether this property should be taken as intrinsic as well. For now, just reconsider the time reversal operator **T**. If we take this operator to change the velocity assignment in the state descriptions, as is done

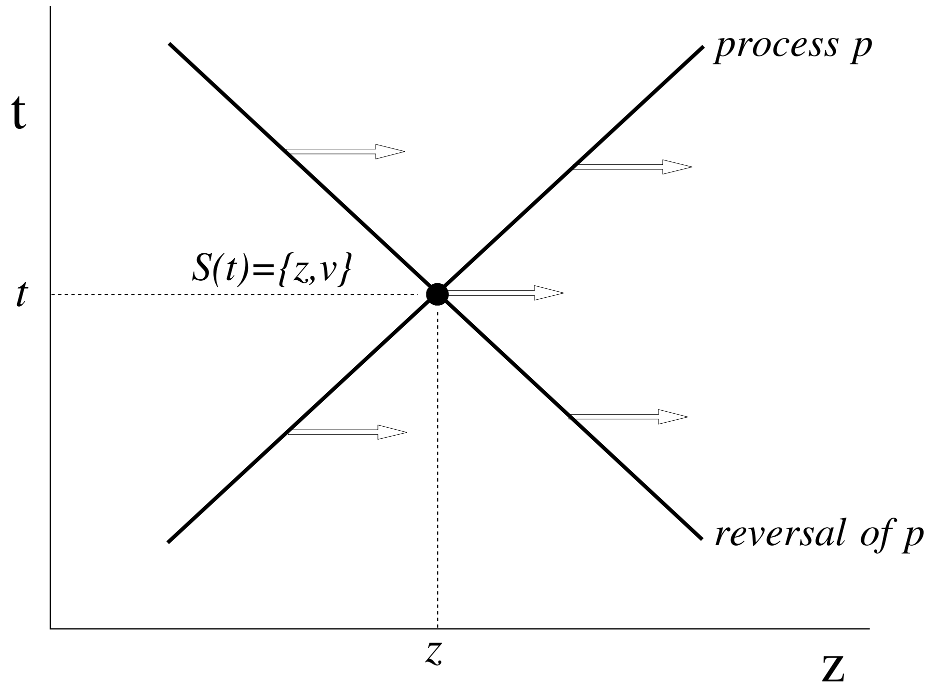

Figure IV.4: A state $S = \{x, v\}$ and two possible processes p and $\mathbf{R}[p]$.

in figure IV.3, a reversal process will differ from the original process in that particular intrinsic property being velocity. If the orientation of states O in the state descriptions is swapped however, as is done in figure IV.2, the processes will differ in the orientations associated with them, that is, in the property of orientation. The important thing to notice is that in using a particular $\mathbf{T}$ a choice is made for changing a particular property of states. Both the velocity v and the orientation O in the state descriptions are real properties of the states.

So in a reversal operation the state descriptions can be altered either in their elements concerning change, such as velocity, or in the orientation associated with these elements of change. In my view a $\mathbf{T}$ that only swaps orientations of states is more natural. This preference can be illustrated by the following. In the previous section it was argued that the reversal of a process was given by its mirror image. In taking the mirror image of a spatial object however, all its properties remain unaltered. The only thing of a glove for instance that is changed in taking its mirror image, is the orientation of the surface that defines its shape. By analogy the states of an arrow must be kept unaltered in a reversal operation as well apart from the orientation of the states. A time reversal operator that changes the orientation of states and not the velocity assignment, I thus find the more natural choice. But I am afraid the above argument is not completely convincing to those who disagree with me. In the following I will therefore not pin myself down to this view. Time reversal operator $\mathbf{T}[\cdot]$ may be understood according to personal preference.

IV.3 A definition and various meanings

The term irreversibility has attained a variety of meanings in the literature on time. As was seen already in the previous section Grünbaum uses *de facto irreversibility* for processes being TA in any respect. In contrast, Grünbaum calls *nomologically irreversible* those processes that are TA because of some lawlike distinction of temporal orientations. Such a lawlike distinction occurs if the same TA process is deemed impossible in the opposite temporal orientation. Following Reichenbach, examples of nomologically irreversible processes are the burning of a cigarette, the pouring of cream into coffee and the breaking of pottery. I will in this paper call irreversible those processes that are nomologically irreversible in Grünbaum's terminology.

Definition 15 *Let $\langle\langle M_R, \Gamma, g\rangle, t\rangle$ be an orientable region of spacetime with a time function $t \in [0,1]$. On this region let $p : I \mapsto \mathcal{S}$ be a process that is governed by a law L, so that $p \in \mathcal{L}$. This process is irreversible iff its temporal reverse $\mathbf{R}[p] : I \mapsto \mathcal{S}$ mapping t to $\mathbf{T}[S(1-t)]$ is impossible according to L, or $\mathbf{R}[p] \notin \mathcal{L}$ for short.*

This definition of irreversible is shared by most authors, including Horwich, Earman and Sklar. Note that the definition makes TS processes reversible by definition, as expected. By the same token all irreversible processes are TA, whereas not all TA processes are irreversible. Because all TA processes are orientable, an irreversible process is always orientable. It is locally orientable if the laws predict of some $f(S_t)$ that it increases monotonically.

Many accept DEFINITION 15, but irreversibility is further associated with a variety of particularities that are not entailed by the definition. Reichenbach for instance aims to reduce temporal becoming and the direction of causation to the irreversibility of thermodynamical processes[2].

> "... the use of growing entropy for the definition of time direction leads to the consequence that causes, and not ends, determine the occurrences of the present. ... The statistical relationships... [underlying the irreversibility] account for our conception that the past *produces* the future, and not vice versa."

Sklar and Grünbaum both successfully criticize this view, albeit on different grounds [3]. Grünbaum in particular warns for the use of 'the' in front of 'direction of time' as he wants to avoid any connection between irreversibility and our sense of becoming. I think these issues are indeed separate.

[2]Reichenbach (1956) [37], p. 154-6 and p. 186-7.
[3]Sklar (1996) [49] and Grünbaum (1963) [18], p. 398.

Another meaning of irreversibility is concerned with processes that have an initial state that cannot be recovered by any process. Uffink notes that in thermodynamics this meaning is often used[4] But *irrecoverability*, as Uffink calls it, is a wholly different notion. The irreversibility of some process as defined above only implies that its initial state cannot be recovered by an occurrence of the reversal process, as the latter is not allowed by some law of nature. This does not mean that the initial state cannot be recovered by any other process. A bicycle for instance is such that riding backwards is impossible. The process of riding to university on a bike is in a sense irreversible. But fortunately it is not irrecoverable, because otherwise it would be impossible for students ever to return home. Therefore one cannot equate irreversible with irrecoverable processes. The *recoverability* of an initial state is an issue separate from the issue of irreversibility[5].

There is another meaning to irreversibility that will later be called enantiomorphy. I only briefly mention it here but in the next chapter it will play an important role. Consider first an arrow in space. This arrow is not invariant under reflection in the planes perpendicular to it, that is, these planes does not divide the arrow in mirror image parts. We therefore say that the arrow has an asymmetry. This asymmetry is orientable because we can distinguish its end-points. However, the orientable asymmetry can be reversed: The arrow can be rotated to point oppositely. Now consider the process of an arrow flying from a bow to a target. This process shows a globally orientable asymmetry in space-time similar to that of the arrow in space. But can this orientably asymmetric process be reversed just like the arrow was reversed, that is, can it be made to point opposite? My claim is that it cannot. A process cannot be reversed in this sense just like a left hand cannot be reversed to become a right hand. In the next chapter this phenomenon will be dealt with extensively.

IV.4 Noninvariance of theories

Earman, instead of focusing on processes, specifies theories that governs processes that are irreversible[6]. Such theories he calls *noninvariant under time reversal*. I will in this section formalize this notion and show its relation to asymmetry and irreversibility of processes. In addition it will be argued that taking irreversibility to be concerned with theories rather than processes has certain advantages, because whether a process is irreversible crucially depends on the theory describing the process. Finally, if one considers the operator **T** only to reverse the orientation associated with states, the dependence on theories disappear.

A theory or a set of laws is time reversal noninvariant either if it allows at least one process of which the temporal reverse is deemed impossible by a law,

[4] Uffink (1998) [53], p. 7-8.

[5] The distinction between irreversible and unrecoverable naturally separates the famous puzzles of the Um- and Wiederkehreinwand. It is then seen that the latter has nothing to do with irreversibility.

[6] Earman (1973) [8], p. 24.

or if all processes allowed by it are irreversible. Earman concentrates on the latter kind of theories. But I think the former kind is more interesting because it is a larger class of theories and yet some processes these theories govern can still be called irreversible. I will therefore concentrate on this latter kind of noninvariance.

DEFINITION 16 *A consistent theory consisting of laws L_i is weakly noninvariant under time reversal iff* $\exists p \in \cap_i \mathcal{L}_i : \mathbf{R}[p] \notin \cap_i \mathcal{L}_i$.

Note that a theory may very well have TA or even OTA models, that is, cause all processes to be TA or even TA with consistent orientation, without being noninvariant under time reversal. Moreover, a time reversal noninvariant theory may allow many TS, and thus many reversible processes. So this weak time reversal noninvariance is not so intimately related to temporal asymmetry and irreversibility as the strong form, for which all allowed processes are irreversible.

For those who hold the time reversal operator $\mathbf{T}$ acts on intrinsic properties of states, it is not a trivial matter to determine whether a process actually is irreversible and thus whether a theory is time reversal noninvariant. This is because mostly it is on the theory itself to decide what the precise form of the time reversal is. To illustrate this I will reproduce an example from Sklar[7] which can be found in Horwich[8]. As said, the same problems do not occur when we consider the operator $\mathbf{T}$ only to reverse orientations associated with states.

Imagine an electric current in the vicinity of the north pole of a magnet. The magnetic field exerts a Lorentz force on every segment dl of the wire according to

$$d\vec{F} = \frac{q}{\epsilon_0}(\vec{v} \times \vec{B})\, dl \tag{IV.1}$$

The loose wire drawn in figure IV.5 will therefore accelerate out of the paper. Now imagine the time reversal of this process. When $\mathbf{T}$ swaps velocities then the electric current, being built up of moving electrons, will reverse direction as well. Consequently the Lorentz force will in the time reversal of the process be counterdirected and accelerate the loose wire out of the paper. The exact time reversal, in which the current goes to the right but the wire is accelerated into the paper, seems impossible by the law of equation (IV.1)! Apparently the process just described is irreversible as in DEFINITION 15 and therefore the theory of electrodynamics is time reversal noninvariant as in DEFINITION 16.

But really the theory of electrodynamics is not time reversal noninvariant, at least not because of Lorentz' law. The irreversibility of the above process is just an illusion. Once it is seen that magnetic fields are generated and determined by small current loops inside the magnet the illusion disappears. For a time reversal then requires us to reverse the electric currents in the loops, which swaps the direction of the magnetic field. The true pair of process and reversal is depicted in figure IV.6. As Horwich concludes[9]:

[7] Sklar (1974) [46].
[8] Horwich (1987) [23], p. 51-4
[9] Horwich (1987) [23], p. 53.

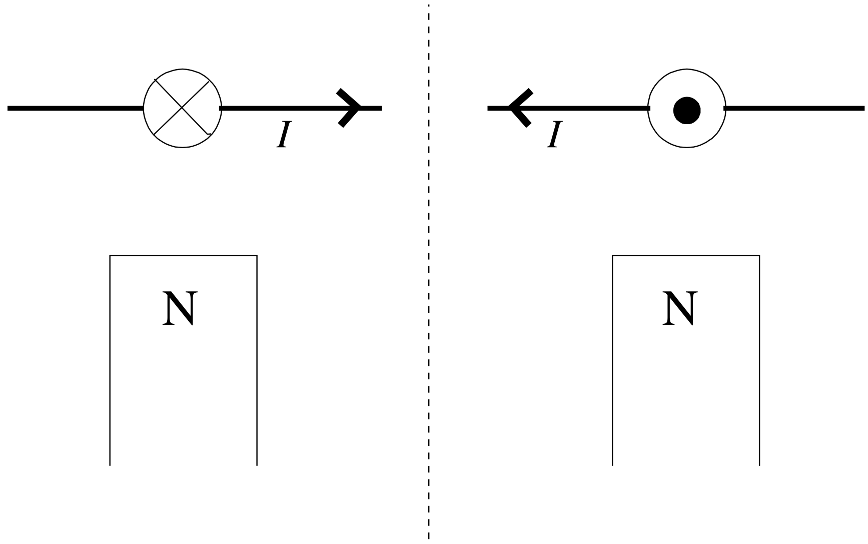

Figure IV.5: The process of a wire with current I in a magnetic field being accelerated by a Lorentz force, and its supposedly impossible time reversal.

> "...the problem of identifying the inverse [reversal] of a given process may be a subtle empirical matter. In order to solve it, it will be necessary to have discovered which mechanisms underly the process in question."

The choice of Earman to concentrate on theories rather than on processes when dealing with irreversibility therefore is very sensible. The 'subtle empirical matter' cannot be settled in philosophy, while judging a theory time reversal (non)invariant can. Moreover, it is doubtful whether such matters will ever be settled conclusively in science.

Note that the discussion leads us back to the question which properties of states are intrinsic. According to Horwich this is for science to decide, but he adds that[10]

> "...no quantity may qualify as 'basic' [intrinsic], in the required

[10] Horwich (1987) [23], p. 53. Note that with this requirement it is unclear how Horwich can solve the paradox of Zeno. I presume he will adapt the requirement so as to allow the redefinition of velocity proposed earlier. But then the incompleteness of state descriptions and the indeterminism resulting from it will remain.

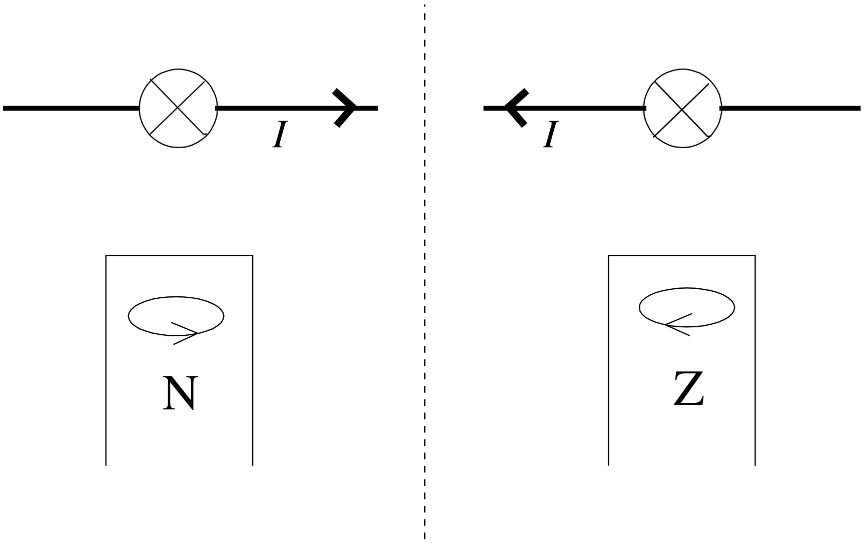

Figure IV.6: The process of a wire with current I being accelerated by a Lorentz force, and its correct time reversal.

> sense, if, like velocity, it consists in there being a relation between distinct states of the process at different times."

Earman, instead of excluding certain properties, signalizes that no property can be taken as basic apriorically[11]. Even the mass of particles may change under time reversal and consequently the universe may be deeply TA or irreversible. As long as we have not discovered all mechanisms underlying physical qualities of things, we cannot conclusively claim that the universe is reversible or whatever. The question of asymmetry and irreversibility will always hinge on particular choices made in physics.

It is readily seen that problems of the sort Sklar presented are avoided when the time reversal operator **T** is adopted that only swaps the orientation of states and no further intrinsic properties of the states, such as velocity and magnetic fields. This is because the problems stem from the ignorance on how to change intrinsic properties of the states. Moreover, with the alternative time reversal operator it is easier to determine whether a theory is time reversal noninvariant.

[11]Earman (1973) [8], p. 24.

This is because the elements of a complete state description, which determine whether a process is irreversible or not in case we adopt the alternative **T**, are easier to come by than the mechanisms underlying these elements, that serve to determine whether a process is irreversible or not in case we adopt the usual **T** .

IV.5 The time direction heresy

In the previous chapter I have concentrated on two attempts to link the orientation of time to particular asymmetries of processes, undertaken by Black and Grünbaum. Grünbaum's attempt was explicitly reductionistic, intending to reduce the orientation of time to nontemporal features, Black's attempt was very similar to it. Earman refuted the link between asymmetry and orientation, as part of TDH_2. But in my view he failed to appreciate both the intention of the authors and the nature of the features they meant to reduce orientation to. Grünbaum and Black meant to *define* orientation by temporal *asymmetries*, not to link the orientation of time as a separate entity to the noninvariance of theories under **T**. Eventually the criticisms of Earman seemed better suited as part of TDH_1.

In the present section, I will discuss criticisms of Earman that are justly motivated by TDH_2. These are directed against attempts to reduce the orientation of time to irreversibility proper, associated with the names of Reichenbach and Gold. That is, both the intention of the authors under consideration and the conception of irreversibility they use, are correctly represented by Earman. So here the criticisms of Earman are in their proper place. The aim of this section is to characterize the attempts by Reichenbach and Gold and mainly the criticisms by Earman, thus completing the picture of reductionism and Earman's heresy.

Before dealing with the criticisms of Earman in detail, let us characterize the reductionism of Reichenbach and Gold. At least three related claims are central to their position.

C The temporal orientation of spacetime and the 'earlier than' relation must be grounded in nontemporal features. In particular, whenever $E(,)$ obtains (or fails to obtain) it must be because some nontemporal physical relation $R(,)$ obtains (or fails to obtain).

C_1 In every time reversal noninvariant theory one can construct a physical and nontemporal relation $R(,)$ such that $E(x, y) \leftrightarrow R(x, y)$.

C_2 For a time reversal invariant theory such an $R(,)$ cannot exist.

Both C_1 and C_2 are particular instantiations of the central claim C, namely that temporal features and relations must be reduced to nontemporal ones. Typical for Reichenbach and Gold is that they require the temporal features to be grounded in *lawlike* features, that is, the relation $R(,)$ must be deducible from theory. Relations that occur merely de facto in a universe, are not considered strong enough to base temporal features.

One of Earman's points directly concerns the above characterization of reductionism. He notes that once the criteria for $R(,)$ are such that C_2 can be satisfied, then C_1 is probably false. Imagine a time reversal noninvariant theory T that is modified in such a way that the irreversible processes are excluded from its models without weakening the language of the theory itself. The modified theory T^* then is time reversal invariant. But if C_2 holds for T^*, then there cannot be any $R(,)$ for T either because its language is not stronger. Further, it is imaginable that a theory is local while being irreversible models due to some global OTA, for instance of entropy. In that case no $R(,)$ can be constructed and C_1 fails.

Another point Earman makes against reductionism, although incorrectly focusing on Reichenbach, deserves some extra attention[12]. It is of particular importance to this paper. Reichenbach maintains that descriptions in positive and negative time are equivalent in that they denote the very same world[13]. Indeed processes described in positive and negative time are the same just like change remains the same word whether it is read from left to right or in reverse. But Earman understands Reichenbach to mean or suggest that in otherwise empty space a process, e. g. the universe, and its time reversal are the same. In the analogy with words, Earman takes Reichenbach to mean that figures IV.1(a) and (c) are identical once they are written on an otherwise empty sheet of paper[14].

Reichenbach nowhere explicitly argues for the view that Earman attributes to him. For the sake of argument I will nevertheless present Earman's reply. Earman judges implausible the conclusion he attributes to Reichenbach on grounds of the following consideration. In physics, Earman argues, the operation of time reversal **T** is on a par with charge conjugation **C** and mirror image reflection **P**. Now if invariance under **T** implies that a universe and its time reversal in otherwise empty spacetime are one and the same, why does not the invariance of universes under **P** and **C** make these pairs of universes the same as well? But in that case the orientation of a hand and the charges of protons and electrons do not correspond to intrinsic properties anymore. That is, a proponent of the view attributed to Reichenbach must also abide by the interchangeability of positive and negative charge and of left and right. Earman concludes that one has to swallow this counterintuitive consequence or argue that **T** is a special case. Gold indeed attempts the latter using relationism[15], but according to Earman this task involves great heroism.

Another of Earman's points has already been touched upon in the previ-

[12] Earman (1973) [8], p. 24.

[13] Reichenbach (1956) [37], p. 31-2.

[14] One way to defend this is to hold that the paper is actually an overhead sheet, as the two words can then be made identical by turning around the sheet! Turning around the analogy, this amounts to relationism, because such a sheet can only be seen once something is written on it. Indeed most authors who hold this view will adopt relationism.

[15] Gold (1967) [17], p. 220-30.

ous section and will briefly be repeated. It is that the time reversal operator **T** cannot be conclusively determined, because it depends on contingent theory. Consequently, it will always remain uncertain whether a theory is time reversal invariant. Once temporal notions like orientation and precedence are made dependent on the occurrence of some theoretical features and relations, and thus dependent on the particular time reversal operator, they share the same conventionality. It therefore seems that reductionism entails an unwelcome conventionality. Note further that, if by some choice of **T** a universe and its reversal have different descriptions, it is not certain that they are actually different. This complicates the question whether a universe and its reversal are the same.

Earman is not attacking a straw man in discussing the view that a universe and its reversal in otherwise empty spacetime are identical. Reichenbach cannot be said to hold it. But Gold does argue that provided theory is time reversal invariant, a universe and its time reversal are identical. He writes[16]:

> "... [the time reversal of the model of our universe] is not describing another universe, or how it might be but isn't, but is describing the very same thing [as the model of our universe].

I will here consider his position in some more detail in order to prepare for the next chapter. Gold's position will there be refuted conclusively. Presumably Gold reasons as follows.

- G_1 Apart from their orientations in time a universe and its reversal cannot be intrinsically distinguished.
- G_2 Apart from asymmetries of a universe the orientations in time cannot be distinguished.
- G_3 Things that cannot be distinguished are identical.

$\Rightarrow$ G A universe and its reversal are identical.

In short, the orientation of a universe leads back to the universe itself and therefore is an empty notion. Note that G_2 is a relationist tenet and that in general the argument is much like the argument Kant devised to prove wrong the relationist. The difference obviously is that where Kant spoke of left and right hands in space, this argument deals with oppositely oriented universes in spacetime.

While the argument of Gold so much resembles the argument Kant ascribed to relationists, its impact will probably depend on whether relationism is adopted or not. Similarly the impact of Earman's consideration will depend on how strong this relationism is. But in which respects do the cases with **T** and **P**, or with universes and hands, match? It may be that the analogy is crucially defective. In the next chapter I will try to answer this question.

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[16] Gold (1966) [16], p. 17.

V

Enantiomorphy

In this chapter I will elaborate a feature of processes that has already been referred to as *enantiomorphy*. In this way I will connect the universes considered by Gold with the hands considered by Kant, because it will appear that oppositely oriented universes differ just like left and right hands. In the first section a criterion of enantiomorphy that is applicable both to objects and to processes, is explicated. It is argued in the second section that on this criterion oppositely oriented processes, and universes in particular, are enantiomorphs. That is, on top of processes being asymmetric, or irreversible, processes have this particular feature of enantiomorphy. This is in agreement with Earman and counters both Gold and, in a sense, Reichenbach.

Following the spatial analogy, there is reason enough to suppose that enantiomorphy has got something to do with temporal orientation, in particular in a reductionist context. The remainder of this paper is devoted to clarifying this relation, mainly in light of reductionism. But before we can do this, we first need to get clear on the philosophical status of enantiomorphy itself. In the third section I will therefore enter into a debate by Smart, Remnant, Earman, Nerlich and Sklar on the consequences of Kant's paradox for the substantivalism vs. relationism controversy, the only debate for which enantiomorphy is traditionally relevant. In light of this debate the prospects of reductionism look bad. Relationism is unable to reason away the enantiomorphy of single objects, and seems forced to adopt orientation as a primitive notion. The position of Remnant for instance, as given in section II.1, is revealed to be seriously deficient. For reductionism with respect to temporal orientation, similar problems will arise.

V.1 Rigid motions

In virtually all articles on the difference between left and right the notion of a rigid motion plays an important role. Frederick[1] for instance presents in the figures of V.1. He then asks in which respects they are identical in shape. Although figures (a) and (b) seem different it is readily seen that they can be made to coincide by rotation and translation in the plane. In Frederick's terminology, figures (a) and (b) can be made to coincide by *continuous rigid motion* and are therefore called *congruent counterparts*. Rigid are those motions leaving invariant the configuration of the parts of an object relative to each other, that is, leaving invariant the metrical properties of an object such as lengths and

[1] Frederick (1991) [13].

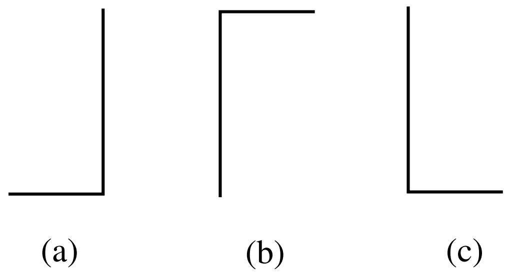

Figure V.1: Three L-shaped figures.

angles of its parts[2]. In contrast figures (b) and (c) cannot be made to coincide by rigid motion and are therefore called *in*congruent counterparts.

But there is a means to make figure (c) coincide with figure (b) after all. This was first pointed out by Möbius in his work Der barycentrische Calcul and has been repeated by Wittgenstein, Jammer, Gardner and many others[3]. The point is that in V.1 figure (c) can be lifted out of the paper, turned around and be put back again just on top of (a). Thus it can be made to coincide with both (a) or (b) after suitable rigid motions in three dimensions. In general incongruent counterparts can be made to coincide by moving them around in a space of one dimension more than the dimensions of their own shape, called a *dimensional* motion. For a left hand to be turned into a right for instance we need a rigid motion in a space of four dimensions. This fact has motivated Jammer to argue that the hands of Kant are actually identical. But Earman correctly points out that although this is correct it is irrelevant to the puzzle of Kant, simply because it is set in three dimensions and not in four.

There is an alternative way to let incongruent counterparts coincide, as was first pointed out again by Möbius. After its inventor it will be called the *Möbius* motion. First imagine the figures (b) and (c) printed on a long strip of overhead sheet and note that they can be interchanged by turning the sheet around. Then imagine the ends of the sheet to be glued together by turning either end once,

[2] In the formal definitions of geometry by Klein, rigid motions are precisely given by the metrical transformations.

[3] Möbius (1827) [33], Wittgenstein (1961) [56], Jammer (1960) [25] and Gardner (1989) [14].

so that the resulting band is twisted. This is called a Möbius band. Let us now move figure (c) along the band until it arrives at figure (b) again. The band has a twist, so figure (c) is turned around once and lies at the back of the sheet. Figure (b) has stayed in its place and lies at the front of the sheet. Recall that figures (b) and (c) could be interchanged by turning the sheet around. Now only figure (c) is turned around and the two can therefore be made to coincide! Note that for the mathematical criterion for coincidence it does not matter that the figures do not lie on the same side of the sheet, because defining such sides would require a third dimension.

Where for dimensional motion an extra dimension of space was needed, for Möbius motion we need space to have a particular topological structure. It appears that this topological structure is captured completely by the negation of orientability. That is, in an orientable space Möbius motions are impossible. Orientability for space is comparable to the orientability of spacetime as in DEFINITION 1. The idea is that a space(time) is orientable if and only if a nonvanishing, consistent vector field can be assigned to it, the field being inconsistent just when some point in space(time) has an ambiguous vector assignment. Cartesian space for instance is always orientable, because an unambiguous vector assignment is a trivial possibility. The fact that orientability entails the impossibility of Möbius motions becomes clear once it is realized that any two incongruent counterparts can be assigned opposite orientations, so that the possibility for the one counterpart to coincide with the other is equivalent with the failure to assign a consistent orientation.

Enantiomorphy, or the phenomenon that objects have incongruent counterparts, can now be defined as follows[4].

DEFINITION 17 *An object o of dimension d is enantiomorph iff it cannot be made to coincide with its mirror image $\mathbf{M}[o]$ by continuous rigid motion in an orientable space $\langle M, \Gamma, g\rangle$ of dimension d.*

If the object o is an enantiomorph, the objects o and $\mathbf{M}[o]$ are said to be incongruent counterparts. So incongruent counterparts are always mirror images. A mirror image $\mathbf{M}[o]$ is construed by transforming o with to the the parity operator $\mathbf{P}$: $x \mapsto -x$, that is, transforming one of the coordinates defining the object. Further, incongruent counterparts always come in pairs. But it must be noted that this is a typical feature of the kinds of spaces we usually imagine. Spaces in which incongruent counterparts and mirror images come in three are imaginable. Which of the two incongruent counterpart an object constitutes, will be denoted by its *orientation*. For instance, given an enantiomorph left hand, then 'left' is its orientation.

V.2 TA PROCESSES ARE ENANTIOMORPH

In this section it will be proved that all TA processes are enantiomorphs. It may cause wonder that the property of enantiomorphy, having spatial objects

[4] Earman (1991) [10], p. 239 and Frederick (1991) [13], p. 4-6.

as typical exhibitors, will here be predicated of processes. But once we consider a process to be an object in spacetime, the wonder will disappear. The process may be viewed as an object as well, in particular, as an object in spacetime. In order to understand the process as a spatiotemporal object, recall the picture of a process being a mapping not of $t \mapsto S(t)$, but of $x \mapsto S(t)$. In this mapping slices of spacetime H_τ with the same value of the time function, determined by $x \mapsto t(x)$, are all assigned the corresponding state description $S(t)$. So a process is a 4-dimensional object built up of slices with the same characteristics, just like an object in Cartesian 3-space with rotative symmetry around a single axis.

In the following this picture of processes as spatiotemporal objects will be employed.

Two separate arguments can be employed to reach the conclusion that processes are enantiomorphs. The first uses DEFINITION 17 and proves that there is no *rigid and continuous* motion that can make a process coincide with its time reversal. It is very confusing to talk of *motions* in spacetime, because motion is itself a change in space that takes time. But here it is used rather as an equivalent of transformation. The notion of transformation covers the same ground yet avoids the confusing appeal to time, and will therefore be used in the following. The second argument is inspired on a consideration by Möbius and purports to show that the spacetime over which a process must be transported to coincide with its reversal, is in fact lacking[5]. Both arguments are conclusive and in my opinion equally convincing. As they seem to complement each other, one focusing on spacetime and the other on processes, they will both be presented.

Let me briefly sketch the process as a spatiotemporal object again. In DEFINITION 6 a process was defined by a mapping of the time function t onto the state space $\mathcal{S}$ and in DEFINITION 5 the time function t was made a mapping of points in spacetime x onto $\Re$. A process as considered in spacetime thus is a sequence of hypersurfaces labeled with $t \in [0, 1]$ to which there are attached state descriptions $S(t)$. Figure III.1 shows such a representation of a process. By DEFINITION 10 and DEFINITION 14 it can be concluded that the mirror image of a process is identical to its reversal. In spacetime the time reversal of a process by the same token is a sequence of hypersurfaces with state descriptions $\mathbf{T}S(1-t)$ attached to the time parameter t[6]. Finally, recall that by DEFINITION 12 any TA process could at least be assigned global orientation. It was already seen that a process being TA of some kind is equivalent to its endpoints being distinguishable.

In spacetime the orientation of any TA process can be represented by a pair of timelike separated, distinguishable points according to the following definition.

DEFINITION 18 *Let* $\langle\langle M_R, g, \Gamma\rangle, t\rangle$ *be an isolated spacetime region with a global time function* t *with range* $[0, 1]$ *and let* $p : x \mapsto S(t)$ *be a temporally asymmetric*

[5] Möbius (1827) [33].

[6] There is a special case in which this picture of reversals is problematic. In highly curved spacetime, e. g. just after the big bang, it can occur that the slice H_1 is much larger than the slice H_0 and that the slice H_1 does not fit in the part of spacetime originally occupied by H_0. To avoid this it is assumed that spacetime is sufficiently flat.

process on this region so that there is a strictly monotone $f(S(t), p)$ *on the domain* $t \in [0, 1]$. *Then this process is uniquely represented by two points* x_i *and* x_f, *the coordinates of the centre of mass in the rest frame of the system at* $t(x_i)$ *and* $t(x_f)$ *respectively, and these points are distinguishable because* $f(S(0), p) \neq f(S(1), p)$.

In the argument this representation will be a convenient tool. Note that the reversal of a TA process is represented by the same two points lying opposite in spacetime. So if for p it holds that $t(x_i) < t(x_f)$, then for $\mathbf{R}[p]$ it holds that $t(x_i) > t(x_f)$.

The first argument can now be presented. The purpose is to prove that a process cannot be made to coincide with its time reversal by rigid transformation. Note that for a process to coincide with its reversal, the order of the labeled time slices will have to be reversed. A transformation of that kind also reverses the order of the pair of points defined above, so that if $t(x_i) < t(x_f)$ holds before the transformation, $t(x_i) > t(x_f)$ holds after it. Put differently, a transformation of that kind swaps the order of x_0 and x_1 in the 'earlier than' relation. In the proof it will be used that if it is not possible to turn around the pair of points in this manner, it is also impossible to turn around the entire process, because the latter presupposes the former. The fact that in a reversal the state descriptions will have to be changed as well will not be needed in the argument.

The following consideration rules out any such transformation turning around the pair of points relative to the global time function. Note first that rigid transformations are always such as to leave invariant the *metrical* properties of the object being transformed. That is, the lengths and angles of the object may not alter during transformation. The set of allowed transformations in Cartesian 3-space for instance was given by the continuous group of translations and rotations, called rigid. For a pair of points defining an object in spacetime it is given by a group of transformations determined by $g_{\mu\nu}$. As long as spacetime is orientable it seems that the required transformation of mirroring does not belong to the group, but in the following we will assume that spacetime is flat, so that the group of allowed transformations is the Lorentz group[7].

The proof that all TA processes are enantiomorph is now easy. Because of the above, a process and its reversal cannot be made to coincide by rigid transformation. Using DEFINITION 17 it can be concluded that such processes are therefore enantiomorph. In short the argument goes as follows. The statements labeled '→' are intermediate conclusions to simplify the argument.

- E_1 If a process p and the reversal $\mathbf{R}[p]$ can be made to coincide by rigid transformation, then their representing pairs of points can be turned around relative to the global time function.

[7] It can be noted that traveling faster than light would make it possible for such a traveler to observe a process in opposite orientation. But it is questionable both whether superluminal observers exist and whether seeing the process in opposite orientation amounts to a transformation of the process itself.

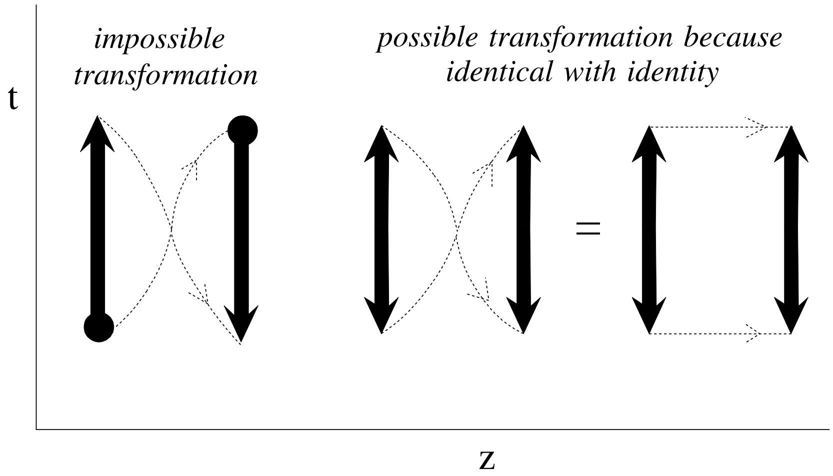

Figure V.2: Possible and impossible transformations of processes in spacetime.

→ If these pairs of points cannot be turned around, then p and $\mathbf{R}[p]$ cannot be made to coincide.

E2 Because the required transformation does not belong to the Lorentz group, the pairs of points representing the processes cannot be turned around.

⇒ E The processes p and $\mathbf{R}[p]$ cannot be made to coincide and are thus enantiomorph according to DEFINITION 17.

The conclusion is in accordance with Earman[8]. Note that by the same argument we may deem enantiomorph a set of processes $\mathcal{P}$ with a particular orientation.

Similarly one can argue that a TS process is enantiomorph as well. After all, the pair of points representing a TS process cannot be transformed in the required manner either, that is, this pair cannot be turned relative to the global time function just as it is impossible for a pair representing a TA process. But the thing to notice is that the points representing a TS process are not distinguishable, that is, the temporal ends of a TS process cannot be told apart. Therefore the required transformation is simply the identity. This is shown schematically in figure V.2. The asymmetric arrows represent TA processes. As argued above, there is no transformation turning a process into its reversal. The double arrows under represent TS processes. Because the reversal is in fact identical to the original process, the identity transformation turns the one into the other. A TS process is therefore not enantiomorph.

[8]Earman (1991) [10], pp. 140-3.

Interestingly enough, the conclusion that reversal processes are enantiomorph opposes that of Reichenbach in his Space and Time[9]. In the opening remarks of a chapter he notes that

> "[time] has non of the difficulties resulting from multidimensionality. Time does not have the problem of *mirror-image congruence*..."

Apparently enantiomorphy, in the eyes of Reichenbach, results from multidimensionality. Moreover, according to Reichenbach time is not multidimensional and as such invulnerable to the problems concerning enantiomorphy. From the remarks of Reichenbach we learn that the enantiomorphy of TA processes is not uncontroversial. Gold for instance disagrees with E as well. He takes oppositely oriented processes to be identical on relationist grounds but in the next section it will be argued that equating these processes is problematic.

In the remainder of this section conclusion E will be proved again by another argument, employing the structure of Minkowski spacetime. This argument may be more illuminating than the former. In particular, it is hoped that the argument explains how a 2-dimensional timelike figure defined by a pair of points can be enantiomorph in 4-dimensional spacetime. This is unexpected because in normal space a figure of smaller dimension than its surroundings is never enantiomorph. To fully appreciate the oncoming argument, it will be useful to present a consideration about enantiomorphy by Möbius first.

Möbius imagined the reconstruction of a figure in d-dimensional space by placing a set of $d+1$ distinguishable points at given mutual distances[10]. For example, the figures in V.1 can be reconstructed by placing three points in suitable mutual distances on a 2-dimensional plane. The first point can be put anywhere, corresponding to a freedom in translation. The second point can be put anywhere on a circle, corresponding to a freedom in rotation. The third point however must be placed on either intersection points of two circles. Note that it is this third point which determines whether the figure is congruent to figure (a) or to figure (c). In general there are always options for putting the $(d+1)$th point and the choice between these last two options, if the resulting figure has no symmetries, makes the figure enantiomorph and determines its orientation[11], In general one can describe the cases in which enantiomorphy arises with the proviso that for the $(d+1)$th point there is no *continuous* set of available positions that can be chosen[12]. A choice to place the $d+1$th point in

[9] Reichenbach (1958) [38], pp. 109-13.

[10] Möbius (1827) [33], p. 40.

[11] To be more precise, for figures V.1 it is because the constructed line is not symmetric around the point where it meets the line joining the intersection points, that the figures thus constructed are enantiomorph. In general, if there is no $(d-2)$-dimensional subspace secant to the line that joins the intersection points, around which the (d-1)-dimensional figure is symmetric, then the d-dimensional figure is enantiomorph.

[12] In the spaces we usually imagine there are always *two* mirror images. The $d+1$th point of a figure defined in d-dimensional space always has two intersection points to chose between, e. g. the two intersection points of two circles. This is because for the kinds of space we usually imagine subspaces defined by a fixed distance to some point always divide space in two parts, like a circle divides the plane in an inside and an outside.

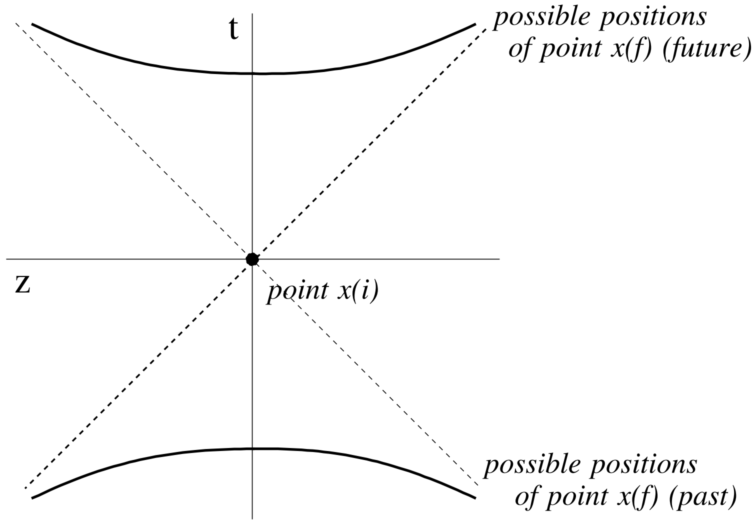

Figure V.3: Minkowski metric in 1+1 spacetime. The curved lines represent the set of points with $s = -1$.

one of the disconnected regions cannot by some continuous transformation be altered into a choice to place it in another.

The Minkowski metric has a distance function that is not everywhere positive like normal space, but given by

$$ds^2 \ = \ (x^2 + y^2 + z^2) \ - \ (ct)^2. \tag{V.1}$$

For timelike separated points this distance is negative. In Minkowski spacetime all points with $\Delta s = -1$ from the origin can be depicted as in figure V.3, where the curved lines represent the three spatial dimensions. Now imagine two points $x(i)$ and $x(f)$ with mutual distance $s = -1$ defining a figure in this spacetime and reconstruct this figure in the manner of Möbius. It appears that for the second point already the set of available positions is discontinuous! This second point cannot be moved from the past to the future half of the set by a continuous transformation that preserves metrical properties, in this case distance. If, like the pair of points representing TA processes, these points are distinguishable, then the construction of the figure already presents us the kind of choice associated with enantiomorphy.

It is thus concluded that the figure given by the pair of points defined with $\Delta s = -1$ is an enantiomorph. With a variation on E_1 we can say the same of the TA process it represents. Note that the pair of points constitutes an enantiomorph even though it is of smaller dimension than the surrounding spacetime. Timelike figures in spacetime, one may say, behave as if they are onedimensional.

V.3 What the hands prove

Against the 1768 argument of Kant several defences have been offered, which invited others to restate the argument or thereupon criticize the restatements. In this section I will survey the controversy over the 1768 argument and its alleged conclusions. First I will briefly review the relationist position of Remnant. His position we have already encountered in section II.1. He held that in fact there is no difference between oppositely oriented enantiomorphs, like left and right hands, in an otherwise empty space. This position is very similar to that of Gold about oppositely oriented universes.

In this review I will present the criticisms Earman has on Remnant, as well as his own reply to Kant. Apart from accusing Remnant of a weak defence, he argues that the original argument by Kant is already confused. That is, he argues that the real problem is even deeper than Kant foresaw and that it concerns relationism and substantivalism equally. Nerlich reacts to this criticisms on Kant and Remnant with a reinforcement of the 1768 argument. The replies to Nerlich by Sklar and Earman, which are aimed at defending relationism on a more deep level than Remnant, will complete the survey. With it I hope to make precise the positions of substantivalists and relationists towards enantiomorphism and thus towards the difference in oppositely oriented processes. The survey may be read as a shadow play of the controversy over Gold's position and relationism about time.

Remnant's position was that a relationist can accept conclusion R of section II.1, simply denying the difference in the orientation of lone hands. To illustrate his point Remnant considers a single hand and, with reference to an example by Kant, introduces a handless human body to determine where the hand fits. Kant argues that the lone hand is determinate in orientation because otherwise the hand would fit both arms, which is absurd. But, argues Remnant, analogous to right and left hands one cannot distinguish right and left parts of a human body. The introduction of a handless body cannot make definite whether the hand is right or left, and this remains indefinite unless it is somehow made explicit. In the words of Remnant[13],

> "... *even though it is quite determinate which arm the hand belongs on*, it remains completely indeterminate whether this is a right or a left arm and consequently indeterminate whether the hand is right or left."[emphasis added for later purposes]

That is, Kant fails to validate that a lone hand has *definite*, or in Remnant's words, determinate orientation, so absolute space is not needed to account for anything.

Two remarks can be made about the position of Remnant. First, contrary to Weyl and Smart[14], who defend similar views, Remnant does not presuppose relationism for his argument. His defence however is aimed at rejecting the

[13] Remnant (1963) [39], p. 57.
[14] Weyl (1952) [54], pp. 21-2, and Smart (1964) [50], p. 7.

substantivalist conclusion of the 1768 argument, namely that space is absolute, and in this sense is relationist. Second, it can already be noticed that there is some ambivalence in the use of 'definite' in the above. The hand in the example of Kant is indefinite in whether we call it left or right. That is, we have not yet determined whether the hand is left or right and the hand is indefinite in that sense. But one may argue that the hand is definite in some other sense. The hand already exists either as a left or as a right hand, irrespectively of whether we have already determined its orientation. Thus it is definite in being enantiomorph, that is, in having either and not both, or neither, orientations. It was Nerlich who saw that these different meanings of 'definite' are confused by Remnant, and that this confusion has destructive impact on his argument.

Earman, in his Kant, incongruous counterparts and the nature of spacetime, criticizes Remnant[15]. He notes that a lone hand simply *must* exist either as right or as left. Two reasons are advanced for this. First, he deems it nonsense to suppose that the parity operator collapses if all other objects in space are removed. Secondly, he argues that difficulties in finding out whether a hand is right or left are irrelevant to the hand being right or left itself. With both reasons Earman seems to accuse Remnant of the epistemic fallacy, of confusing existence and epistemic access. This already hints at the main criticism of Earman, to which I will turn later on.

A further remark by Earman is that the fate of relationism is relatively unimportant because

> "...modern science rejects the relational view of space."

Although it may be possible to defend relationism against all philosophical criticisms, Earman claims that for scientific purposes relationism is simply untenable. Science therefore seems to favour a genuine enantiomorphy even of lone hands, going against Remnant's position. Finally, Earman remarks that if Remnant's argument is granted, the argument of Kant can be turned around to refute absolutism. But this latter argument, argues Earman, has no more plausibility than its original and really the original plausibility is very weak, because according to Earman it suffers from a much more serious mistake. This main criticism of Earman will shortly be dealt with.

Thus far the remarks of Earman do not completely refute the position of Remnant or of any other relationist. The fact that a lone hand must have definite orientation cannot be made into a convincing argument, because it bluntly asserts the determinateness of lone hands that Remnant simply will not accept. The second reason Earman advances, namely that Remnant is guilty of the epistemic fallacy, has been elaborated by Nerlich and will be discussed below. In the text of Earman it has not attained its most destructive form. The remark on the substantivalist preferences of science is, strictly spoken, irrelevant to philosophical debate. The final remark by Earman merely states that Remnant's argument eventually is no better than Kant's, but it is not yet

[15]Earman (1991) [10], pp. 134-5.

an argument against Remnant in the strict sense. To his final criticism we will now turn.

Earman's main criticism is principally directed against Kant himself. It purports to show that the 1768 argument is completely misguided and that the actual problem behind Kant's puzzle presents itself both to substantivalists and relationists. With his analysis Earman implicitly criticizes any relationist defence against Kant's argument on the fact that they fail to see the real problem and thus fail to solve it. So also the accounts by Smart and Weyl are criticized in this main criticism. The major problem, according to Earman, is not limited to the single hand in relationist space. It is that establishing enantiomorphy even fails when reference can be made to absolute space or other objects, because it remains unclear how absolute space or other objects cause an enantiomorph object to be enantiomorph, that is, to be either of two incongruent counterparts. The real issue, according to Earman, is ontological. The challenge is, both for substantivalists and for relationists, to establish enantiomorphy at all, even with the help of absolute space or other objects.

Interestingly, this is precisely the 1783 problem in the puzzle of Kant, concerning the causal or ontological ground of enantiomorphy. There the suggestion was indeed that both substantivalists and relationists were facing the same problem. It is not surprising that Earman can raise this problem against the Kant of 1768, as Kant himself eventually conceded that one cannot distinguish between right and left hands *even by reference to absolute space*. The reason for this latter fact, in modern terms, is that space is invariant under parity: When an object stands in a certain relation to a particular part of space, its incongruent counterpart bears the same relation to another part of space. But these parts, being mirror images, do not differ intrinsically. In a comparable way reference to other objects cannot be ontological ground for a distinction of orientation either. In sum then, both Kant and Remnant present flawed arguments because both fail to supply ontological ground for enantiomorphy. It seems that orientation is needed as basic property, whether absolute space is invoked or not. In later articles both Earman and Sklar accommodate this need.

But before these articles appeared, Nerlich, in his Hands, knees and absolute space, elucidated a few issues[16]. Two of them are of relevance to the present survey. Note first the quote from Remnant, in particular the emphasized part. There Remnant concedes that a hand fits only one arm and thus that a hand is enantiomorph, irrespectively of its orientation. Nerlich, building on this, argues that really the enantiomorphy of hands is all that Kant needs. He notes that whereas we cannot know which orientation a hand has, we can be sure it is enantiomorph. Kant himself writes[17]:

> "[On the supposition of relationism] . . . whether it be right or left, there is no difference in the relations of its parts to one another, the hand would in respect of this characteristic be absolutely indeterminate, i. e., it would fit either side of the human body, which is

[16]Nerlich (1976) [34].
[17]Kant (1768) [26], p. 32.

> impossible."

So, crucial is not that the hand fits *one particular* arm, but that the hand fits *only one* arm, no matter which. In this distinction we find the same opposition as in the two meanings of 'definite' alluded to above: Whereas the hand is not definite in its particular orientation, it is definite in having only one orientation and not both or neither, that is, in being enantiomorph. In a sense Earman's accusation of epistemic fallacy also hinted at this subtlety. Earman suggested that *knowing* which orientation a hand has is not important to the hand having orientation. Nerlich eventually reveals the essential deficiency in Remnant's position.

To reinforce the Kantian argument however, Nerlich also needs to argue for absolute space as a necessary part of any account of enantiomorphy. In contrast Earman had argued that absolute space by itself is useless in accounting for determinate orientations. He does not say that an account of enantiomorphy is not served with absolute space either, but this seems implicit. Nerlich in his reply invokes Kant (Kant (1768) [26], p. 27).

> "...the region towards which this ordering of the parts is directed [that is, the orientation of an object] involves reference to the space outside the thing; not, indeed, to points in this wider space — for this would be nothing else but the position of the parts of the thing in outer relation — but to *universal space as a unity* [emphasis added] of which every extension must be regarded as a part."

A few comments are in order. In the first sentence of the quote Kant accounts for determinate *orientation* by reference to absolute space, that is, Remnant's criticism that without reference to external space a lone hand has no orientation seems correct. In the second sentence Kant seems concerned mainly with the problem raised by Earman, namely that reference to space by itself is of no help, and with attempts to avoid it by reference to absolute space as a unity. Like Earman I find it hard to make sense of this suggestion. It seems best to suppose, with Earman, that Kant had in mind something like an oriented structure of space itself. But suppose we adopt Nerlich' reconstruction. In that reconstruction Kant is concerned with an account of enantiomorphy rather than orientation. To that aim the second sentence is indeed illuminating, as I will now show.

In order to understand the vague phrase of Kant about 'universal space as a unity', Nerlich appeals to rigid motions. In particular, he notes that enantiomorphy of a given object depends on the structure and dimension of space, as expressed in DEFINITION 17. Therefore universal space as a unity determines enantiomorphy. Nerlich further claims that the same determination cannot be given by a relationist, because the latter cannot satisfactorily express the requirement of orientability. He concludes that adopting absolute space is the only option. Note that Nerlich refers only to the emphasized phrase and not to the phrase before it, which is clearly about definite *orientation*. The fact that Nerlich only stresses the phrase about definite *enantiomorphy* may give cause to suspect that the real concern of Kant in fact escaped the attention of Nerlich. On the other hand, his reconstruction makes the argument of Kant look much more plausible.

Both Earman and Sklar disagree and argue that relationists are perfectly able to handle enantiomorphy. Sklar in his argument[18] appeals to *possible* relations and stuffs the otherwise empty universe with *possible* objects, so that orientability can be predicated of relational space and rigid motions can be confined to particular dimensions. Thus both orientation and enantiomorphy can be made intrinsic features. Yet these features, being based on possibilia, are quite obscure and even Sklar seems unwilling to get entangled in an elaboration. Nerlich comments that the features can hardly be called intrinsic when involving *relations* to possible objects[19]. Moreover, it is hard to see how possible objects can provide causal ground for enantiomorphy, that is, it is hard to see how they can answer the first question of Kant. Finally, I feel the relationism of Sklar does not stand out for elegance and simplicity.

A more detailed account of enantiomorphy is given by Earman[20]. He solves most problems in manner similar to the Kant of 1783, leading back enantiomorphy to observers and the way they represent objects spatially. The idea of Earman is that really incongruent counterparts differ themselves and that at the same time it is humans adding the particular orientation to an enantiomorph in observation. He further claims that this solution is neutral towards the debate over the nature of space. Most remarkable in the proposal of Earman is that he takes the relations of orientation like ‘left’ and ‘right’ as *internal* properties of a system. This at once solves a problem any relationist of today has to face, namely the violation of parity in certain subatomic processes.

In 1958 the Chinese physicist Wu discovered that certain physical systems behave differently from their counterparts[21]. That is, performing an experiment with K-mesons, as well as the mirror image experiment in the room next to it, led to quantitative differences in the results of the respective experiments. Spatial orientations can therefore be distinguished by a physical process in which parity is violated. Relationists however do not accept orientation per se and therefore cannot not handle these experimental facts. But to that aim Earman introduces the intrinsic property of orientation. Earlier on, in criticizing both Remnant and the 1768 argument by Kant, he had suggested that oriented properties were inevitable both in substantivalism and relationism in order to account for the reality to the difference between left and right. An intrinsic property of spatial orientation solves this latter problem as well.

Earman’s solution is relationist because eventually he attempts to reduce the intrinsic property of orientation to *modes of representing*. This move is very much Kantian in nature, for the reality of handedness is in a sense degraded to a reality in modes of representing again. Nerlich on the other hand finds Earman’s solution too much substantivalist in character because relations of

[18] Sklar (1991) [47].
[19] Nerlich (1976) [34], p. 258.
[20] Earman (1991) [11].
[21] Gardner (1989) [15].

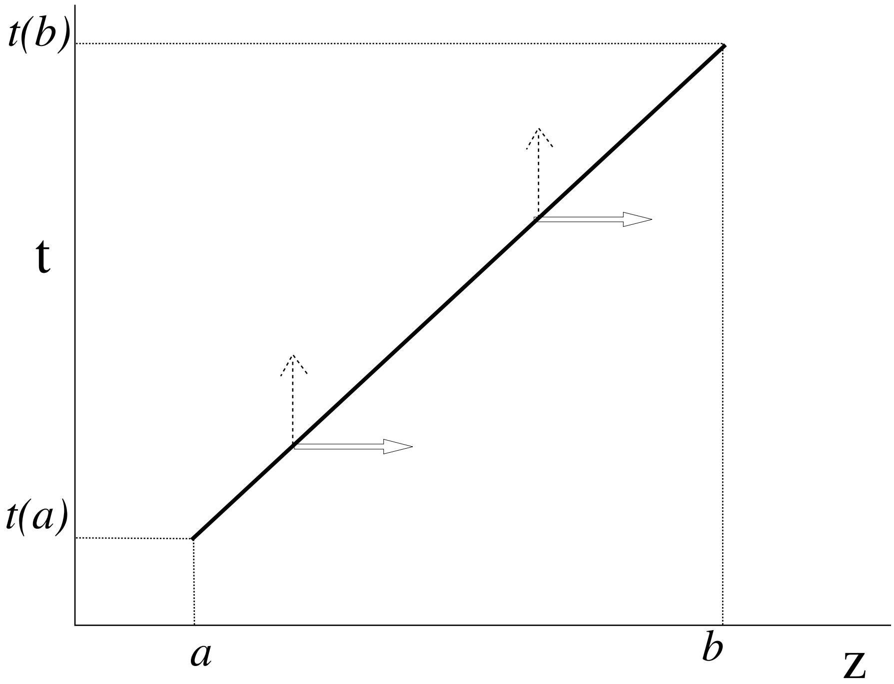

Figure V.4: A single process of an object moving from $z(a)$ to $z(b)$ in a particular orientation.

orientation are based on global intuitions of space[22] He further holds that by considering orientation to occur at the level of representation, enantiomorphy of lone objects as an ontological problem is still left unaccounted for. Earman, in the closing of his article, concedes that

> "...the accumulation of enough epicycles [to relationism] may cause one to loose interest in the theory."

Just like with Sklar's attempt and just like Earman thinks himself, I feel that the attempt of Earman has saved relationism at the cost of simplicity and elegance.

V.4 Consequences for processes

Obviously these final remarks do not settle the discussion. For present purpose however, the survey suffices, because it enables us to determine how the conclusions of the last two sections pertain to the enantiomorphy of processes. The

[22]Nerlich (1976) [34], pp. 260-2.

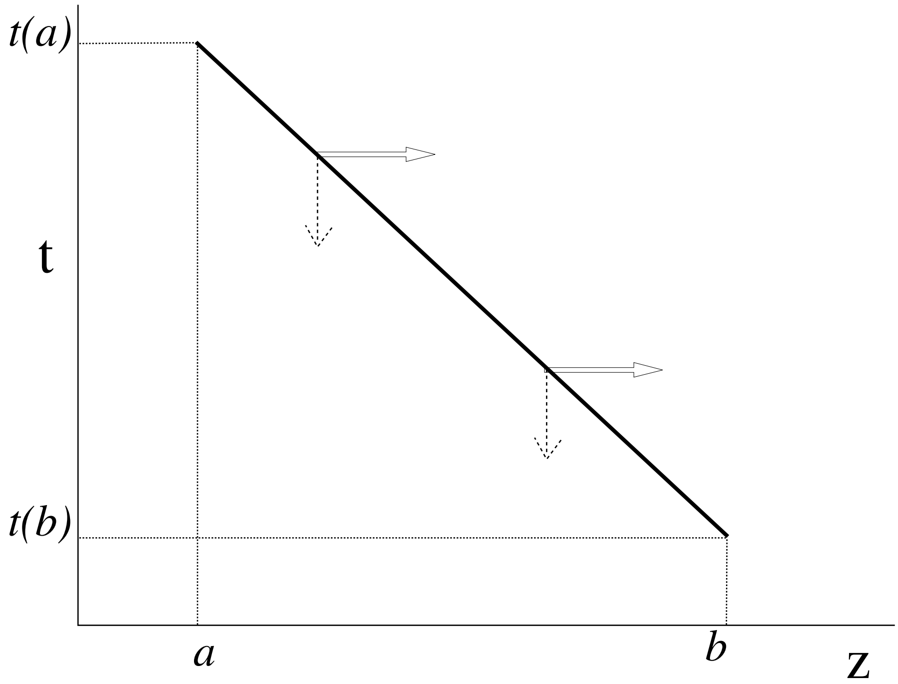

Figure V.5: A single process of an object moving from $z(b)$ to $z(a)$ in another orientation.

position of Remnant can be compared to that of Gold, because both judge orientation of single objects illusory and because both do this on relationist grounds. I take the present survey to indicate, not prove, that Gold must be wrong in the same manner as that Remnant was wrong: They both commit the epistemic fallacy and fail to see the subtle difference in being enantiomorph and having particular orientation. Other relationist authors such as Sklar and Earman can handle the 1768 argument and Nerlich' reformulation, but they must concede that orientation and enantiomorphy exist and are somehow intrinsic features. To any relationist the orientation and enantiomorphy of processes will therefore be existent and intrinsic as well. To substantivalists these features are implicit in entering processes in spacetime. Earman revealed that substantivalists also need an intrinsic property of orientation. In general then, the discussion shows that reductionism with respect to spatial orientations is wrong.

A last remark must be made concerning the 1783 problem implicit in the puzzle of Kant and the analogy with enantiomorph processes. Recall from the puzzle in section IV.2 that a state description needed something of an orientation because otherwise a process was not uniquely determined by it. It was this additional orientation that made the process into either of the incongruent counterparts. The orientation associated with states now seems to have a parallel in the discussion about enantiomorphy in space, namely in the intrinsic properties of orientation proposed by Earman. Just like an object is made either left or right by the intrinsic property of orientation of its constituent parts, a TA process is determined in the orientation of its asymmetry by the intrinsic property of orientation of its states. It seems that assigning orientation to time dependent features such as velocity is not as strange as expected, at least not when relying on Earman's analogous analysis of spatial enantiomorphy.

Velocity is naturally associated with the temporal orientation in which that velocity is on a par with our observations. This can be illustrated with figures V.4 and V.5 showing the two processes of figures IV.3 and IV.2 again. Processes in general are determined completely by a position, a velocity *and an orientation in which the velocity is to be understood.* The processes shown in the figures, which are reversals of each other, are distinguishable only by the orientation of the states, the element O in the state description. This orientation generates precisely the same kind of orientation of parts that Earman deemed indispensable to distinguish left and right hands. Here the orientation of states in the process makes for a distinguishability of oppositely oriented processes. Whether we are to consider states ontologically distinct because of differing orientations, is another question, depending on whether orientation of states is an element of reality or just an artifact of convention. That is, it can be that the orientation of states is of the same kind as the right hand rule for the Lorentz force, more like a rule of thumb than like a law of nature. Whatever the outcome of this issue, on grounds of this chapter it must be accepted that orientation of processes is an intrinsic property of processes.

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VI

Irreducible, inexplicable

Many of the controversies about time concern the oriented temporal asymmetries observed in nature. In this chapter I disentangle four questions about these asymmetries using the apparatus developed in the previous chapters, in particular the distinction between asymmetry and enantiomorphy. This will reveal three problems for reductionism towards the orientation of time and towards the orientation of processes in time. All problems will be laid out in the context of explanations of such asymmetries, the first dealing with requests for explanations, the second and third dealing with explanations themselves. The three problems are the problems that were announced in the introduction. Together they form the challenge to reductionists.

In the first section the attempt of Reichenbach to reduce the orientation of time to the entropy gradient will be discussed. It will be argued that his reductionism allows to answer a particular question (Q_1) but fails to appreciate an equally valid other one (Q_2). The disentanglement of questions is made explicit using an article by Sklar. In the second section attempts to explain the orientation of a process within physics by applying boundary conditions are considered in general terms. Section two also sums up the requirements for explanations that are relevant to these attempts. It will be seen that an answer to Q_2 requires boundary conditions to have orientation, in fact that no reasonable explanation of orientation can be given without making use of that notion. In the third section a problem with explaining OTA sets of processes will be considered. This problem flows from the problem elaborated in section VI.2. Further it prepares the discussion of the oncoming three chapters.

VI.1 Orientation cannot be reduced

In his Lectures on gas theory the Austrian physicist Boltzmann[1] speculated on reducing time direction to the entropy gradient. He imagined the universe to be in thermal equilibrium apart from small spacetime regions. In these regions the entropy fluctuated from its equilibrium value. Such a region Boltzmann called a single world. He wrote[2]

> "For the universe, the two directions of time are indistinguishable, just as in space there is no up and down. However, just as at a

[1] In the late nineteenth century Boltzmann in vain attempted to found the second law of thermodynamics in the underlying mechanisms. The solution finally came when he realized that his H-theorem was essentially statistical: at any time and in any temporal orientation the chances of increasing entropy are much larger.

[2] Boltzmann in Price (1996) [36], p. 26.

> particular place at the earth's surface we call 'down' the direction toward the centre of the earth, so will a living being in a particular time interval of such a single world distinguish the direction of time toward the less probable state from the opposite direction (the former toward the past, the latter toward the future)."

It is notable that Boltzmann considers indistinguishable the time directions for a universe, much like Gold considered such universes identical. I will consider this issue in dealing with Reichenbach.

Reichenbach read the suggestions by Boltzmann and set out to make them precise. In his book The direction of time he attempted to reduce the direction of time to entropic features of processes[3]. More precisely, he attempted to range all temporally directed features under the heading of a large scale TA with respect to entropy in this part of the universe. Examples of such directed features[4] are the fact that time seems to flow, that causes precede their effects, that we know more of the past than of the future and that the past seems determined while the future seems not. In general a feature f is directed when it is physically meaningful and when some OTA is defined by it. I will not go into the details of the reduction but confine myself to a definition that summarizes the relevant conclusion[5]. This definition is

> "The direction in which most thermodynamical processes in isolated systems occur is the direction of positive time."

That is, all directed features of processes that we associate with a particular orientation, say *positive* time, are taken to be principally in agreement with the entropy gradient in the region of the universe that we observe these processes. Our sense of orientation in time is similarly coupled to that gradient, so that we will never observe any directed feature of process in opposite orientation, in negative time. It is controversial whether Reichenbach succeeds in explaining all features in terms of entropy gradients, but that is not an issue here. At present the reductionism sketched here will be criticized conceptually.

In the article Up and down, left and right, past and future Sklar aims to typify what kind of reduction Reichenbach actually intends. First, he therefore discerns two types of reduction. The first he calls *epistemological*. It aims to base a notion in its constituents to which we relate directly. Any physical object for instance can be epistemically reduced to elementary sense data such as spots on the retina. The logical empiricism of Mach and Carnap. provides examples of this kind of reductionism. The second type of reduction Sklar calls *scientific*. It consists in identifying a notion with underlying entities and mechanisms. These latter entities and mechanisms must then be part of some scientific picture. As an example, water can be reduced to H_2O molecules with a certain mean kinetic energy. Sklar correctly argues that the reduction of Reichenbach falls under the latter type. Reichenbach intends to *identify* the direction of time with

[3] Reichenbach (1956) [37].
[4] cf. Reichenbach (1956) [37], pp. 19-24.
[5] Reichenbach (1956) [37], p. 127.

the direction of positive entropy gradient. He is not claiming that the epistemic access we have to orientation in time is most directly felt in our sense of the entropy gradient. He argues that the orientation of time can be identified with an orientation described in scientific terms.

Secondly, Sklar considers two possible analogies for the reduction of past and future. First he regards the opposition of 'past' and 'future' analogous to 'left' and 'right', and secondly to 'up' and 'down'. Both the oppositions of 'left' and 'right' and of 'up' and 'down' can be reduced scientifically to physical entities or mechanisms. Certain weak interactions involve parity violation and can thus be used to identify the opposition of 'left' and 'right'. The gradient of the gravitational field can obviously be used to identify the opposition of 'up' and 'down'. But there is a difference between these two scientific reductions. Whereas we adapt the references of 'down' and 'up' when the gravitational field alters, we do not swap the reference of 'left' and 'right' if, as Sklar puts it, some fairly substantial miracles changed the nature, in particular, swapped the parity of the weak interaction[6]. The case with 'left' and 'right' Sklar therefore takes merely as a contingent correlation between spatial orientations of objects and certain interactions. The difference between the two scientific reductions considered is that the reduction of 'left' and 'right' to parity violations does not at the same time provide an ontological basis for this distinction, whereas the reduction of 'up' and 'down' to the gravitational field does.

Sklar claims that a the reduction of 'past' and 'future' by Reichenbach is intended to provide such ontological basis. The feature of Reichenbach's reduction that Sklar wants to stress with this analogy, the fact that his reduction provides such a basis, is important for the oncoming argument and must therefore be made clear in more detail. In the case of 'left' and 'right' typical asymmetries in the universe, like that most people are righthanded, are not controlled by the parity of the weak interaction. Swapping that parity will not alter the fact that most people use their right hand for most tasks. The fact that we do so cannot ultimately be traced back to the violation of parity in weak interactions. By contrast, all asymmetries pertaining to 'up' and 'down' can eventually be traced back to the gradient of the gravitational field. The reduction Reichenbach that aims at is analogous to the reduction of 'up' and 'down' because Reichenbach wants to trace back *all* further asymmetry pertaining to past and future to the entropy gradient.

Two features thus characterize the reduction Reichenbach had in mind. First, temporal orientation and entropy gradient are *identified*. Secondly, any other directed feature is assumed to be ontologically based on this entropy gradient and consequently can be traced back to it. There cannot be any distinction between the orientations of time than that given by the entropy gradient, because if anything allows for a distinction of orientation it can be traced back to just the entropy gradient. Note finally that it is held possible that the orientations of the entropy gradients in separate spacetime regions oppose each other

[6]Sklar (1993) [48], p. 101.

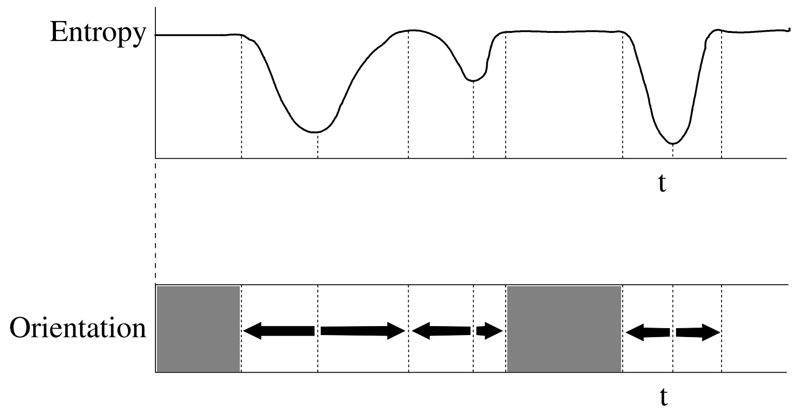

Figure VI.1: The entropy curve of some region of the universe.

globally. Reichenbach remarks that[7]

> "...whether time directions alternate, depends on the shape of the entropy curve plotted by the universe."

For a region with the entropy curve depicted in figure VI.1 for instance the time directions in separate regions of spacetime do not agree. It will be seen that the two features, together with the fact that the orientations of the entropy gradients can oppose each other globally, cause a problem for the reduction at issue.

As said, Reichenbach aims to reduce all directed features of processes by an appeal to an entropic TA. Such directed features define some OTA_f and must be physical, that is, describable using the tools of physics, because otherwise the feature falls outside the domain of relevance of Reichenbach's claims. The question Q, that physics wants to answer, can according to Reichenbach be reduced to question QR_1[8].

Q Why is the direction of feature f, observed in the TA_f process p, towards the future?

QR_1 Why is the direction of feature f, observed in the TA_f process p, on a par with the entropy gradient?

[7] Reichenbach (1956) [37], p. 128.

[8] In the literature the questions to be discerned below are posed mainly of OTA_f sets of processes. For simplicity I will here limit the scope to single TA processes.

But the reduced question Q_1 does not do justice to all aspects of direction questioned in Q. The 'future' can also refer to a particular extremity of spacetime that has been fixed beforehand. The reduction must then be:

QR_2 Why is the direction of feature f, observed in the OTA_f process p, towards this particular extremity of spacetime?

That questions QR_1 and QR_2 are not equivalent can be seen from the fact that the entropy gradients in separate regions of spacetime may oppose each other. By contrast, a particular extremity of spacetime is unique.

To make explicit the difference in the questions just disentangled, let us consider the following questions.

Q_1 Why is the process p temporally asymmetric with respect to a certain feature, or TA_f, irrespectively of its orientation?

Q_2 Why does the process p, being TA_f, have this particular orientation?

Question Q_1 asks to explain that the process p is asymmetric, or equivalently, enantiomorph, while question Q_2 asks to explain what orientation it has. Because entropy gradients do not naturally attach to any particular orientation, QR_1 cannot ask anything more than Q_1. The extremity of spacetime in QR_2 on its turn can be interchanged with the orientation that Q_2 asks for. Recall that in an orientable spacetime all TA processes, and all OTA sets, are enantiomorphs. The disentangled questions QR_1 and QR_2 thus relate to enantiomorphy and orientation respectively.

The problem in the reductionism of Reichenbach is revealed by the above separation of questions. Recall first that any directed feature in TA processes must be explained by the local entropy gradient. Gradients in separate regions however can oppose each other. Therefore the directed features of two processes can be physically TA in opposite orientations. This much is certainly granted by Reichenbach. Recall further that such processes are enantiomorph. The oppositely oriented processes exhibiting the directed feature to be explained, relate like left and right hands. By their opposite orientation they are structurally different. But Reichenbach equates time direction with the entropy gradient. Therefore the structurally different processes cannot be distinguished by their orientation in time. This is shown in figure VI.2, in which processes p and $\mathbf{R}[p]$ are shown. As the orientation is given by the entropy gradient, these reversal processes can by no means be distinguished. It seems that questioning the particular orientation of a TA process is impossible. Reichenbach can never ask Q_2 whereas, from the discussion in section V.3, this question concerns an intrinsic property of the process.

The following may help to understand the problem. Consider a TA process oriented to a particular end of spacetime. Depending on the entropy gradient in the region of the universe in which the process exists, it has for instance positive orientation. The process can now by rigid transformation be taken to another region of the universe, where the entropy gradient is opposite to the entropy gradient in the initial region. But because the process has been

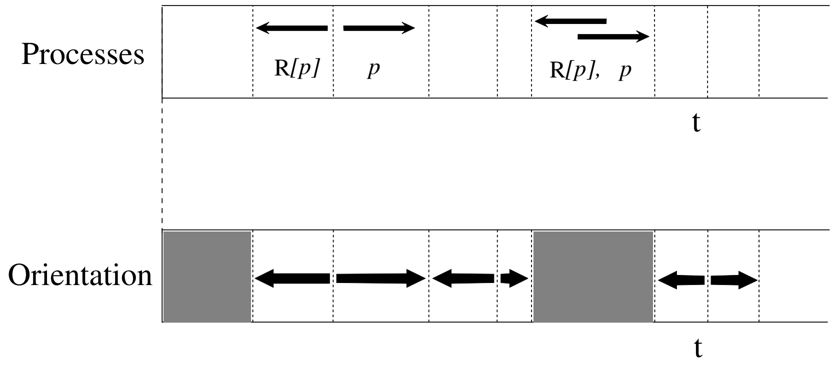

Figure VI.2: According to Reichenbach the processes p and $\mathbf{R}[p]$ have equal orientation. In fact they are oppositely oriented but they lie in regions of spacetime with opposite entropy gradients.

transported rigidly, it is nevertheless oriented towards the same particular end of spacetime. With the new entropy gradient the process will therefore have negative orientation. But, unless Reichenbach wants to say that our universe has a very special topological structure, this cannot be correct. The view of Reichenbach is comparable to the view that in a flat spacetime a left hand can still be turned into a right hand by taking it into another region, where the physical conditions, or possibly the laws, are different. But in flat spacetime such a transformation is impossible whatever the conditions or laws may be.

The problem for Reichenbach can be summarized with two separate arguments. Premisses are taken from Reichenbach himself and have been prepared in the discussion by Sklar.

U$_1$ The orientation in time of an OTA set of processes is on a par with the local entropy gradient.

U$_2$ Local entropy gradients can oppose each other globally.

$\Rightarrow$U The orientations in time of OTA sets of processes can oppose each other.

The conclusion follows from Reichenbach's reductionism with respect to all oriented asymmetries. It refers not to a consequence of convention, but to a fact of nature. Note however that in the previous chapter it was established that two OTA sets of processes with opposite orientations are structurally different. It is therefore to be expected that troubles will emerge from the conclusion.

U$_1$ The orientation of any OTA set of processes is always on a par with the local entropy gradient.

U$_3$ There is no way to discern orientations of time apart from the entropy gradient.

$\Rightarrow$ U' Orientations of OTA sets of processes in time cannot oppose each other.

Conclusion U' is in direct conflict with conclusion U. Therefore one of the premisses must be abandoned.

Reductionism is contained both in premiss U$_1$ and in premiss U$_3$. Both of them are established by Sklar's analysis of the kind of reductionism Reichenbach intends, stressing the analogy between 'past' vs. 'future' and 'up' vs. 'down', and that this reduction is an identification of entropy gradient with future orientation instead of epistemological foundation. Premiss U$_2$ is held by Reichenbach and moreover it seems unnatural to deny it for the sake of reductionism. If all premisses are to be upheld, the only possibility is to deny that orientations of OTA sets of processes refer to anything real. But in the previous chapter it has been argued that the distinction between oppositely oriented processes is structural.

There is no choice but to deny either U$_1$ or U$_3$. In my opinion it will not be of much help to deny only U$_1$, because then the orientation of time will be dependent still on the entropy gradient. Transforming a process to its incongruent counterpart by transporting a process to a region of spacetime with opposite entropy gradient will then remain possible. It seems much better to deny U$_3$ introduce an orientation of time apart from the entropy gradient. In Sklar's analogies, this will cause the reduction of past and future to be less like the reduction of up and down and more like that of left and right. The conclusion of the conflict between U and U' must be that reductionism fails. In terms of the questions discerned above, the conclusion is that answering Q by reducing it to QR$_1$ ignores that QR$_2$ is another valid reading of Q. Further it turned out that the reduction amounts to answering Q$_1$ but at the same time making it impossible to pose Q$_2$. Before turning to the other problem emerging from the distinction of Q$_1$ and Q$_2$, let me make a few remarks.

First, it can still be argued that the processes p and $\mathbf{R}[p]$ do not structurally differ. In that case premiss U$_2$ cannot be upheld so that the argument resulting in U cannot be performed. But we saw that such a position, championed by Remnant, was untenable in the debate about space. Secondly, the principle of precedence (PP) by Earman[9] drives at the same weakness in reductionism as the above argument. This principle states that time orientation, once defined, must overrule time orientations defined on the basis of other criteria or in other regions of spacetime. It flatly denies that local time orientations based on the entropy gradient can oppose each other globally. In fact the above contradiction is a motivation for adopting PP. Thirdly and most importantly, that reductionism causes oppositely oriented OTA sets $\mathcal{P}$ to be indiscernible stands to reason. It

[9] Earman (1973) [8], p. 22.

was already clear that incongruent counterparts in time were indiscernible by intrinsic features. Reductionism aims to catch all temporal features in intrinsic ones, so the orientation of an OTA set $\mathcal{P}$ is obviously lost in such a project.

VI.2 Only orientation explains orientation

In order to critically assess explanations of oriented temporal asymmetries it will be of use to characterize explanations in general. They will here be presented with a very general explanatory scheme more or less inspired on that of Hempel[10]. This scheme allows for both a causal and a unificationary picture of explanations. It is important to stress beforehand that I do not want to get involved in the intricate discussion on explanations themselves. The present discussion aims to show that problems emerge with reductionism on any reasonable account of explanations. The particular features of causality or unification do not matter to these problems. Only two requirements on explanations are of relevance for the present purpose. They will be presented after the general scheme has been given.

The simple model that will here be used discerns two common ingredients of an explanation, laws of nature and conditions to which they apply. Any explanation aims at explaining some fact or phenomenon, called explanandum, and consists in a set of facts that explains, called explanans. Typical members of the explanans are laws of nature and antecedent conditions that effect the explanandum. Apart from those two an explanans usually employs antecedent conditions. The schema of explaining some phenomenon can be summarized as an inference, or more losely, as a set of facts leading up to a fact that needs explanation.

L A law or a theory that governs the phenomenon.

C Particular antecedent conditions that effect the phenomenon.

A Auxiliary hypotheses.

⇒ E The phenomenon itself.

The law can be any law of physics L. Indeterministic laws are left out of consideration. The conditions can be fixed by any subset of possible states $\mathcal{S}$. The phenomenon can be any process, on itself or exhibiting a particular feature or leading up to some event. Examples are the explanation of a rainbow (E) by Snellius' law (L), the composition of sunlight and its refraction in water (C). Many more conditions can be cited, what the relevant conditions are may vary. An example of an antecedent hypothesis (A) that from a certain angle of incidence inside the raindrop the light is mirrored and not refracted. The process associated with E then is the propagation of light and the spectral decomposition.

[10] Hempel (1987) [22].

One of the requirements on explanations alluded to above is that the explanans must favour the explanandum over other facts that the members of the explanans pertain to. The explanans of a rainbow for instance cannot be correct if it explains the occurrence of a golden circle in the sky just as well. The explanation, in other words, must single out the fact that is the explanandum as the fact that it explains. This requirement is that the explanation must be satisfactory. We usually do not accept the promise of God after the Flood because it is not a *satisfactory* explanation of a rainbow. A second requirement is that an explanation must not, inherent to the explanatory scheme itself, hide any essential part of the explanation, that is, any member of the explanans must be explicit. If for instance the causal structure of some process is presupposed in explaining the orientation of the process, for instance in applying the conditions in a certain manner, and if that assumption is not made explicit, we say the explanation is not explicit.

Before plunging into the problems that arise from these requirements, it must be stressed that thus far no particular assumptions are made in the explanatory scheme presented. All explanations in the literature on the orientation of time and the asymmetry of processes can be fit in. The conditions can be given a variety of interpretations. To some authors conditions are particular antecedent causes of the asymmetry or orientation that is to be explained. The explanatory scheme is then interpreted causally. To other authors the conditions are simply restrictions to $\mathcal{L}$ to take care that the explanandum is in fact accounted for. Explanation is then interpreted as more of a deductive procedure. Both interpretations of the explanatory scheme given above are perfectly possible.

It will in the following be seen that the two requirements, minimal and intuitive as they are, create problems for reductionist explanations of the orientation of processes in time. These problems consider explanations of the orientation of a TA process. The problem emerges from the disentanglement of questions Q_1 and Q_2. The form of an explanation answering Q_1 for a TA process is as follows.

L A time reversal invariant law L as in definition 16 governs the process.

C A subset $\mathcal{C} \subset \mathcal{S}$ such that $\forall S \in \mathcal{C} : \ p = (S, L) \ \Rightarrow \ \text{TA}_f(p)$ gives all possible states at any instant for the particular process p.

$\Rightarrow$ E The process p is TA_f.

Statement L is held to avoid irreversibility, which most authors abhor. The conditions are postulated to occur at some instant and put a restriction on the set $\mathcal{L}$ of solutions to L. Usually the set $\mathcal{C}$ applies to some initial instant.

Recall the two disentangled questions Q_1 and Q_2. The explanation answers Q_1 because the explanandum E states that the process is TA. But the same explanandum does not state what orientation the TA process has, so question Q_2 remains unanswered. That is, the above explanation is not satisfactory as an answer to Q_2 and if it is, then that is because it is not explicit in all its members of the explanans. Yet Q_2 as a question cannot simply be disposed of, because in chapter V we saw that orientation of processes was a definite and real property of processes. Let us rephrase the question Q_2 as follows.

QP Why does p rather than $\mathbf{R}[p]$ occur?

It must be noted that this question has not often been asked in the literature. As said, some authors like Gold will judge it meaningless, but to most it is a meaningful question. Some authors again will judge it unanswerable. A reductionist like Reichenbach holds that we cannot, apart from the entropy gradient, distinguish particular orientations. He would therefore consider it impossible to determine whether we are part of process p or its counterpart $\mathbf{R}[p]$. Many authors however will just attempt to answer it.

An answer to QP will either invoke a particular feature of the law, or construct an auxiliary hypothesis, or adapt C. First, one can appeal to the time reversal noninvariance of the law, excluding the process $\mathbf{R}[p]$ from $\mathcal{L}$. But most authors find time reversal noninvariance unattractive. Many argue that this move introduces the notion of orientation to ontology and wield Ockham's razor against it. Secondly, one may construct an auxiliary hypothesis that excludes $\mathbf{R}[p]$, for instance by stipulating that the explanation is not applicable in a certain orientation. It seems to introduce orientation as a separate notion as it refers to particular orientation. Most authors prefer an appeal to conditions, adapting $\mathcal{C}$. Recall that processes p and $\mathbf{R}[p]$ are successions of states in $\mathcal{S}$, with $p = \{S(t) = S_i | t \in [0,1]\}$ and $\mathbf{R}[p] = \{S(1-t) = \mathbf{T}[S_i] | t \in [0,1]\}$. Excluding $\mathbf{R}[p]$ can be achieved by adapting $\mathcal{S}$ to incorporate all S_i but not all $\mathbf{T}[S_i]$.

It is crucial to the latter explanation that the states S_i and $\mathbf{T}[S_i]$ differ. From the discussion of section IV.2 however it will be clear that their difference is subject to controversy. To some authors the properties pertaining to change, attached to the states S_i and $\mathbf{T}[S_i]$, differ intrinsically. The time reversed states for instance show spatially opposite velocities. It is also possible that the states S_i and $\mathbf{T}[S_i]$ do not differ. To authors adopting this view the states S_i and $\mathbf{T}[S_i]$ do not differ intrinsically, but were differently oriented in time. But as I have argued with the puzzle in section IV.2, whatever view is taken on $\mathbf{T}$, some orientation of states will have to be assumed to make a distinction between reversal processes and predict only one of them and not the other.

So whatever the precise attitude towards $\mathbf{T}$, one thing stands out. Any discernment of the states S_i and $\mathbf{T}[S_i]$ hinges on an orientation of states in time. Restricting $\mathcal{C}$ to incorporate all S_i but not any of the $\mathbf{T}[S_i]$ cannot be done on any other criterion. An explanation that answers QP that employs conditions C and no laws or auxiliary hypotheses will thus contain the following condition.

C' A subset $\mathcal{C} \subset \mathcal{S}$ such that $\forall S \in \mathcal{C} : \; p = (S, L) \Rightarrow \text{TA}_f(p)$ so that p is orientable and $\forall\, t\prime < t : \; f(S(t\prime), p) < f(S(t), p)$, gives all possible states at a particular instant.

The requirement that the explanation is satisfactory, in this case that the explanation provides in that the asymmetry agrees with a particular orientation in time, makes for the above restriction on $\mathcal{C}$. Note that the additional restriction makes use of an independent notion of orientation, as it refers to the particular orientation of the time parameter. At any stage of the process to which the

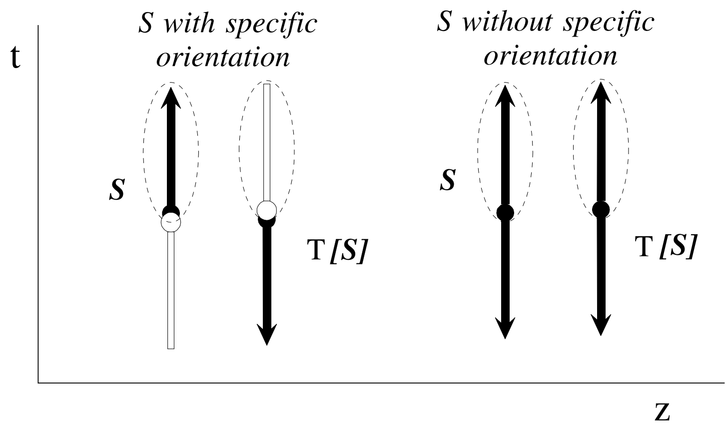

Figure VI.3: The process on the left has a condition that, reversed in time, results in another process over the relevant region of time. The condition of the process on the right can be reversed without any effect.

condition is considered to apply, also at the boundaries of the process, it is essential that the conditions are applied in the correct orientation. This can only be achieved when reference to such a particular orientation is made.

Note that in some cases the addition is superfluous. It can be that the asymmetry in f is such that the condition $\mathcal{C}$ that effects it, yields the same asymmetry of f in opposite orientation. Both the state S_i and its reversal $\mathbf{T}[S_i]$ then cause the observed asymmetry in both temporal orientations. This is exemplified in figure VI.3, in which both a condition that needs an orientation and a condition that produces the same asymmetry in both orientations of time are depicted. That this latter is not a mere technical possibility is seen from the entropic TA in the next chapter. A low entropy state that is not further specified microscopically will effect an increase in entropy towards any orientation. But in such cases where the addition is superfluous, it becomes crucial for the orientation of the process that is to be explained, at what stage of the process the condition is applied. If for instance condition C containing low entropy states is applied at the boundary of the process at which the entropy is highest, then that condition fails to explain the orientation completely. It even predicts the oppositely oriented process. So explanations for which the addition in C' is superfluous must contain an auxiliary hypothesis that fixes at which stage of the process the condition is to be applied. Otherwise they are not satisfactory or not explicit.

But what conclusion stems from these considerations? It seems anyone willing to answer QP can do so. Well, one can only do so by appealing to a particular orientation of time. Either one takes the law L to be applicable in one particular orientation, or one makes the set of conditions $\mathcal{C}$ specific for a particular orientation. Adapting a law is usually avoided because of the 'horror orientatio' alluded to above. But restricting $\mathcal{C}$ forces one to make reference to particular orientation after all! If the reference to orientation turns out to be superfluous, this is only because in fact an auxiliary hypothesis is needed that employs orientation. It thus seems that the orientation of processes, because of their being enantiomorph, cannot be accounted for unless an appeal is made to particular orientations of time and thus to orientation as a basic notion. There are no explanations using intrinsic properties that explain the orientation of a process but those that employ orientation itself.

VI.3 Consistent orientation

In this section I want to prepare the problem that will be elaborated in the next three chapters. It concerns attempts to explain OTA_f sets of processes, as undertaken by Reichenbach, Zeh, Davies, Price and many others. These explanations answer a separate question, namely

Q$_3$ Why is the set of processes $\mathcal{P}$ oriented temporally asymmetric with respect to the feature f?

Note further that an OTA set of processes has a particular orientation in spacetime. Just as with TA processes it comes in incongruent counterparts. Explaining the particular orientation of an OTA is again a separate question.

Q$_4$ Why is the OTA$_f$ set of processes $\mathcal{P}$ oriented towards this particular extremity of spacetime?

These questions are closely linked to questions Q$_1$ and Q$_2$ dealing with single processes p respectively. The difference between the questions is clarified in figure VI.4.

With respect to question Q$_3$, explaining that all processes are TA with respect to some feature f is not enough to explain an OTA with respect to this feature. It also must be explained that the TA$_f$'s are consistently oriented, that is, that they are all oriented towards the same extremity of spacetime. The explanatory scheme of the previous section, with condition C, can easily be extended to explain the fact that all processes in some set $\mathcal{P}$ are TA$_f$, as in figure III.7.

L A time reversal invariant law L as in DEFINITION 16 governs the process.

C A subset $\mathcal{C} \subset \mathcal{S}$ such that $\forall S \in \mathcal{C} : \ p = (S, L) \ \Rightarrow \ \text{TA}_f(p)$ gives all possible states at any instant and for any process in the set $\mathcal{P}$.

$\Rightarrow$ E The set of processes $\mathcal{P}$ is OTA$_f$.

But the consistent orientation of this TA set $\mathcal{P}$, as in figure III.8, is not explained with the above scheme. To that aim the scheme can be adapted, using C' instead of C, or extended with an auxiliary hypothesis.

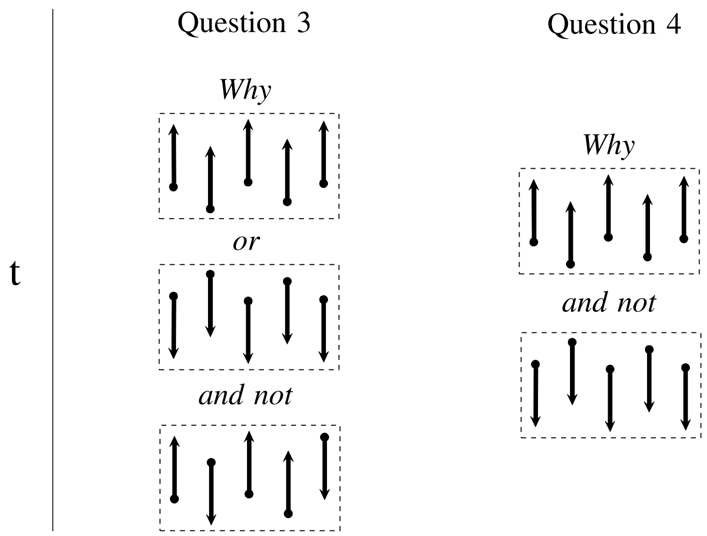

Figure VI.4: Questions Q_3 and Q_4 illustrated with spacetime diagrams. Whereas Q_3 concerns the consistency of orientation of processes, whatever their particular orientation, Q_4 deals with the particular orientation of such an oriented set of processes.

A Any hypothesis taking care that the TA_f processes p making up the OTA_f set $\mathcal{P}$ have consistent orientation.

This hypothesis must somehow stipulate that all $p \in \mathcal{P}$ are consistently oriented.

Note that invoking C' to assure consistent orientation makes reference to orientation as a basic notion, for otherwise the sets $\mathcal{S}$ and $\mathbf{T}[\mathcal{S}]$ cannot be composed. Moreover, in practice it appears not at all easy to construct an auxiliary hypothesis that orients the TA processes consistently without invoking the same basic notion of orientation, an orientation attached to spacetime itself. Chapters VII and VIII will illustrate this point, because time and again it will turn out that explanations answering Q_3 make use of such oriented auxiliary hypotheses. It therefore seems that reductionism faces a third problem, albeit a practical problem in physics. It is that Q_3, which is one of the major questions concerning temporal asymmetry, is hard to answer without employing orientation as a basic notion.

For later purposes it is important to notice that reference to orientation in order to ensure consistent orientation of processes is not the same as reference to a particular orientation. These must be distinguished sharply. Just like the statement that some universe contains five hands with equal orientation does not yet involve telling whether they are all right or left, it does not necessarily involve reference to particular orientation to explain that processes in some region of spacetime all have equal orientation. Obviously this hold just when the orientation in time of us observers is not taken as particular orientation. The orientation of observers must be defined to be identical with the orientation of the processes to be explained, because only then the orientation of the processes is not made particular by the way in which they relate the observers. In assessing Price's objections concerning the double standard fallacy in sections VII.4, VIII.3 and IX.1, it will turn out that the distinction drawn here presents a particular problem to the mentioned objection.

Finally let us return to the problems for reductionism. For a reductionist towards orientation of time reference to orientation as a basic notion, even when employed only to ensure consistency of orientation, is a problem because his reductionism aims to dispose of the notion of orientation period. Reference to particular orientation obviously presents a problem for a reductionist as well. With respect to question Q_4, it is more closely linked to Q_2 than Q_3 is to Q_1 and it is even equivalent with it if we view the universe as one single process. In chapter IX the problem with Q_2 that was elaborated in the previous section will be identified in cosmology. In sum, the next three chapters are devoted to an identification of two problems for reductionism laid out in this chapter, namely that explanations of particular orientation must employ orientation as a basic notion and that explanations of consistent orientation strongly invite reference to orientation.

VII

Thermodynamical asymmetry

In the previous chapter it appeared that the only acceptable way to explain the orientation of a process was to appeal to an orientation in the antecedent conditions. It was also put forward that many explanations of consistent orientation of OTA sets of processes employ orientation in either conditions or auxiliary hypotheses. It was argued that such appeals are against the common strand of reductionism. In the next chapters three OTA's will be examined within physics, in particular the explanations that physics gives to answer questions Q_3 and Q_4. It will be seen that many explanations are either not satisfactory or not explicit, certainly those answering Q_3. Special attention will be payed to the ideas recently put forward by Huw Price in his book Time's Arrow and Archimedes' Point[1]. His reductionist position will turn out particularly vulnerable to the problems elaborated in chapter VI.

The present chapter is devoted to thermodynamical asymmetry. The first section contains a sketch of this asymmetry as well as some historical background. I will then deal with Reichenbach's branch hypothesis in the second section and argue that it suffers serious yet surmountable deficiencies. To this I will add a brief discussion of the thermodynamical asymmetry on cosmic scale. In the third section I will deal with the view of Price on the asymmetry of thermodynamics. It will be seen that his position is liable to confuse Q_3 and Q_4. Further criticisms are postponed until chapter IX.

VII.1 Improbable history

Before turning to its explanation, a clear account of the OTA of thermodynamics is required. For later purposes some historical facts will be presented as well. The thermodynamical asymmetry is expressed in the *second law* of thermodynamics. This law states that the entropy E of an isolated system never decreases during any thermodynamical process in a particular orientation of time. That is,

$$\Delta E \geq 0. \qquad \text{(VII.1)}$$

The second law makes a set $\mathcal{P}$ that is submitted to it globally OTA, because all processes in the set will show an asymmetry with respect to the feature of entropy in the same orientation of time. Because the entropy E may remain constant the orientation is not always local. It is important to note that equation VII.1 expresses a law in the theory of thermodynamics. This makes the theory of thermodynamics time reversal non invariant. But thermodynamics is a theory

[1] Price (1996) [36].

about macroscopic phenomena. The microscopic mechanisms underlying these phenomena are governed by other theory, mainly by electrodynamics. Whereas thermodynamics itself is time reversal non invariant, the underlying theories are not. Therefore it is sometimes said that the OTA of entropy is not lawlike.

There has been much controversy over the relation between the second law, with its asymmetric consequences, and the laws underlying it. Boltzmann repeatedly attempted to reduce the former to the latter. His first try was a derivation of the H-theorem in 1872. According to this theorem the quantity H, defined in terms of the microscopic state of a system, decreased in any evolution. Boltzmann identified $E = -H$. Yet the theorem was paradoxical because it described irreversible processes but based them on reversible mechanisms, and in 1876 Loschmidt launched the Umkehreinwand to criticize it. In the argument Loschmidt imagined the reversal of the velocities of all individual particles in a system with decreasing H and concluded that in the reversed system H would *in*crease. Thus there were systems that violated the H-theorem, but that were permitted by microscopic laws. The reduction of Boltzmann had not succeeded. It was later revealed that the derivation indeed contained asymmetric assumptions. In particular Boltzmann utilized the so-called Stoßzahlansatz, which states that velocities of particles are uncorrelated before they collide.

Boltzmann set out to repair his derivation. In 1877 he came with a version that was based on statistical considerations: It is not necessarily so that E increases in a unique temporal orientation, it is rather *highly probable* that E increases in *any* temporal orientation. The reason he gave was that low entropy states correspond with much less microscopic states than high entropy states. A process that is initially in a microscopic state corresponding to low entropy, when evolving arbitrarily, will very probably lead to a microscopic state corresponding with higher entropy, simply because of such microscopic states much more are available. This probabilistic fact is illustrated in figure VII.1. Note that the high probability for increasing entropy holds for both orientations in time. After all, statistical reasoning can never discern orientations in time. But just the complete symmetry of Boltzmann's argument had some unwelcome consequences. Most notably, following his reasoning it appears ultimately improbable that history has occurred as we think it has. Applying the argument of Boltzmann backwards, history as we know it requires a very improbable decrease in entropy towards that temporal orientation.

The quote of Boltzmann in section VI.1 however can be read as an answer to this problem. History, according to the quote, is the result of a large entropy fluctuation in our region of spacetime. Reichenbach elaborated this position in his *branch hypothesis*, mainly to explain how the OTA of the surroundings is grounded in the larger fluctuation[2]. Consider a glass of water with an ice cube, standing in the kitchen. The most probable history is that the cube was formed by temperature fluctuations in the glass, but obviously this is not what happened. The ice cube was presumably taken from the fridge and put in a glass with water. Reichenbach calls this phenomenon *branching*: A system of

[2] Reichenbach (1956) ([37], pp. 117-43.

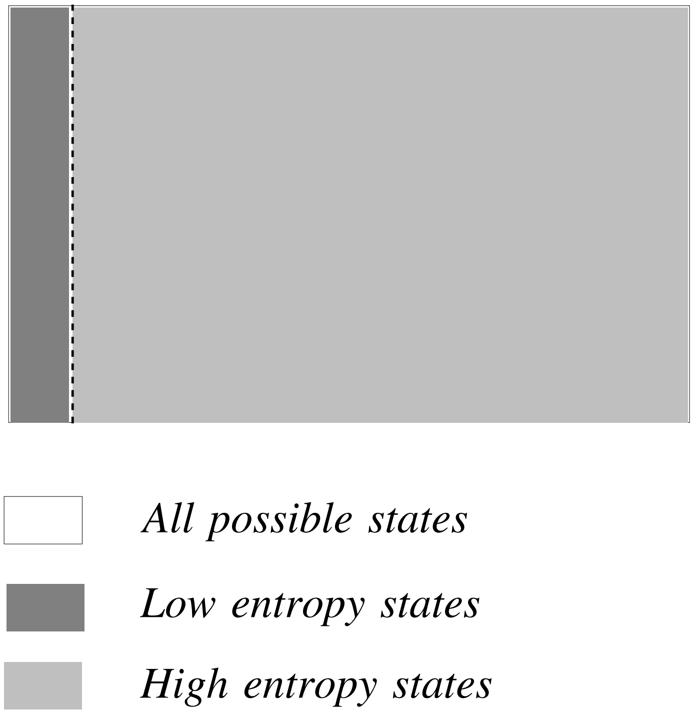

Figure VII.1: The figure shows the space of all possible microscopic states $\mathcal{S}$ of some system. If we assume that the evolution of the system is completely mixing within finite time, the probability for high entropy is proportional to the area of the high entropy part of $\mathcal{S}$. This holds both before and after the system is in low entropy.

low entropy (ice cube and water), originally part of the larger system (kitchen), is taken in isolation. The entropy gradient of the larger system then becomes visible by the entropy increase in the branched process, which is divided off at low entropy. The branched process may be absorbed again at high entropy. Essential is that the entropy is low when branching. Thus Reichenbach explains the OTA of surrounding processes with the branching from the entropy slope that we live on: From the branching onwards every process has increasing entropy.

VII.2 Lopsided branching

Before turning to Q_4 I will consider Reichenbach's branch hypothesis as an explanation answering Q_3. It will turn out that Reichenbach fails, because he is unable to fix the orientation of branched TA processes. The resulting set of TA processes is therefore not oriented. It turns out that the explanation

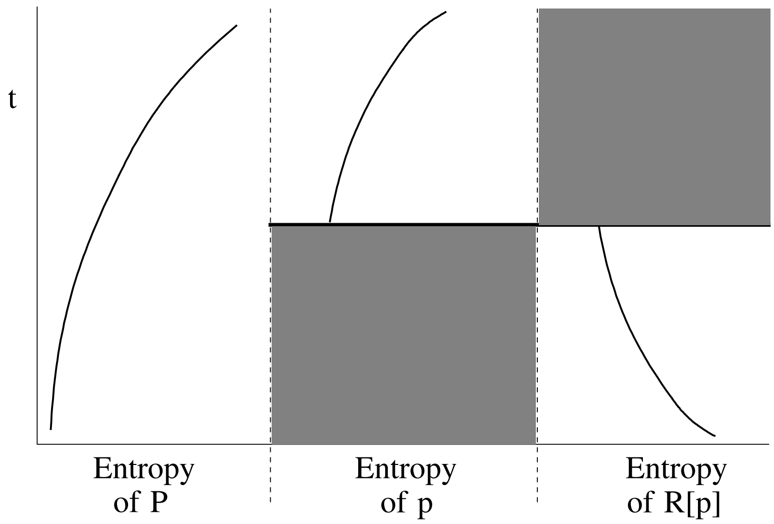

Figure VII.2: Oppositely oriented processes branching off from a larger system P.

Reichenbach offers must be supplied with an auxiliary hypothesis, which will have to make reference to orientation. In the present discussion of the branch hypothesis I have made unmentioned use of the expositions by Davies, Horwich and Reichenbach[3].

First note that a branched process need not return to the original system. The glass of water may be taken from the kitchen, never to return. So a process is not fixed both in its low and in its higher entropy state, rather in a single state that is comparatively low[4]. Note further that in both orientations of time the entropy will increase from this state onwards, comparable to the process shown on the right side of figure VI.3. The orientation of the TA process that branches off therefore depends on the temporal orientation in which it continues after branching. In figure VII.2 this is shown schematically. Both p and $\mathbf{R}[p]$ present possible branched processes. The process p is exemplified by the usual story about the ice cube, the process $\mathbf{R}[p]$ by the unusual story that after bringing a glass of water into the kitchen, an ice cube forms, which is then put in the fridge. The forming of the cube would in the latter case, in the figure represented by the process $\mathbf{R}[p]$, be explained by the branching *later on*. Nothing prevents this possibility, so it must be concluded that branching on itself is not enough to explain the consistent orientation of thermodynamical processes. That is,

[3]Davies (1977) [5], pp. 68-78, Horwich (1987) [23], pp. 59-76 and Reichenbach (1956) [37], pp. 108-43.

[4]Clearly Reichenbach succeeds to answer question Q_1, because with a fixed low entropy initial state all processes will be entropically TA.

branching fails to answer Q$_3$

Recall that the initial states S_i in $\mathcal{C}$ together with the law L determine the process $p = (L, S)$. In the usual cases L describes the Hamiltonian evolutions, which is time reversal invariant, and it seems incorrect to introduce an asymmetry of the Hamiltonian evolution to explain the consistent orientation at issue. The branching hypothesis can be made to work by restricting $\mathcal{C}$, as was done in C' of section VI.2. In whatever temporal orientation the branched process continues, it can then be arranged that all branched off TA processes are oriented on a par with the original TA system. Another possibility to fix the orientation of the branched process to be consistent is to invoke an auxiliary hypothesis. We may stipulate that the branched process always continues towards the orientation of the positive entropy gradient. In effect, condition are then exclusively applied to one particular temporal end of the branched process. In fact, Reichenbach himself may have had this view[5]. But whatever solution is chosen to make the branching hypothesis work, one thing stands out. Any solution makes reference to orientation as basic notion. The reductionistic attitude of Reichenbach is thus proved mistaken.

The refinement of Grünbaum that the possible initial states of branched processes be randomly distributed over all states compatible with the initial entropy is not a solution to this problem[6]. It can only certify that from the branching onwards the entropy of the branched system will increase in either temporal orientation. This was already implicit in Reichenbach's stipulation that the branched process can be regarded as a segment in the evolution of an arbitrary, perpetually isolated system, because by far the majority of such systems with some low entropy E_l are precisely in a local infimum of E. So Grünbaum must also reside to lopsided branching. Note further that a truly symmetric branch hypothesis is that every branched process eventually gets absorbed and that the random Reichenbach-Grünbaum state obtains at both temporal ends of branched processes. But then we are left with terribly improbable occurrences at the higher entropy end of every branched process. But here is not the place to solve this additional difficulty.

Reichenbach in part motivated the branch hypothesis with the improbable history problem: Branching explained the occurrence of low entropy states at the outset of processes and avoided the strange consequence of Boltzmann's analysis that every initial state was the result of a fluctuation. But many authors (e.g. Davies, Horwich, Hawking) hold that such fluctuations do not occur anyhow and that the universe has only one entropy gradient with unique orientation. An alternating gradient is held impossible because of cosmological conditions, that is, the universe as a whole is taken such that entropy increases towards one end. Other authors (e.g. Zeh, Price, Gold) maintain that the entropy increase is linked to the expansion of the universe and that in the contraction phase the entropy gradient may well be opposite. They abandon fluctuations as well. Yet in answering question Q$_3$ all authors will have to deal with the problem raised

[5] Although I find his formulation unclear, I think Horwich hints at the same asymmetric assumption in Reichenbach in Horwich (1987) [23], pp. 68-70.

[6] Grünbaum (1963) [18].

above, while all invoke branching to account for the consistent orientation of processes[7]. The problem with the branching hypothesis is therefore not typical for Reichenbach's position, it applies across the board.

VII.3 The orientation of entropic asymmetry

The issue of question Q_4 is a separate one. It will here be discussed very briefly, in fact only repeat the problem elaborated in section VI.2. This problem was that the orientation of a process p cannot be explained by anything accept by referring to a particular orientation and thus to orientation as a basic notion. Now the problem applies not to a single process p but to regions of the universe in which an OTA of entropy occurs. If it is assumed that the entropy gradient in the universe cannot swap orientation, the problem applies to universes as a whole. It is then identical to Q_2. But the central issue of the problem remains the same, namely that a reductionist will not be able to explain orientation.

Two moves can again fix the orientation of an OTA set of processes in some region of the universe, or a TA universe as a whole. First one can restrict $\mathcal{C}$ such that the entropic asymmetry is oriented to a particular temporal end of spacetime. The condition $\mathcal{C}$ then depends mainly on the time of application and on particular the orientation of the allowed states $S \in \mathcal{C}$ in time. Secondly one can stipulate that the unrestricted set of low entropy states $\mathcal{C}$ is applicable only at a particular temporal end of spacetime. In that case there is no need for an appeal to the orientation of states. An appeal to some orientation however seems unavoidable, certainly when an explanation is required for the condition itself or for its restricted applicability, its being applicable at a particular end and not at the other. In chapter IX I will return to cosmological considerations explaining these conditions and deal with the mentioned authors in more detail.

Let me summarize the results of the discussions on Q_3 and Q_4. In the previous section two explanations to conclusively answer question Q_3 about the entropic OTA have been treated. To answer Q_3 one can either invoke the auxiliary hypothesis of lopsided branching, or one can restrict C to entail asymmetric processes. Both solutions employ orientation as a basic notion. As said, the use of orientation as basic notion is not unavoidable, yet in practice most explanations in physics will make use of it. In the next section it will argued that an explanation for the OTA of entropy can be given without making reference to orientation at all. Question Q_4 was briefly considered in this section. It was claimed that the notion of orientation is indispensable in answering it, like it was argued to be indispensable in section VI.2.

[7] Presumably all maintain that branched processes must eventually be absorbed, thus taking care that the branched process has conditions at both temporal ends, but none of them is explicit about this.

VII.4 Confusing questions

Price raises a particular problem in explanations of several OTA's. He calls it the *double standard fallacy*. For the thermodynamical asymmetry I will argue that his objection invites confusion over the questions Q_3 and Q_4. Most authors do not attempt to answer question Q_4. The objections of Price are unfair in so far as they take the attempts to answer Q_3 as attempts to answer Q_4. They are even more unfair because Price himself judges unimportant question Q_4. This latter claim will first be argued for.

In his recent book[8] Price states that the real puzzle of the OTA of entropy is the low entropy in the past, not the fact that it increases towards the future[9]. It is clear from several remarks that the puzzle to be solved is the entropy being low in the past *irrespectively of the orientation the past has to us*. He writes[10]

> "... *the* major task of an account of thermodynamic asymmetry is to explain why the universe as we find it is so far from thermodynamical equilibrium, and was even more so in the past. (We should bear in mind that we have found no reason to doubt Boltzmann's anthropic hypothesis—viz., that the fact that we regard the temporal direction concerned as the past is itself to be explained in terms of the low-entropy condition of that region.)"

It is implicit in Price's remark on Boltzmann that the word 'past' is here not meant to denote a particular temporal end of the universe. It is meant to denote any temporal end of the universe as opposed to another. The task of an account of thermodynamics according to Price is therefore to answer question Q_3, to explain the oriented asymmetry of thermodynamics irrespectively of the particular orientation in which the asymmetry lies.

But attempts at such explanations answering Q_3 are repeatedly met with the objection that no cause is cited or reason is given to expect the asymmetry towards one end of the universe instead of towards the other. For instance, Price holds that nothing in particle mechanics provides reason to adopt the Stoßzahlansatz towards the future and not towards the past. When the fact that the velocities of particles are uncorrelated *before* interaction is added to the description of these interaction, Price complains that it is unfair to add such a particular orientation. But really the Stoßzahlansatz is not meant to add *orientation*, rather it is meant to add *asymmetry* in no matter what orientation. It serves in an answer to Q_3, not to Q_4. Once the Stoßzahlansatz is taken as explicitly asymmetric condition in an explanation answering Q_3 the objection of Price looses its force because in that case there is no talk of any orientations.

That Price not always separates the questions Q_3 and Q_4 is most clear from his criticism on Prigogine and his adherents[11]. He intends this criticism to apply

[8] Price (1996) [36], pp. 22-49.

[9] It has been remarked by K. Ridderbos (Ridderbos (1996) [40]) and others that in fact the increase of entropy *does* pose a problem. It appears very difficult to define entropy in such a way that it changes in the Hamiltonian evolution.

[10] Price (1996) [36], p. 36.

[11] Price (1996) [36], pp. 43-4.

to all attempts at explaining time asymmetry, that is, answering Q_1 or Q_3, with nonlinear dynamics or comparable technical work. Price proposes to confront advocates of such attempts with a kind of reversibility objection.

> "...we describe an example of the kind of physical system to which the new method is supposed to apply, specifying its state at some time t. We then ask our opponents to tell us the state of the system at another time, say, $t+1$, *without being told whether* $t+1$ *is actually earlier or later than* t ...If our opponents are able to produce an answer without this extra information, then their theory must be time-symmetric, ...[if not], this can only be because at some point their theory treats the two directions of time differently."

The last claim is correct but the preceding one is not. Surely there are ways to generate asymmetry from some t onwards into any orientation. When the state at t is given by some suitably chosen $\mathcal{C}$, making no use of any orientation, asymmetry into both orientations can be generated. For example, recall the puzzle of section IV.2. If no orientation is added to the state descriptions but if it is stipulated that only one of the pair of oppositely oriented states is realized at t, time asymmetry without any particular orientation is seen to follow. Price is incorrect in claiming that a theory cannot explain a TA process or an OTA set of processes without at the same time making reference to a particular orientation in which it shows this asymmetry.

Price is correct however when he presents the objection to show that a theory cannot give *oriented* results unless the orientation is fixed in advance. For indeed a theory cannot fix or explain the orientation of a process without making reference to orientation as a basic notion. Moreover, such references to orientation indeed show a double standard, because no reason can be given for choosing one orientation and not the other. With the double standard fallacy Price can therefore legitimately criticize the attempts by Prigogine and others on their inability to foundate *orientation*, that is, to answer Q_4. But this is not at all aimed at in those attempts. In sum then, the double standard fallacy applies not to all attempts to answer Q_3, because this question can in principle be answered without reference to particular orientation. The double standard does apply to attempts to answer Q_4, but there it is unavoidable.

Note that it was to be expected that the double standard fallacy would be applied to attempts at answering Q_3. In section VI.3 it was already argued that many attempts to answer Q_3 could only be made to work when supplied with an additional restriction on the condition C or an auxiliary hypothesis. Although this was not deemed necessary, both these additions were liable to make use of orientation as a basic notion in order to ensure the consistent orientations of TA processes in the OTA set. The explanation using branching for instance could only be made to work with the help of some additional hypothesis using orientation. In light of the references to orientation in answers to Q_3, Price's criticisms are understandable. Recall however that reference to orientation in order to ensure consistent orientation of processes is not the same as reference to a particular orientation, just like the statement that some universe contains five hands with consistent orientation does not yet involve reference to left or right. So even when an explanation answering Q_3 employs *consistent* orientation, no reference needs to be made to any *particular* orientation.

Then again, it may be that Price asks for an explanation of the asymmetry itself. Possibly that is what the double standard fallacy aims at. Price's complaint then is that such an explanation of time asymmetry only restates the original asymmetry. In his discussion of Horwich for instance, this becomes apparent. The condition Horwich proposes is that in the past there were no microscopic correlations, which he calls *initial micro chaos*, while at the same time the distribution of matter was ordered. Horwich openly states that this condition is asymmetric. Microscopic correlations are considered to grow from the initial state onwards and the orderly distribution of matter are considered to grow into disorder. Price argues that[12]

> "... [Horwich' explanation] is just the requirement that the initial condition not be correlated in such a way that entropy decreases in the future. There is no explanation in the offing here, but only another way of describing what was thought to require explanation."

I think this objection is correct but just as unavoidable as the use of orientation in explaining orientation. Some asymmetry must be assumed to reproduce the time asymmetry of the processes. It can be said that just like orientation, asymmetry is explained only by asymmetry[13].

[12] Price (1996) [36], p. 42.

[13] As Zeh (1989) [58], p. 32, remarks in a footnote, reducing the entropic asymmetry to an asymmetry in particle mechanics is not trivial. This may be reason to ascribe explanatory force to the reduction of Horwich after all.

VIII

Asymmetry of radiation

In this chapter the asymmetry of radiation will be considered. In the first section I will make explicit the OTA of radiative processes in physical terms. A particular boundary condition needed to explain this OTA is then considered and seen to pertain to orientation as a basic notion. In the second section I will treat an alternative to this boundary condition that is on itself not oriented in time. It will be seen that this alternative is only able to explain observations under particular extra conditions. In the third section various attempts to explain the boundary conditions and its asymmetry will be discussed. It will be seen that any boundary condition ensuring consistent orientation of radiative processes is oriented. Other explanations involve auxiliary hypotheses in which reference to orientation as basic notion is made. In the fourth section the position of Price is discussed. His boundary condition will be presented as part of an alternative to the Wheeler-Feynman theory. It will be shown that this condition is insufficient. It will also be argued that his accusation that other authors have double standards is flawed.

VIII.1 Retarded potentials

This section deals with the radiative OTA in the usual way. First classical electrodynamical waves are briefly spelled out, after which the Sommerfeld condition is presented. This condition accounts for the asymmetry of radiative processes. In the next section the alternative by Wheeler and Feynman is presented. For the theory in this section, and in the next, there has been made use of the expositions of Zeh, Jackson and Davies[1]. I will limit the treatment to the most basic formulas and some discussion about justifying the conditions.

Waves are temporally asymmetric processes. This is apparent from the fact that wave patterns are *expanding*. That is, the extension of a wave is a feature of the process of a wave that increases monotonically in time. The radiative process p is therefore said to be TA with respect to the feature of extendedness. Further, the set of TA processes of radiation form an OTA set. This can be seen from the fact that waves patterns always expand towards the same temporal end of spacetime, namely towards the future. This oriented asymmetry, it must be noted, holds for water waves in a pond and for electromagnetic waves. Now the fact the set of radiative processes is OTA with respect to extendedness requires explanation. In the following attempts at explaining just this OTA of radiation will be considered.

[1] Zeh (1889) [58], pp. 12-21, Jackson (1975) [24], pp. 223-6, and Davies (1977) ([5], pp. 112-20, pp. 127-30).

In general an explanation of the radiative asymmetry will conform to the scheme presented in section vi.2. Such an explanation cannot employ a time reversal noninvariant law. The law governing these waves is time reversal invariant, namely

$$\partial^\nu \partial_\nu A^\mu(\vec{r}, t) \;=\; -4\pi j^\mu(\vec{r}, t), \tag{VIII.1}$$

with $c = 1$ fixed. Note that the wave equation (VIII.1) can be derived from the Maxwell equations and that these are time reversal invariant as well. The invariance is therefore deeply embedded in electrodynamics. There is another way to see that the theory of electrodynamics is invariant under time reversal. For any allowed radiation process p the reversal $\mathbf{R}[p]$ must be allowed as well, because transformation $t \mapsto -t$ causes $\partial^0 \mapsto -\partial^0$ and $\partial_0 \mapsto -\partial_0$, so that $(-\partial^0)(-\partial_0) = \partial^0\partial_0$. Transforming positive to negative time thus has no consequences for $\mathcal{L}$.

Equation (VIII.1) has a class of solutions. Such a class can be characterized by a special solution and a class of solutions to the homogeneous variant on equation (VIII.1), for which $j^\mu(\vec{r}, t) = 0$. Two special solutions can be constructed. These two special solutions are associated with the influence of sources being either on the forward or the backward lobes of the light cones, along which all electromagnetic influences are carried.

$$A^\mu_{\text{ret}}(\vec{r}, t) \;=\; \int \frac{j^\mu(\vec{r}', t) - |\vec{r} - \vec{r}'|)}{|\vec{r} - \vec{r}'|} d^3\vec{r}', \tag{VIII.2}$$

$$A^\mu_{\text{adv}}(\vec{r}, t) \;=\; \int \frac{j^\mu(\vec{r}', t) + |\vec{r} - \vec{r}'|)}{|\vec{r} - \vec{r}'|} d^3\vec{r}'. \tag{VIII.3}$$

With these two special solutions we can construct the special solution

$$A^\mu(\vec{r}, t) \;=\; c_1 A^\mu_{\text{ret}}(\vec{r}, t) \,+\, c_2 A^\mu_{\text{adv}}(\vec{r}, t), \quad c_1 + c_2 = 1. \tag{VIII.4}$$

The vector potential $A^\mu_{\text{ret}}(\vec{r}, t)$ is determined by $j(\vec{r}, t - |\vec{r} - \vec{r}'|)$, that is, the sources on the backward light cone of the point $(\vec{r}, t)$. This potential is called retarded because its sources are in its past: At $(\vec{r}, t)$ the past sources are reacted upon with delay. The vector potential $A^\mu_{\text{adv}}(\vec{r}, t)$ is determined by the sources on the forward light cone, $j(\vec{r}, t + |\vec{r} - \vec{r}'|)$, and is therefore called an advanced potential: At some $(\vec{r}, t)$ the past sources are anticipated in advance. The wave patterns associated with these two potentials are respectively expanding from a source towards the future, and converging onto the source in the same orientation.

Boundary conditions can be applied by adding solutions of the homogeneous variant of equation (VIII.1) to the linear combination of solutions. Because in the homogeneous equation the source term is zero, these additional solutions are called *free fields*. The full characterization of the class of solutions for the radiative activity in a region is then given by

$$A^\mu(\vec{r}, t) \;=\; c_1 A^\mu_{\text{ret}}(\vec{r}, t) + c_2 A^\mu_{\text{adv}}(\vec{r}, t) + A^\mu_{\text{boundaries}}, \quad c_1 + c_2 = 1. \tag{VIII.5}$$

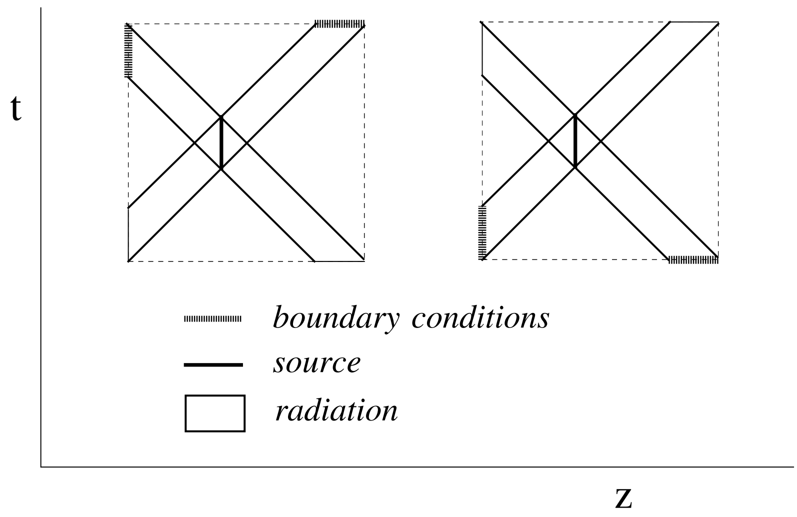

Figure VIII.1: Boundary value problem by Kirchhoff with one source acting during limited time in an otherwise empty universe.

But this expression can be simplified. The radiative activity at the future boundary of the region can be accounted for by the retarded influence of the source in the region and the incoming activity A^{μ}_{in} at the past boundary of the region. The condition at the future boundary of the region can therefore be disposed of without in any way restricting the radiative activity in the region. A similar reasoning applies in opposite orientation, so that the expression for the radiative activity in the region can be written in either of the following forms,

$$A^{\mu}(\vec{r},t) = A^{\mu}_{\text{ret}}(\vec{r},t) + A^{\mu}_{\text{in}}, \tag{VIII.6}$$
$$A^{\mu}(\vec{r},t) = A^{\mu}_{\text{adv}}(\vec{r},t) + A^{\mu}_{\text{out}}. \tag{VIII.7}$$

As will be clear from the formulas (VIII.6), there are two completely equivalent representations of the class of solutions for the radiative activity in some region. Figure VIII.1 illustrates these two ways.

As a matter of fact, radiation processes in nature always show expanding wave patterns in future orientation. Similarly, lightning only occurs after charge has cumulated, and instantly placing a charge in empty space causes fields afterwards but never before the charge is placed. All such asymmetries can be explained by the fact that electromagnetic sources exert their influence only to the future. Some textbooks argue that due to causality advanced potentials are impossible. But in fact the choice for one of the special solutions in equation (VIII.2) only concerns the *representation* of the class of solutions, it does not restrict it. A correct statement of the asymmetry involves conditions on the boundaries of the region. The fields can be restricted by an $A^{\mu}(\vec{r},t)$ at the boundaries $(\vec{r}, t)$ as in figure VIII.1. Note further that the boundary condition does not determine anything about the ratio of c_1 and c_2 in equation (VIII.5). It only determines the facts of the matter on the radiation in the region. The asymmetry of electrodynamics can be reformulated as concerning the boundary conditions, namely that these are always such as to render a retarded result.

The usual way to restrict to class of possible solutions is to postulate that there are no free fields in the past.

$$A^\mu_{\text{in}} \;=\; 0 \tag{VIII.8}$$

This boundary condition, corresponding with exclusively retarded source fields, is known as the Sommerfeld boundary condition. In the representation of Kirchhoff, figure VIII.1, the radiation is then fixed as is done in the left box. Note that because sources in this representation produce exclusively retarded radiation, it only seems natural that from the past there is no free radiation entering at the boundaries. Such radiation can only be *advanced* radiation, unless it has no source at all. This sourceless radiation again can never add to an explanation of asymmetry using boundary conditions, as it is itself completely symmetric. Finally note that the Sommerfeld boundary condition makes reference to a particular orientation, the past, to fix the oriented asymmetry of radiation. A reductionist account of radiation will have to find some condition underlying equation (VIII.8) that has no such implicit reference.

VIII.2 Advanced physics

Wheeler and Feynman were dissatisfied with the asymmetry in the Sommerfeld condition. They proposed to take a boundary condition that was symmetric, namely

$$A^\mu_{\text{in}} + A^\mu_{\text{out}} \;=\; 0. \tag{VIII.9}$$

Just like the Sommerfeld boundary condition imposed on some region in an otherwise empty universe implied that a single source within that region produced only retarded radiation, the Wheeler-Feynman condition on the same region implies that the source radiates equally retarded and advanced. So equation (VIII.1) takes as solution the linear combination

$$A^\mu \;=\; \frac{1}{2}(A^\mu_{\text{ret}} + A^\mu_{\text{adv}}). \tag{VIII.10}$$

The condition (VIII.9) can be seen as stating that at both temporal ends of any region in spacetime the same radiative activity has to come out. But in that reading it is clearly seen that the only way to make sure that no advanced radiation remains in the past end of spacetime, that is, to make sure that theory agrees with observation, is to stipulate that in the future end of spacetime no radiation remains either. The condition then is more specific, namely

$$A^\mu_{\text{past}} \;=\; A^\mu_{\text{out}} \;=\; 0. \tag{VIII.11}$$

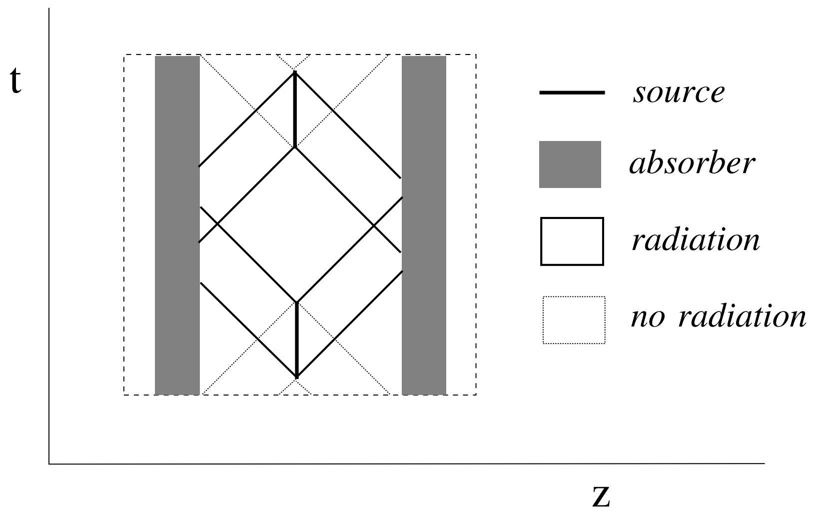

Figure VIII.2: The representation of the Wheeler-Feynman theory of radiation in a Kirchhoff boundary value problem.

The wave patterns that we observe can be described with this latter condition (VIII.11) on the universe as a whole and condition (VIII.9) on any boundary within it, to incorporate influences by other sources.

In figure VIII.2 the diagram associated with the Wheeler-Feynman theory of radiation is depicted. The absorbers at the sides seem to take care that the emitter at the top, the later emitter, cannot actually produce advanced radiation, that is, into the past. Similarly the first source takes care that the advanced radiation from the absorbers cannot continue into the past. Note that both absorbers and emitters are sources, where 'source' is used to denote an object that radiates both retarded and advanced. The time asymmetric picture usually associated with emitters and absorbers does not apply anymore. Note further that condition (VIII.11) states that there are no completely free fields in either temporal orientation. These can freely be added to other radiation, as we will never be able to detect, that is, absorb or emit, them.

The fact that common wave patterns are accurately described by Wheeler and Feynman is not so obvious. The causal picture associated with the Wheeler-Feynman theory is illustrated with figure VIII.3. Note first that an expanding wave from i can be imitated by waves contracting onto all surrounding particles j, that is, the circular waves collapsing on these particles add up to a singular expanding wave. Consider the particle i instantaneously radiating partly retarded and partly advanced at $t = 0$. All particles j radiate likewise at $t = \frac{x}{c}$, when the expanding wave of i arrives at j. It can be argued that irrespectively of the shape of the surrounding surface of j's the advance wave of i is canceled

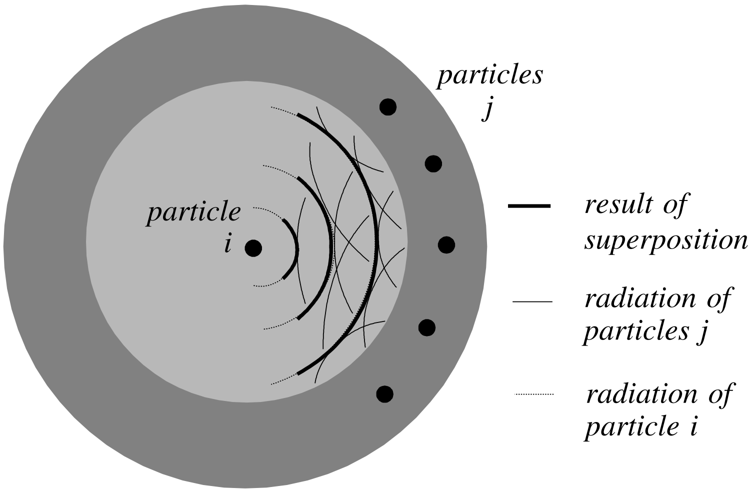

Figure VIII.3: Construction of retarded waves in the Wheeler-Feynman theory out of advanced and retarded action from the absorber and emitter respectively.

by the advanced waves of the j's, and likewise for the retarded waves, while the retarded wave of i and the advanced waves of the j's add up to an expanding wave between the particle i and the surface of j's[2]. Thus the waves will constitute an expanding wave between $t = 0$ and $t = \frac{x}{c}$, but cancel before $t = 0$ and after $t = \frac{x}{c}$.

It must be noted that the Wheeler-Feynman theory can only be made to agree with observation under the particular conditions stated earlier: All radiation must be both emitted and absorbed and the sources must radiate equally retarded and advanced radiation. These particular conditions may now be illustrated using the causal picture of figure VIII.3. First, without these conditions the theory predicts advanced radiation from i in figure VIII.3, whereas such advanced radiation is never observed in reality. That is, the Wheeler-Feynman theory only agrees with observations when advanced radiation eventually cancels out and the canceling out only works under the assumption that all waves get both emitted and absorbed. Further, if it is imagined that sources i and j radiate advanced and retarded at a different ratio the canceling out fails after all. Another reason for the conditions stems from the fact that we sometimes observe complete absorbsion of radiation. The retarded radiation of j must in such cases get canceled and this canceling only works out if the amount of retarded radiation of j equals the amount of retarded radiation emitted at i.

Note that these two particular conditions do not yet entail that radiation shows its typical asymmetry with respect to extendedness. The situation in

[2]Wheeler (1945) [55], Davies (1977) [5], pp. 130-8.

figure VIII.3 gave expansion only because the absorbers, being the sources at t_2, were distributed over space while the emitters, being the sources at t_1, were centered. The small wave front was therefore realized earlier than the larger wave fronts. Note further that there was nothing in the Wheeler-Feynman theory that already favoured any particular orientation, as was shown in figure VIII.2, in which asymmetric radiation was shown in both orientations. Wheeler and Feynman employed additional conditions based on the thermodynamical properties of absorbers in order to fix the asymmetry and consistent orientation of radiative processes. To the precise condition I will turn in the next section.

VIII.3 Popper's pond

As said, the asymmetry of radiation can be cast in terms of asymmetric conditions. The burden of explaining the OTA of electrodynamic processes and of radiation in particular is thereby shifted to these conditions, either the Sommerfeld boundary condition or the symmetric alternative by Wheeler and Feynman. In this section I will deal with some attempts to justify these conditions and thus explain the OTA of radiative processes. It will again be seen that the explanations make reference to orientation as a basic notion, that is, to a distinction between orientations.

Popper, in a famous letter to Nature[3], attempted to justify the Sommerfeld condition (VIII.8) by an appeal to probability[4]. To that aim he considered waves expanding over a pond after a stone has been dropped in. The reversal process, Popper argued,

> "... cannot be regarded as a possible classical process. (It would demand a vast number of distant coherent generators of waves, the coordination of which, to be explicable, would have to be shown, ..., as originating from one centre."

In the situation of figure VIII.3 this quote can be illustrated. Popper deems a wave originating from the bank j and collapsing onto an incident stone at i very improbable, even so improbable that in the quote Popper claims the process of this wave to be impossible. The reason he cites for the impossibility is that such a process requires the coherence of distant generators in the bank in producing the wave. That is, Popper justifies the Sommerfeld boundary condition by arguing that a violation of it, as sketched in the above, is very improbable. The coherence, argues Popper, can only be organized from the centre and consequently the process of the wave can only occur with a generator of the wave at the centre as well.

But has Popper satisfactorily explained the orientation of the asymmetry of radiation in time? Put differently, has he in fact justified the Sommerfeld boundary condition? As was suggested in section VII.1, probabilistic reasoning

[3]Popper (1956a) [35], Price (1996) [36] p. 51.

[4]Einstein in his correspondence with Ritz (Zeh (1989) [58], pp. 13-4) championed a similar view.

can never discern orientations in time and the justification of Popper is thus suspicious. As a test procedure, let us attempt to apply the same reasoning in opposite temporal orientation. We can just as well argue that the coherence of waves at the banks some time after the stone has been dropped in is very improbable, because strictly speaking this coherence is the same as the coherence before the dropping of the stone, which was judged improbable. Popper can only accept the coherence after the dropping of the stone and reject the same coherence before it if somehow an orientation is assumed to make these two coherences different. Popper, witnessing the quote, judges the coherence of generators after the stone has been dropped in the pond different because this coherence can be coordinated from the centre. Popper seems to assume that such a coordination cannot be organized in opposite orientation, that is, he seems to assume an orientation of causality.

Davies proposes to explain the asymmetry of radiation using a kind of branching hypothesis[5]. He presents a state space for waves in a pond that is analogous to the state space considered in section VII.1. The possible states in this state space are taken to be all possible combinations of waves in the pond. A good candidate for such a state space is an infinite dimensional space of all Fourier components of the wave. An evolution in this state space then corresponds with wave patterns in the pond that change over time. Davies considers the case that in such an evolution a coherently converging and subsequently expanding wave occurs. In that case the components of the wave suddenly interact in such a way that the pond spontaneously shows coherent wavepatterms that contract and subsequently expand again. Such wave patterns, Davies argues, are very seldom and may be compared with the fluctuations into low entropy that Boltzmann considered in thermodynamical systems. Like states of low entropy, the states of the pond with coherent wave fronts form a small minority in the totality of states in state space.

Now recall the branching hypothesis. It stated that isolated systems having relatively low entropy are not the result of fluctuations in state space towards low entropy, but that such systems have come into existence by branching off from a larger system that shows increasing entropy. The pond can now be treated in similar fashion. Every time we see coherent wave fronts in a pond we can against intuition assume that these occur as a rare part of the evolution of the pond. But it is more probable that the pond was brought in a state of low probability by external influences such as a stone being thown in. Like a thermodynamical system branches off at a state of low entropy, so a system of radiation branches off at a state that will cause an evolution with coherent wave patterns. The explanation for the Sommerfeld boundary condition (VIII.8) must then be that, in accordance with section VII.2, branching of radiative systems is lopsided. The coherent wave patterns due to branching then occur only in one orientation. Davies himself remarks that

> "...the existence of retarded waves is assured by *the asymmetric way* [emphasis by me] in which the branch system is formed."

[5] Davies (1977) [5], pp. 116-20.

The emphasized part may indicate that Davies indeed adopts such an auxiliary hypothesis of lopsidedness in order to explain consistent orientation. But whatever Davies' position, it seems clear that explanations of the asymmetry of radiation or justifications of (VIII.8) using branching make reference to orientation as a basic notion.

Apart from the above reasoning Davies advances yet another explanation of the Sommerfeld boundary condition (VIII.8). This explanation appeals exclusively to the thermodynamical properties of absorbers. Advocates of this explanation are apart from Davies also Zeh and Wheeler and Feynman[6]. The idea to base the asymmetry of radiation in that of thermodynamics however dates back from Einstein. I will here present the view of Zeh and argue that again the explanation hinges on orientation as a basic notion.

Zeh notes that the usual absorbsion of electromagnetic waves is a common thermodynamical process. Radiative activity is taken in by some absorbing material and the heat that is produced is dissipated thereafter. The absorbsion thus is an approach to equilibrium for the radiative activity plus absorber. The reversal process is consequently a depart from equilibrium. The process of the production of radiative activity from heat in a piece of absorber material requires the molecular movements in the absorber to be coordinated in such a way that the charged particles at the surface of the absorber material acquire enough energy to start radiate. Heat is in such a process not dissipated but, on the contrary, concentrated. So the absorbsion of electromagnetic waves in opposite orientation is not at all a common thermodynamical process, even so that there can be perfect absorbers.

According to Zeh the asymmetry of radiation can ultimately be traced back to this asymmetry of thermodynamics. The thermodynamical properties of absorber material take care that advanced radiation cannot occur. In more detail, at the far future end of spacetime a large scale absorber can take care that $A^{\mu}_{\mathrm{out}} \approx 0$, so that waves can expand towards that absorber in future orientation. At the past end there will for thermodynamical reasons not be any large scale emitter to which the waves can expand in past orientation. Put differently, according to Zeh the asymmetry of radiation can be explained with the fact that thermodynamics allows for large scale perfect absorbers, dissipating all radiative energy as heat in them, but not for large scale perfect emitters, gaining all energy in them to produce radiation. Recall that in the Wheeler-Feynman theory all emitters and absorbers were actually sources radiating both retarded and advanced. A perfect absorber is a material in which the retarded radiation of the sources is immediately absorbed again and dissipated as heat, so that no retarded radiation can escape from it as A^{μ}_{out}. Emission in this picture only occurs when the energy density is very high, as it is in stars and light bulbs. This asymmetry between emission and absorbsion will be dealt with more extensively in the next section.

A few things must be noted. First, the thermodynamical explanation of

[6]Davies (1977) [5], pp. 118-9, Zeh (1989) [58], pp. 18-21, Wheeler and Feynman, Einstein *ibid.*

the radiative OTA is different from the probability arguments given by Popper or Davies. It is not about the coherence of distant generators, nor about the probability of coherent wave patterns, but about the properties of wave generators separately. It may be argued that eventually the fact that heat gets dissipated can be traced back to probability considerations concerning absorber material, but this falls outside the scope of the present survey. Second, the Wheeler-Feynman theory of radiation can employ this thermodynamical reasoning as part of an explanation of the asymmetry of radiation. As it deals with advanced and retarded waves symmetrically, it could not employ any of the probability arguments. But to explain the asymmetry completely, Wheeler and Feynman further need that emitters and absorbers are differently distributed over space. To this I will return in the next section, when dealing with Price's symmetric proposal.

At first glance the thermodynamical explanation invokes only the asymmetry of the global entropy curve. But in fact it makes crucial use of orientation as a basic notion. When the dissipation of heat in absorber material towards particular orientation is taken as a consequence of the second law of thermodynamics, it is the law that makes reference to particular orientation. If the absorber material is described on molecular level, orientation as a basic notion is needed as well. To see this, consider the time reversed state of an absorber and let it evolve in time. It will then obviously produce coherent, converging waves. From the possible states $\mathcal{C}$ cited in C those states that effect the production of radiative activity must be excluded. Those that effect the insertion of radiative activity must be included. This will involve the admission to $\mathcal{C}$ of either state in every pair S_i and $\mathbf{T}[S_i]$ and thus the reference to orientation as a basic notion.

Price reacts both on Popper's and on Davies' proposal[7]. He argues that they are based on double standards. Popper grounded the asymmetry in probability and it was suggested in section VII.1 that statistical reasoning in general cannot discern temporal orientations. Popper's proposal thus must contain an assumption to discern orientations. The double standard, according to Price, is that the two coherent states of the bank that lie in opposite orientations are not judged equally probable. Indeed Popper treats the two opposite temporal ends of the region in spacetime where the radiation occurs differently. But, it must be noted, he need not make reference to *particular* orientations to explain the *consistent* orientation of the radiative processes. Assuming an asymmetry of causality will suffice to make the probability argument work. When Popper assumes that causation works in only one orientation, irrespectively of which one that is, his probability assignments can be justified. Similar to the discussion in section VII.4 it must be concluded that there are no real double standards but only an assumed asymmetry.

Price criticizes Davies on the same points as Popper and in fact takes them to advance the same arguments. A remark of Davies suggests that his arguments

[7]Price (1996) [36], pp. 54-8.

are indeed a reformulation of Popper's argument. He writes[8]

> "*in spite of this fact* [the improbability of advanced absorbsion on thermodynamical grounds] [emphasis by Davies], the spontaneous production of a wave by the pond's edges would very probably not produce a converging, *coherent* [emphasis by Davies] circular wavefront, precisely because this would require the cooperation of influences emanating from different directions of the edges."

But Davies takes this rather as additional reason for excluding advanced radiation. His major argument is the one stemming from thermodynamics. So Price is attacking Davies not in something that is central to Davies' position.

Let me note however that Price fails to appreciate even the precise idea of Davies on the additional argument concerning probability. Recall that Davies based it on the branching hypothesis. Davies agreed with Popper in deeming improbable the advanced radiation, but the retarded radiation Davies deemed just as improbable and only admissible because of the branching hypothesis. Conceptually Davies' idea resembles that of Reichenbach for thermodynamics much more than that of Popper for radiation. But the proposal of Reichenbach was in fact accepted by Price. So it is quite strange that Davies is accused of double standards *by Price*, who accepted Reichenbach's reasoning. On the other hand, in light of section VII.2 we also know that Price unwittingly criticizes Davies correctly because just like Reichenbach Davies will have to employ orientation in an auxiliary hypothesis after all.

In sum, it appears that nearly all attempts at justifying the asymmetric boundary conditions (VIII.8) or (VIII.9) and thus nearly all attempts at explaining the OTA of radiation eventually appeal to orientation as a basic notion. Davies' appeal to the branching hypothesis was seen to be asymmetric for the same reason as Reichenbach's appeal was. The explanation using thermodynamics was seen to be based either on an oriented law of nature or on restrictions on the absorber material in condition C that made reference to orientation. Popper's appeal to probability was seen to be asymmetric because it fell back on an asymmetry of causation. It is debatable whether he would invoke orientation to make explicit the asymmetry of causality that he tacitly assumed. Without the auxiliary hypothesis on causality his proposal was simply flawed or oriented after all. A reductionist is therefore challenged to come up with an explanation of the OTA of radiation that does not somehow invoke orientation.

VIII.4 A—SYMMETRIC ALTERNATIVE

In the previous section it was argued that nearly all explanations of the OTA of radiation must make reference to orientation as a basic notion. It has been argued in section VI.3 that in fact reference to orientation is nearly unavoidable in explanations of the consistent orientation of TA processes. Price however

[8] Davies (1977) [5], p. 119.

rejects all such explanations because he views them as based on a double standard[9]. In the previous section it has also been argued that the accusation of double standards is misplaced, because in explanations of consistent orientation usually nothing pertains to particular orientations. The present section aims to show three separate things. First, the Wheeler-Feynman theory of radiation will be enriched with a condition to explain the asymmetric feature of extendedness of radiation. Price adopts just this condition but reinterprets the Wheeler-Feynman theory in order to allow for a completely symmetric picture of radiation. It will be seen secondly that the reinterpretation fails in an important way. Thirdly, it will be argued that Price's symmetrical proposal cannot explain the consistent orientation of radiation. Also it will be shown that the attempt can easily be be made to succeed by adding a particular asymmetric auxiliary hypothesis.

The symmetric proposal by Wheeler and Feynman was furnished with consistent orientation of the radiation processes using thermodynamics: Absorbers were such as to absorb radiative activity in only one orientation. That is, in the explanation answering question Q$_3$ Wheeler and Feynman adopted an auxiliary hypothesis employing orientation and thus succeeded in accounting for the consistent orientation of radiation processes. But, it must be noted, nowhere in the conditions it was stated that radiative activity has the particular asymmetry with respect to extendedness, that is, the asymmetry of circular wave fronts expanding in one orientation of time. Yet this asymmetry has been implicit in the auxiliary condition concerning thermodynamics. It was already argued that emitters must have a energy density that is much higher than its surroundings, because otherwise the process of emitting would not even occur. It is now a small step to stipulate that emitters do not only have a high energy density but are also concentrated in small parts of spacetime, for material with a relatively high energy density cannot obviously occupy large portions of space. With this latter additional condition, that emitters are concentrated and small whereas absorbers are distributed and large, the Wheeler-Feynman theory is completed.

Price's explanation of the OTA of radiation processes consists in a reinterpretation of the Wheeler-Feynman theory. Quite a few aspects of this theory are altered. The oriented auxiliary hypothesis based on thermodynamics is dropped and further a distinction between retarded and advanced radiation is removed. Also Price claims that there is no need anymore for a future absorber. In the following these changes will be elaborated and commented on.

The move of dropping the auxiliary hypothesis using thermodynamics is made for peculiar reasons. On the explanation using thermodynamics, that was proposed by Wheeler and Feynman, Price writes[10]

> "...this is exactly the same argument that Popper used to attempt to explain why we don't see incoming water waves ...this attempt to rely on a statistical explanation involves a temporal double standard."

[9]Price (1996) [36], pp. 67-9.
[10]Price (1996) [36], p. 68.

That is, after characterizing the asymmetry of thermodynamics as statistical in origin, Price equates the explanation using thermodynamics with that of Popper using probabilistic reasoning. In the above discussion however we saw that these were in fact separate arguments. Popper's argument, if it is to work properly, makes crucial use of a causal asymmetry to ensure consistent orientation for all TA radiation processes. The thermodynamical argument employs a large scale TA of entropy to ensure this consistency. The explanation using thermodynamics has been argued to make reference to orientation in order to fix condition C, but it has also been argued that the explanation did not assume double standards. So rejecting the argument because it assumes double standards is dubious.

The auxiliary hypothesis that Price proposes is supposed to be free of any reference to orientation as a basic notion. Price states that radiation is accounted for by the fact that absorbers are large whereas emitters are small. That is,

AP The parts of material adding energy to the electrodynamic field, called sources, are clustered whereas the parts of material detracting energy from it, called sinks, are widely distributed.

Note that a comparable condition was already added by Wheeler and Feynman to make sure that the radiation processes were in fact asymmetric in time, that is, to make sure that the extendedness of the wave is a monotone function. Both for Price and for Wheeler and Feynman the cited condition derives from cosmology: For some reason our early universe is furnished with an uneven distribution of electrodynamic energy and the explanation of this fact must be sought in the very special history of our universe. Because Price and Wheeler and Feynman have both adopted some form of the above condition, it seems that Price does not really put anything in place of the thermodynamical argument.

But Price's reinterpretation further differs from the original theory by Wheeler and Feynman. First, Price removes the distinction between retarded and advanced radiation. He argues that retarded waves from an emitter and added advanced waves to an absorber, as depicted in figure VIII.3 are in fact equivalent: The descriptions of radiation with $c_1 = 1$ and $c_2 = 0$ and vice versa in equation (VIII.5) can both be used. Second, Price claims that in the reformulated theory there is no need anymore for the existence of a future absorber. Just because a wave may be represented either as the result of many advanced waves converging onto absorber particles and as one retarded wave expanding from an emitter particle, one need not postulate any absorber. A wave can after all be described as consisting exclusively of the retarded action of a source.

First consider the alteration concerning the choice of c_1 and c_2. As was argued in section VIII.2, the case of a single source in some region in an otherwise empty universe can only satisfy the Wheeler-Feynman boundary condition (VIII.9) if it radiates equally retarded and advanced radiation, that is, if $c_1 = c_2$. Moreover, in the example of figure VIII.3, the combined waves only cancel before $t = 0$ and after $t = \frac{x}{c}$ if it is assumed that the waves of i and j are equal in force, that is, if the choice for c_1 and c_2 applies across the board and for

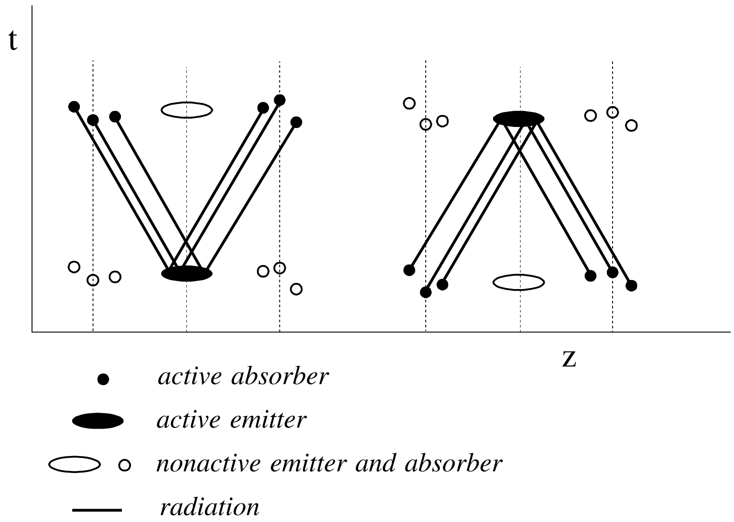

Figure VIII.4: Radiation processes that are possible according to Price.

absorber and emitter particles equally. So in the Wheeler-Feynman theory it certainly matters what values for c_1 and c_2 are chosen.

Concerning the second alteration, if it is maintained that no absorber is needed while at the same time it is assumed that c_1 and c_2 are free to choose, the Wheeler-Feynman condition will be violated. Let us take the process of the universe and drop the condition that no radiation comes out at the future end. Then the universe radiates into the future. But how, if c_1 and c_2 are free, can we be sure that just as much radiation comes in at the other end? Moreover, even if we assume that an equal amount of radiation goes in and out, this is not satisfactory. In that case we still allow advanced radiation entering the universe, whereas in fact we never observe such radiation. The conclusion must be that Price not only reinterprets the theory of Wheeler and Feynman but alters it [11].

But let us simply attempt to apply the auxiliary hypothesis $\mathrm{A_P}$ in an explanation answering $\mathrm{Q_1}$ and $\mathrm{Q_3}$ and see if it works. To see that in fact the hypothesis does not yield consistency of orientation consider figure VIII.4. Note that radiation is taken to be limited at both temporal ends. For the sake of the argument we will take both source and sink to radiate half retarded and half advanced, so that the above problem does not surface. We may then take radiation to exist only between its appearance at the source and its disappearance at the sink. By the auxiliary hypothesis $\mathrm{A_P}$ we also know that sources are centered on coherent wave patterns whereas sinks surround these wave patterns. Question $\mathrm{Q_1}$ is satisfactorily answered with $\mathrm{A_P}$.

But is there any reason to exclude one of the above radiation processes? That

[11] A similar conclusion has been expressed by Ridderbos (Ridderbos (1996) [41])

is, has question Q_3 been satisfactorily answered? This depends on what we take sources and sinks to be. From Price it is clear that sources add energy and that sinks detract it. But adding and detracting seem themselves oriented words: When an addition of energy is considered in reverse it is a detraction. It depends on the setting, and presumably on a human perspective, what counts as addition and what as detraction. Price can rebut that cosmological considerations fix the order of addition and detraction, just as the situation of clustered sources and distributed sinks was based on cosmology. But it is hard to see how cosmology can fix the order of events as close in time as the emission in a bulb and the absorbsion in a wall. Certainly the wall existed long enough to 'absorb' the light before the 'emission'. Unless it is clarified how in such cases order may arise, the rebuttal fails. It is then unclear how the auxiliary hypothesis A_P is to be read, that is, which orientation must be assigned to it.

The conclusion must be that in Price's reinterpretation question Q_3 cannot be answered satisfactorily. Processes of radiation cannot be fixed in a consistent orientation. There is an obvious way however to repair the auxiliary hypothesis A_P, namely by stipulating the orientation in which adding and detracting are to be read. Note that this repair refers to orientation as a basic notion. Yet I do not see any other way to repair this particular attempt at explaining the OTA of radiation. It seems that this particular reductionist attempt at explaining the OTA of radiation has failed on its essential point.

IX

Cosmology

In this chapter I will discuss asymmetries of the universe at cosmological scale. These asymmetries serve to underpin particular explanations of OTA's, such as the entropy slope of the universe intended to explain the consistent orientation of branch systems. In the first section it will be elaborated in cosmology that questions concerning asymmetry and orientation, must be separated. In particular it will be seen that current explanations of the time asymmetry of the universe are not based on any double standards, contrary to what Price maintains. In the second section explanations of orientation are considered. Again it turns out that no author has as yet addressed that question. It will be argued that any answer to it must refer to an orientation in spacetime. To this fact the puzzles of Kant, Zeno and Leibniz will be connected in order to, so to say, put God in doubt. The argument resulting from the puzzles brings in trouble reductionism towards orientation again.

IX.1 Confusion again

Before discussing explanations purported to answer questions about asymmetry, it must be clear what these questions are precisely. In previous chapters the aim of physics was to answer mainly Q_3, and in addition Q_4. These questions concern sets of processes and their (consistent) orientation. The present chapter deals with questions Q_1 and Q_2, that is, it is concerned with a single process. In particular it is concerned with the single process that constitutes the universe. This has some consequences for the problems encountered in the explanations. Whereas in previous chapters we saw that the *consistent* orientation of all TA processes troubled the issue of question Q_3. In this chapter such a confusion will not emerge. There is only a single TA process to explain, so auxiliary hypotheses to ensure consistent orientation of TA processes in the OTA set of processes will not be needed in explaining asymmetry.

It is important to note once more that question Q_1 differs from question Q_2. In the literature there is confusion over these questions, because again attempts to answer Q_1 are taken to be aimed at answering Q_2. In the next section question Q_2 will be considered. In the remainder of this section it will be argued that Price falls subject to the same confusion in his discussion of the cosmological arrow as the confusion elaborated in section VII.4. In particular, Price criticizes Davies and Hawking on adopting a double standard[1]. In the following I will be concerned with these two accusations, considering Davies' proposal first.

[1] Price (1996) [36], pp. 78-113.

From Davies' discussion two things must be noted. First, he applies an asymmetry ensuring condition at an *arbitrary* temporal end of the universe. Second, he employs no particular orientation in characterizing the condition[2]. In more detail, the asymmetry of the universe follows from his condition much like the asymmetry of entropy follows when the condition $\mathcal{C}$ at some temporal end of a process contains only low entropy states. The condition of Davies is not in any way oriented, that is, the restrictions on the possible states of the universe $\mathcal{C}$ that make for the condition C, do not pertain to the notion of orientation and certainly not to any particular orientation. In fact the Davies' condition resembles that of Horwich presented in section VII.4. Further, no *particular* temporal end is chosen for applying the condition. In other words, any temporal end can be made to satisfy the condition. Once the condition is applied at one end however, it cannot be applied to the other end without further consideration. Given the condition at one end the same condition becomes very improbable at the other end, just because the condition favours an asymmetric universe and will not, with some state S_i at one end have the same S_i at the other. Applying a condition at an arbitrary end is obviously different from applying the same condition at both ends.

Hawking has a more subtle condition, applying to the whole of spacetime. It is the condition that spacetime has no boundaries, or that spacetime is a closed hypersurface in of four dimensions. Hawking's condition has come to be known as the *no boundary proposal*. The simplest instance of such a spacetime without boundaries is a hyper-hypersphere. It can be shown that such a spacetime favours asymmetric evolutions of the matter distribution[3]. To arrive at these asymmetric evolutions, the matter is taken to be smoothly distributed, yet slightly perturbated, over the spacetime at one temporal end. The perturbations are such that there exist perturbation modes with a symmetric evolution, diminishing at both temporal ends. But other perturbation modes however will grow during the evolution of the metric and become nonlinear towards the other temporal end of the universe. These latter perturbation modes then explain that the universe has an asymmetric evolution. Note that the asymmetry is explained without fixing the orientation of the asymmetry. The temporal end with small perturbations is arbitrarily chosen, as the condition can in principle be applied at both ends. Note further that by the nature of the evolutions it is improbable that the condition actually occurs at both temporal ends.

Price objects to both above explanations. Against Davies he argues that there is no reason to apply a condition at one temporal as opposed to the other. He concludes that there must be some double standard by which Davies takes the condition to apply at a particular end and not at the other. This problem Price calls the *basic dilemma*. But as was argued Davies does not apply the condition to a *particular* temporal end. He applies it to an *arbitrary* end and then argues that the resulting evolution is asymmetric. That is, rather than also answering Q_2 Davies aims to answer only Q_1. To confirm this the following

[2]Davies (1977) [5], pp. 103-9.
[3]Hawking (1982) [21].

quote of Davies may be considered[4].

> "... a recontracting universe arriving at the big crunch would not undergo 'deflation', for this would require an exceedingly improbable conspiracy of quantum coherence [at the end at which the condition is already applied]."

Davies thus considers improbable a symmetric universe *given the condition at one end*. Price ignores the fact that Davies is talking of a *conditional* probability, namely the probability of the condition at one end when the same condition is already given at the other end[5]. His objection is therefore flawed.

In his discussion of the no boundary proposal Price holds a similar position. It is remarkable that Price takes the no boundary condition to be applicable at temporal ends of spacetime whereas Hawking intended the condition to be applicable to spacetimes as a whole. Because Price ignores this subtlety his criticisms are confused already, but more confusions can be noted. Recall that Hawking showed the universe to evolve asymmetrically when smooth at an one end. In his criticism Price asks why the asymmetry cannot be taken in the opposite orientation, that is, he brings up the basic dilemma again. But Hawking has not applied the condition of particular perturbations at any particular end of spacetime. He is not at all answering question Q_2, his no boundary condition is an answer solely to question Q_1. Hawking employs precisely the loophole that Price sketches to circumvent the basic dilemma. He shows that a universe, in this case constrained by the no boundary condition, has asymmetric evolutions when particular perturbations are given for either of its temporal ends, whereas the physics governing the universe is time reversal invariant. Price calls this the *corkscrew loophole* because a corkscrew is always enantiomorph whereas the physics describing its elementary constitution is spatially symmetric.

In sum then, Davies' proposal consisted in applying a condition to one end of spacetime. The proposal of Hawking was to apply a condition to spacetime as a whole and then derive asymmetric evolutions from particular perturbations at one temporal end. But in neither explanations reference was made to any particular orientation, not in applying boundary conditions and not in auxiliary hypotheses. The explanations given were aimed at answering only Q_1 and not Q_2. Therefore the objection of the double standard fallacy is flawed if it intends to show that the explanations explaining asymmetry in cosmology favour one particular orientation over another. If the double standard fallacy aims to show that the explanations assume some ungrounded asymmetry, similar to what was suggested at the end of section VII.4, then it is a correct criticism but at the same time unavoidable. I therefore conclude that Price's objections employing the double standard fallacy have no force against Davies and Hawking.

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[4] Davies (1983) [6], p. 399.

[5] Price eventually arrives at the position that a universe must be time symmetric because any condition applying to one end can be applied at the other end as well. In other words, Price asserts that the process of a universe cannot be enantiomorph because in that case no reason can be cited for the realization of the one incongruent counterpart and not of the other.

IX.2 Putting God in doubt

This section is concerned with question Q_2 applied to the universe as a single process. It purports to show, in line with section VI.2, that any explanation of the particular orientation of the universe has to make reference to orientation as a basic notion. Further, using this fact an argument against reductionism very similar to the argument of Leibniz against substantivalism will be developed. This argument will draw together the puzzles of Kant, Zeno and Leibniz presented in chapter I.

How can question Q_2 be answered? In particular, how can question Q_2 be answered for a universe? Note that this question is similar to the question which hand is realized in the otherwise empty universe that was considered in section I.1. This question was rephrased as QP in section VI.2. In general there were given three possibilities to answer QP, adapting the law governing the process, restricting the conditions which fix the process or adding an auxiliary hypothesis. It turned out that all three answers to QP had to appeal to particular orientation and thus to orientation as a basic notion. For example, an appeal can be made to oriented conditions $\mathcal{C}$ or to auxiliary hypotheses that refer to a particular orientation. Now note that Price will nevertheless consider such answers to QP mistaken: Any reference to particular orientation is based on double standards. Attempts to answer QP however will run into double standards by necessity. So Price can only choose to leave QP unanswered.

Let me now bring to bear the puzzles of Kant, Zeno and Leibniz using the above conclusion. First the considerations of Kant have shown that questions like QP are meaningful. Maybe that question had also been meaningful if oppositely oriented processes were congruent counterparts, but certainly their being incongruent ones makes QP to mean more. Secondly the considerations by Zeno have revealed that properties of states pertaining to change have a special status. It has turned out that they can be taken as reasons for the orientation of TA processes. In this manner the difference in oppositely oriented states has been given physical basis. Now these two facts can readily be applied in an argument similar to that of Leibniz. Recall that Leibniz argued that a substantivalist put God in doubt because He was to choose between different yet indiscernible positions for Creation. I will here present an argument in theological fashion as well. Its physical variant is easily obtained from it by replacing 'sufficient reason' with 'cause'.

First assume that orientation is a theologically and physically meaningless notion. This means that there is no way to discern temporal ends of a spacetime or to discern the orientations of states. Then consider God who, after having written the book of natural laws, is about to create the universe by choosing a state and a stage of the universe at which that state applies. As the universe and its reversal differ just like incongruent counterparts do, God will want to make a choice between them in Creation. But if orientation is taken to be meaningless, He cannot make that choice. He cannot single out a state S as opposed to its reversal state $\mathbf{T}[S]$, nor can he single out a particular temporal end of spacetime to apply his condition to. Without orientation as a basic notion, and the possibility to refer to particular orientations, God will never be able to create a universe and not its reversal. God is thus put in doubt by all those that consider orientation as a separate notion to be empty.

It seems that reductionism towards orientation runs into another problem. But this problem is in fact nothing but a special case of the problem already encountered in section VI.2. The difference is that for universes renouncing all orientation can be put to use in an argument immediately, analogous to the puzzle by Leibniz presented in section I.3. With this latter argument I want to close the three chapters on physics theories.

X

Conclusions

This chapter summarizes the results of the previous chapters. It is aimed at drawing together the threads and providing an overview. From this overview will emerge an answer to the main question of this work, namely whether reductionism towards orientation is tenable. Further, this conclusion contains some suggestions to use the insights of this paper in unsolved problems. These suggestions however are not worked out sufficiently to fill a separate chapter. Moreover, they are somewhat speculative. Before presenting them I will first summarize some more secure results.

Chapter I presented three puzzles. They were aimed at preparing certain philosophical issues. The relevance of these issues for the present work was to be clarified in the course of it. In chapter II on orientation I have sketched the prerequisite facts on spacetime structure. After distinguishing a series of questions and suppositions (section II.1) I dealt with the predominant view on orientation, namely reductionism, and influential criticisms on this view by Earman (section II.2). Reductionism was characterized as the view that the orientation of time could be based in other notions and understood in terms of them. In the two chapters following this I elaborated on asymmetry and irreversibility. Both notions are important to reductionism as they are used to base orientation. In chapter III we saw that temporal symmetry was a kind of mirror symmetry (section III.2) and that asymmetries in nature involve a consistent orientation of asymmetric processes (section III.3). Finally we saw that to some authors, Black and Grünbaum, any asymmetry sufficed to attach orientation to time. The criticisms of Earman were argued not to be in their proper place against such authors.

In chapter IV irreversibility was dealt with. Reversal was specified using an analogy with words (section IV.1). The analogy made plausible that in reversing a process the states had to be reversed as well. The nature of state reversal was discussed subsequently and it was argued that reversed states are in a particular way associated with opposite orientations in either space *or time* (section IV.2). Then irreversibility was defined as a notion applicable to processes and several alternative meanings of it were excluded explicitly (section IV.3). An alternative to predicating irreversibility of processes was proposed by Earman, who considered physical theories and their time reversal noninvariance (section IV.4). It was argued that this proposal better accommodates the fact that whether a process is irreversible depends on its description and therefore on the theory used to describe it. Finally Earman's criticisms of reductionism were put in proper place against reductionists like Reichenbach and Gold (section IV.5).

In chapter v the feature of enantiomorphy was introduced. Enantiomorphy was defined in terms of rigid motions (section v.1). Then it was proved that all TA processes are enantiomorph (section v.2), so that all TA processes could be said to have orientation just like hands are left or right. The proof was illustrated by an argument due to Möbius. Finally the debate over the hands of Kant was reviewed and put in perspective (section v.3). One of the main questions of this debate was whether relationists, those who take spacetime as built up from relations between objects in spacetime, can take a different stance towards enantiomorphy than substantivalists, those taking spacetime as an independent substance. It was seen that both relationists and substantivalists are forced to take oppositely oriented enantiomorphs as different. Certain relationist tenets, most notably Remnants denial of definite orientation to hands, were argued to be false. The analogy of Remnant with Gold made it plausible that Gold's position is not tenable either. The relationist solutions by Earman and Sklar both embrace orientation of hands and express it in relations that take orientation as a basic notion. It was argued that in fact substantivalists will have to adopt such relations as well, because it is nowhere elaborated how substantivalists express orientation otherwise.

Chapters II to V form a unity. They deal with the orientation of time and three separate features of processes that can be linked to orientation. All three stand in a particular relation to reductionism towards orientation of time. The first two notions have been used to base orientation. The orientation based on asymmetry, called anisotropy by its reductionist proponents, was arguably weak. The orientation based on lawlike asymmetry or time reversal noninvariance of theories was subjected to criticisms by Earman. It was seen that such reductionist proposals incorrectly assumed a direct connection between processes in time and orientation of time. The third feature linked to orientation, enantiomorphy, has been introduced in the present work. More than any of the other features enantiomorphy seems to relate to orientation, both to the orientation of spacetime and to the orientation of processes. It was argued that both a relationist and a substantivalist will have to accept orientation of enantiomorphs as a notion with actual content. Further, the argument of Kant showed that the orientation of processes cannot be expressed in intrinsic features, so that the notion of orientation has to be accepted as basic. In relation to reductionism this is of particular importance.

In chapter VI the consequences of the enantiomorphy of asymmetric processes were elaborated on. First an attempt to reduce the orientation of time to properties of processes, in particular the reduction to the entropy gradient as proposed by Reichenbach, was critically assessed. It was argued that the reduction of orientation of time to the entropy gradient is blind to the difference between oppositely oriented processes (section VI.1). The conclusion was that orientation of time is not reducible to such a gradient. The puzzle of Kant even suggested that such reductions are impossible in general. Secondly, explanations of both the asymmetry and orientation of processes were considered. The orientation of any TA process or OTA set was shown to be inexplicable unless reference is made to orientation as a basic notion. A further conclusion was that typical explanations of OTA's must invoke auxiliary hypotheses in order to account for the consistent orientation of TA processes in the OTA set, and that these auxiliary hypotheses will probably refer to orientation as basic notion (section VI.2).

Chapter VI has a central position in this work. It elaborates on consequences of the fact that, apart from asymmetry and irreversibility, enantiomorphy can be predicated of processes. From this chapter it follows that reductionism faces three problems.

PROBLEM 1 A reduction of the orientation of time to particular properties of processes is impossible.

PROBLEM 2 An explanation of the orientation of a process is impossible without making reference to orientation as a basic notion.

PROBLEM 3 An explanation of the consistent orientation of an oriented temporally asymmetric set of processes typically makes reference to orientation as a basic notion and thus invites confusion over the notions of asymmetry and orientation.

From PROBLEM 1 I conclude that reductionism towards orientation of time is untenable. From PROBLEM 2 I conclude that reductionism towards the orientation of processes in time is untenable as well. These problems form the challenge to reductionism that was promised in the introduction. The third problem is surmountable for reductionists as it still allows explanations of consistent orientation of OTA's without reference to orientation as a basic notion. Yet in physics it turned out that most explanations, e. g. the branching hypothesis by Reichenbach and the proposal for radiation by Price, must make reference to orientation as a basic notion. Therefore PROBLEM 3 is more of a practical problem for reductionists.

Chapters VII to IX were intended to identify PROBLEM 2 and most notably PROBLEM 3 in the explanations of physics, thereby making use of the disentangled questions Q_1 to Q_4. Chapter VII discussed the thermodynamical asymmetry. First the asymmetry was introduced (section VII.1), in particular explanations of it using the Stoßzahlansatz and the branch hypothesis. It was argued subsequently that just like the Stoßzahlansatz the branch hypothesis is based on an assumed orientation of processes in time in order to explain the consistent orientation of the entropy gradient of processes. That is, the explanation of the consistent orientation of the entropy gradient of processes, answering Q_3, was seen to make reference to orientation as a basic notion. In addition, it was seen that an explanation of the orientation of the set of these processes, answering Q_4, requires reference to orientation as a basic notion as well (section VII.2). A reductionist attitude to the OTA of entropy thus faces PROBLEM 2 and PROBLEM 3. Finally the position of Price was critically assessed (section VII.3). It was shown mainly that Price fails to appreciate PROBLEM 3. He criticizes explanations of the consistent orientation of processes on the fact that these explanations make reference to orientation. But he ignores the fact that most explanations will have to do so and that in fact his own explanation is no better.

In chapter VIII the asymmetry of electrodynamics was discussed. It was shown how this asymmetry is usually fixed with the Sommerfeld boundary condition imposed on a description of radiation in terms of retarded potentials (section VIII.1). The Wheeler-Feynman theory with its boundary conditions was presented as a symmetric alternative to the Sommerfeld condition (section VIII.2). Several attempts at explaining the asymmetry of radiation using either the Sommerfeld or the Wheeler-Feynman condition were subsequently dealt with (section VIII.3) and it was argued that nearly all of them make reference to orientation in order to explain the consistent orientation of radiation processes. Finally the proposal of Price was considered (section VIII.4) and criticized. It was made clear that Price changes the causal picture associated with the Wheeler-Feynman theory. The causal picture he associates with it was seen to be based on a presupposed orientation. His alternative could only be made to work using an auxiliary hypothesis that referred to orientation as a basic notion. Price again failed to appreciate PROBLEM 3.

Chapter IX dealt with time asymmetry in cosmology. In both preceding chapters the cosmological asymmetry had been mentioned to base the asymmetries assumed in auxiliary hypotheses. In this chapter it was argued that cosmology can indeed explain the temporal asymmetry of the universe without reference to any particular orientation, making use of the corkscrew loophole (section IX.1). It was also shown that Price again failed to appreciate PROBLEM 3, confusing matters of asymmetry and orientation. It was further noticed that the question concerning orientation, in this case Q_2, was not answered by any of the treated accounts (section IX.2). This led into a particular problem linked to that of Leibniz, namely of how the universe can have orientation if nothing underlies this orientation. It turned out that an orientation inherent to the conditions under which the universe came into existence or an orientation inherent to time itself had to be adopted.

Like chapters II to V chapters VII to IX form a unity. The problems raised in chapter VI are identified in several parts of physics in the subsequent chapters. It is thereby claimed that the asymmetry of thermodynamical processes and of radiation cannot be explained unless some asymmetry is assumed in (the application of) conditions or mechanisms as part of an auxiliary hypothesis, that explaining the oriented temporal asymmetry of a set of such processes requires explaining the *consistent* orientation of the processes above their being asymmetric and that this invites reference to orientation as a basic notion. In explaining thermodynamical processes and radiation a reductionist is confronted with PROBLEM 3. The asymmetry that is being assumed in the auxiliary hypothesis can be explained in cosmology without any reference to orientation. Explaining the orientation of the asymmetry of the universe however, that is, answering Q_2 for the universe, requires orientation as a basic notion. Therefore in cosmology the reductionist faces PROBLEM 2. He is in this case putting God in doubt. The only way to solve the latter problem is to introduce orientation as a basic notion or claim that question Q_2 for the universe is meaningless.

Particular attention has been given to Price. On several occasions it was shown that his explanations were deficient. He adopted the branching hypothesis of Reichenbach whereas this hypothesis did not in fact answer Q$_3$. Further he confused Q$_3$ and Q$_4$ in criticizing other attempts to explain the entropic asymmetry. His reinterpretation of the Wheeler-Feynman theory of radiation was seen to be a disputable change of that theory. But at the same time his condition was not able to give the TA radiation processes consistent orientation and thus could not answer Q$_3$. In criticizing attempts to explain the cosmological asymmetry he fell subject again to confusing questions Q$_3$ and Q$_4$. Further, because Price radically rejects any orientation to processes or spacetime he failed to explain the orientation of the universe. He therefore puts God in doubt. In sum, Price was seen to be confronted with PROBLEM 3 in explaining the OTA's of thermodynamics and radiation and with PROBLEM 2 in explaining the orientation of the asymmetry of the universe in cosmology.

Two things must still be clarified. First, the arrow of Zeno has not yet reached the same relevance as that of the other two puzzles. Second, it has not been made precise how to assume orientation as an element in the state description. But in several sections the relevance of the arrow of Zeno and the assumption of the orientation of states has already been suggested. I will here draw together these two threads. The result is somewhat speculative, but in line with many small hints made earlier on.

From Zeno's puzzle in section I.2 it followed that velocity, but in fact any property pertaining to change, has to be assigned to states of processes. It further showed that different velocity assignments satisfied the same sequence of states in some process of movement. These velocity assignments had to be associated with opposite orientations in time. In section III.3 it was seen that pairs of processes p and $\mathbf{R}[p]$ were associated with pairs of states S and $\mathbf{T}[S]$. Such pairs of states were in a certain interpretation of $\mathbf{T}$, introduced and explicated in section IV.2, considered oppositely oriented in time, just like the processes p and $\mathbf{R}[p]$ were. In section IV.3 the suggestion of Earman was connected to the orientation of states. With respect to hands in space Earman holds that the distinction between left and right can be given ontological basis if an intrinsic property of orientation is introduced. In sum then, Zeno showed that velocities and other properties of change were to be assigned to states. Such assignments made it possible for states to be associated with different orientations in time. The discussion on $\mathbf{T}$ then showed that these different orientations were associated with oppositely oriented processes. I will now turn to an application of Earman's suggestion.

This suggestion is that the orientations of states should be taken as the intrinsic properties of the states and thus of the processes, supplying an ontological basis for the distinction of reversal processes. That is, the orientations of states together with a velocity assignment should be taken as elements of reality, not as artifacts of convention in the state description. Note that adopting such orientations of states can provide a criterion for allowing states to an oriented condition $\mathcal{C}$ in an explanation answering Q$_4$ or Q$_3$. When the orientation in states due to e.g. velocities is taken to be conventional, the allowance of states to this $\mathcal{C}$ remains unpleasantly vague. But more importantly, the orientations of states define a so-called master arrow from which any other oriented feature of the universe can be derived. I will here make some final remarks on such a master arrow. The ideas are quite speculative, but they may nevertheless provide a fresh look on several issues.

First, the orientation of time dependent features such as velocity may base causality. The behaviour of systems under intervention, e.g. placing a red filter half way down a ray of light or altering the course of a tennis ball by hitting it with a racket, is temporally asymmetric. In first instance this asymmetry is usually ascribed to causality. But the same asymmetry may be explained by the fact that the influence of an intervention has the same orientation as all other time dependent features. Such features may be said to propagate causal influence in the manner described by Salmon[1]. Keeping fixed the past is much more natural once all elements in the state descriptions are indeed oriented to the future[2].

A second suggestion concerns flowing time. Many authors, such as Mellor, Smart, Price and avant la lettre, McTaggart, maintain that the supposition of a 4-dimensional static universe rules out a moving present and all alternatives to it[3]. Some authors, such as McBeath, have therefore attempted to justify our intuitions on flowing time by appealing to a fifth dimension and then considering a moving present that at different meta-times visits different times[4]. But I think such a counterintuitive move unnecessary. We need not postulate anything above or against the block universe so strongly favoured by science. An orientation that is inherent in states may explain our feeling of flow at every instant without there being any moving present. Nobody has ever experienced the present itself moving, we only feel that at every instant we are oriented. So an orientation of states suffices to explain our feelings.

[1] Salmon (1993) [44].
[2] Lewis (1993) [31].
[3] Mellor (1981) [32] and McTaggart (1908) [52].
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