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Casual processes and time flow

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CAUSAL PROCESSES AND TIME FLOW

A Thesis

Presented to

**The Faculty of the Department of Philosophy
San Jose State University**

In Partial Fulfillment

of the Requirements for the Degree

Master of Arts

by

Eugen Gershon

August, 1995

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ABSTRACT

CAUSAL PROCESSES AND TIME FLOW

by Eugen Gershon

The physical description of the world considers the principle of “cause precedes effect in time” (CPE) true, and it associates CPE with forward causation. The inverse time relation EPC (effect precedes cause) is not allowed in the scientific analysis of physical systems. In general, time and causality are perceived as interdependent.

This thesis is an attempt to separate time and causal relations by allowing both CPE and EPC in a causal chain. Since EPC aspect is not contradictory in principle, time and causality can be conceived as separate concepts. As far as any cause-effect relation is identified to be part of an explanation, and time is part of the spacetime physical frame or a mathematical model of it, there is no need to tie causality and time in a necessary way.

The thesis also discusses some related ideas, such as time reversal, backwards causation and time travel.

To my wife Evie

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1. INTRODUCTION

1.1 Overview

The concepts of time and causality have deep roots in philosophy, especially in the philosophy of science. The following are two early attempts (out of quite many) to characterize what time means; these attempts like all others are to be viewed through glasses adjusting primarily for the historical context of science and philosophy at the time of their writing.

The first passage belongs to Aristotle:

On the other hand, we may examine the more influential view [of Plato] which identifies time with some kind of movement or change. But contrary to this view, a change or movement of anything is in the changing thing only or is where the moving or changing thing itself is; whereas time is everywhere and in all cases alike. Also, unlike time, change is fast or slow. We define "fast" or "slow" by reference to time: that is "fast" in which there is much going on in a short time; that is "slow" in which there is little going in a long time. But we do not define time by reference to so much time or to such and such a kind of time. Hence, time is evidently not movement or change. (We need not, in present context, state how movement and change differ.) . . . time is evidently neither identical with nor independent of movement; . . .¹

Aristotle argues against the claim that time can be identified with *any specific* kind of change or movement, a claim which he attributes to Plato. He brings up two interesting issues:

a. If time is identical to a specific kind of change, then the rate at which the change happens will be mirrored by the rate at which time flows; sometimes the change is fast and time "flies," and sometimes the change is slow and so is the flow of time. To Aristotle this seems not to be the case "unlike time, change is fast

¹ Aristotle, "Physica," trans. R. P. Hardie and R. K. Gaye in *The Basic Works of Aristotle*, ed. Richard McKeon (New York: Random House, 1941), 290.

or slow." The time flow is constant would be Aristotle's view, but here there are some problems. Since Aristotle would not accept time as a Form, he must associate it with a particular process. *Cosmological time*, the succession of day and night and of yearly seasons seems to be the best candidate. This is what he probably had in mind by saying "time is everywhere and in all cases alike." But cosmological changes (or processes) do not have a constant rate of change either, although Aristotle could not know it.

b. Although time cannot be identified with any particular change, time depends on movement or change for its existence. A universe without changes cannot have a time dimension. Change precedes time in a metaphysical sense.

The second selection belongs to St. Augustine:

For what is time? Who can explain it easily and briefly? Who can grasp this, even in cogitation, so as to offer a verbal explanation of it? Yet, what do we mention, in speaking, more familiarly and knowingly than time? And we certainly understand it when we talk about it; we even understand it when we hear another person speaking about it.

What, then, is time? If no one asks me, I know; but, if I want to explain it to a questioner, I do not know. Yet, I say with confidence that I know that, if nothing passed away, there would be no past time; and if nothing were existing, there would be no present time.

Then, how do those two periods of time, the past and the future, exist, when the past is already not existing, and the future does not yet exist? And again, the present would not pass away into the past, if it were always present; indeed, it would not be time but eternity. So, if the present, in order to be time, must be such that it passes over into the past, then how can we say that it *is*; for the sole reason for its existence is the fact that it will stop being; that is to say, can we not truly say that time *is* only because it inclines not to be?²

Trying to make statements about time is sometimes confusing because ambiguity in words such as 'is,' 'flow of time,' and even 'present,' 'past,' 'future,' and also because a

²Saint Augustine, *Confessions*, XI, in *Fathers of the Church* edited by R. J. Deferrari et al., (New York: Catholic University of America Press, 1948), 343-344, quoted in Vernon J. Bourke, *The Essential Augustine* (Indianapolis: Hacket Publishing Company, 1974), 229.

lack of clarity in the associated concepts. Augustine discusses some of the confusion related to the popular view of time flow from past through present to future.

Modern science has brought new dimensions to the questions of time and causality which have not simplified the issues. The Special Theory of Relativity redefines 'time' and 'simultaneity,' while Quantum Mechanics redefines 'causal relations' in the physical world.

Although each of the two concepts of time and causality is still waiting for further philosophical investigation, their interdependence seems to be widely accepted. This is somewhat intriguing because on one side their interdependence seems to persistently withstand various situations of test cases and, moreover different interpretations of "time" or "causality," and on the other side there is no clear convergence of the philosophical debate to why this is so. Causal relations are invariably perceived in time suggesting a strong correlation between the two. The question naturally arises whether the concepts of causal order and time are necessarily dependent on each other. The traditional philosophical positions are in favor of a necessary connection but, interestingly enough, they disagree on what form the connection takes. There are a few possible dependency roads to take.

One road leads to the strong claim that time is reducible to causal relations. Causal chains define the flow of time. This is the path Hans Reichenbach takes in his last book³. Causality is a time-independent concept, explained by *probabilities*. In other words, statistical correlation between events ties them in causal chains, which in turn define the flow and the direction of what we call time.

A second road to follow might be the claim that causal relations and causal order are reducible to time. Not surprisingly, this claim has not been made, most probably because

³Hans Reichenbach, *The Direction of Time*, ed. Maria Reichenbach (Los Angeles: University of California Press, 1991), 24.

the concept of causality is perceived to be a much broader encompassing concept than time is. Most philosophers have taken a third road which leads to the different but similarly strong position that a time relation is a necessary condition for establishing a causal relation (see Hume's view in 3.1 below). The basic link of a causal chain, the individual cause-effect relation, must include as a necessary condition that the event called 'cause' precedes in time the event called 'effect.'

If the necessary connection is not accepted, then one might argue either that there is no connection at all or that the connection is contingent on other factors. As far as the books I reviewed teach, there is nobody claiming that no connection exists. In fact I have only encountered positions that assume or argue for a necessary connection. Starting from this assumption philosophers are then faced with challenges such as time travel, time reversal and backwards causation. For instance, any trip taken in the time dimension (called somewhat improperly 'time travel') necessarily has effects on some causal chain; if the trip is into the past, it affects an existing causal chain, and if the trip is into the future, it establishes causal relations before the time of the normal occurrences of the events involved. In both cases contradictory situations might arise. Even if the contradictions are somehow avoided (usually by adding artificial rules to the experiment), the causal outcome of time travel is not easily justifiable, and naturally casts serious doubts about the premise of the possibility of time travel.

This thesis will present and defend a slightly different view of the relation between causal order and time order, one which does not require the assumption of their necessary dependency in a logical or even metaphysical sense. I shall show that causal chains can be consistently conceived without involving time. As such, they allow the cause to be in *any* time relationship to its effect. Time can be also conceived independently of causality; in this thesis time (spacetime) is assumed to be an epistemic tool, part of the frame of reference for the understanding of the physical world, and there is no

commitment to its metaphysical status. If a causal chain of events is entirely contained in the physical world (which seems to be an assumption made by many philosophers), then it will take place in spacetime and be consistent with the major, accepted theories of physics. However, this should not imply a preferred time direction.

The thesis reviews the issues related to the concept of causality in section 3 and those related to time in section 4. It is obviously not an exhaustive inclusion of the issues of time and causal order. I have tried to explain and discuss only the problems that are connected with the assumed correlation between time and causal order. Even within this context the discussion is only a partial account, narrowed down mostly to the classical aspects of time and causality (with one or two exceptions).

Sections 1 and 2 set the stage of the discussion by delimiting its scope and defining its context. Sections 3 and 4 consist of a few introductory parts that explain existing philosophical positions and debates, followed by one or more claims I would like to make regarding the issues involved, such as forward and backwards causation, the arrow of time, time reversal and time machines.

1.2 Assumptions

A number of basic assumptions are made in this work. Some are easy to recognize even if they are not explicitly stated, e.g., the existence of time, the existence of causal relations between two or more entities. Other assumptions, although very important, might be hidden and need to be made explicit:

1. It is assumed in this thesis that the principle “every event has a cause” is true. This assumption is mentioned and shortly discussed in section 3.2.1. It is the most important assumption I make in this thesis because it touches upon a very basic issue in philosophy. Does the assumed principle mean that if an event took place and no cause could be identified, we would still believe that the event had

been caused? Yes, that's exactly what it means. I should emphasize here that nowhere in the thesis does caused mean self-caused. This trivial form of causality (although not trivial under other aspects) is not discussed because it does not fit into the context of the thesis, i.e., it sheds no light on the issue of backwards causality or the connection with time flow. To summarize, it is assumed that every event has a cause which is other than itself. The meaning attributed to the concept of cause or causal relation may vary, but the underlying assumption will not change. The principle can be also stated as "every event is causally-related to a non-zero number of other specific events."

2. It is not assumed that events are ontological atoms. Other ontological entities might exist, and might (but are not required to) be causally connected. Moreover, although events can cause other events and are themselves caused by other events, their metaphysical status is not necessarily unrelated to other entities (e.g., objects, ideas, emotions, etc.). Still, the principle "every event has a cause" applies only to events and, as far as this thesis goes, causal chains are exclusively built of events.

Davidson discusses the metaphysical importance of "events," sentences about events, and some of the aspects of causal relations among events⁴. Davidson refers to events in a way in which they seem to be "descriptive entities," some form of a (short) story. An event can be John getting married, a person drying himself with a towel, a fire, etc. The description of an event is made out of statements which Davidson analyzes using symbolic logic tools. He and other philosophers cited in his essays, such as Hume, Mill, and more recently Strawson use a "high-level language" (e.g., English) to describe an event, which leads to a certain amount of

⁴Donald Davidson, *Essays on Actions and Events* (New York: Oxford University Press, 1980), 103.

vagueness in the range or the limits of what should be included in the event and what should be left out. Davidson identifies a number of classes of events, such as "changes in a substance," "mental," "particular vs. general," "eternal vs. ephemeral," and so on⁵. He says: "I do not doubt that Strawson is right in this: most events are understood as changes in a more or less permanent object or substance."⁶ However, he disagrees with the unidirectional dependence of events on objects, and defends events as being a fundamental ontological category. Davidson also proposes that ". . . the causal nexus provides for events a 'comprehensive and continuously usable framework' for the identification and description of events analogous in many ways to the space-time coordinate system for material objects."⁷

I would like to define all events in terms of changes in objects, and more generally, changes in a system. This approach is in some ways different than Davidson's and others, as explained below. A set of entities forms a "system." In its most general form a system can be a mixed collection of physical and non-physical "things." A system can be subjectively selected by a specific observer, or agreed upon collectively by a number of observers. Changes in an existing, relatively stable state of a system are called "events;" a change is the set of differences between two distinctive states of a system. This definition gives ontological priority to objects, which is in disagreement with Davidson's view.

The above definition needs further discussion. Events as changes in the system state might have a convoluted description. The system state should be defined in physical terms of position, velocity, energy, temperature, etc. of its physical

⁵Ibid, 174, 190, 207.

⁶Ibid, 173.

⁷Ibid, 180.

objects, and also in the appropriate vocabulary regarding its mental objects.⁸ Any change in the state of the system as described will be considered an event although may be not a significant one. This includes a change in speed, or temperature of one of its physical objects, a new idea in one's mind, and so on. Since the description is not in ordinary language, it might not give to a person a direct idea of an event in the sense Davidson and others talk about events. For instance, "the house is burning" is the description of an event for Davidson. Under my definition, the system of objects that includes the house and maybe other items, will undergo a series of changes, temperature increase, chemical reactions, etc., that are equivalent to the burning but they give only an indirect description of the event.

Events as changes are traditionally associated with a time dimension. The approach in this thesis is to separate causal chains of events from their implicit, though unwarranted time dimension. This will be a passive separation in the sense that no dependency on time will be assumed.

Questions regarding backwards causation involve the (implicit) assumption of time going forward. Most commonly, backwards causation is described as the effect preceding its cause *in time*. Similarly, time travel of macroscopic creatures is typically associated with entering time-machines that would transport a person into the past or future, consisting of a realm of events that have direct and indirect causal connections to his or her present.

It will be shown that correlating causal order and time is possible in more ways than the one usual way in which cause precedes effect in time.

⁸Mental objects represent here all flavors of non-physical objects. It is not my intention to claim a dualistic ontology, but to allow both sides of the dispute to accommodate my definition of "system."

3. Is there a connection between causality and time? As mentioned, the traditional answer admits a necessary connection, and varies from the relatively “mild” position requiring that cause must come before the effect (causal order and time order are always the same) to the strong view that time is reducible to causality. True, it is quite difficult to think about one without involving the other, but that is not sufficient to justify the assumption that some sort of connection exists. This thesis argues against the assumption (found elsewhere) of the correlation between time and causality, and describes a symbolic graphic representation of causal chains without involving time (see 1.3).

1.3 Chain representation

In this section I try to show a possible graphic representation of chains that will help to separate the causal order and time flow concepts. The basic attributes of the chain are its order and the connections between the links. Chains are also geometrically unidimensional. Although the word ‘chain’ is normally used for causal connections, the causal interdependence is not necessarily unidimensional; nevertheless, for the sake of simplicity, I will keep the chain idea. Time and causal chains (and perhaps other types of chains or successions) can be represented by a sequence of numbers using some simple basic definitions that relate the metric of the sequence (the interval unit) to a time interval or a unit of causal relation. At a minimum, the sequence of numbers expresses the order that the chain is supposed to have which is the most important characteristic of the chain, at least in respect to this thesis topic. For chains having an identifiable beginning and distinctive steps, the so-called natural numbers (1, 2, 3, 4, etc.) would suffice; other chains are open-ended on both sides and may require integer numbers (.....-3, -2, -1, 0, 1, 2,). Time, because its special situation in the theories of physics, can have different representations. One area of complexity in the determination

of how time should be represented is the question of continuous versus discrete time (which translates into real versus integer numbers).

A chain order does not necessarily imply a general direction (arrow). The order is local and has to do with what comes after what. The arrow is global and has to do with a direction defined by general principles; the chain advances to the right or to the left. A general direction of time for example would imply that if we select any finite interval of the chain (that is large enough to mask local fluctuations of the direction), we always find the same direction of flow. The direction of time flow can be determined by an unidirectional universal process such as the generation of heat during energy exchanges, (known as the "thermodynamic arrow of time"), or by the evolutionary expansion of the universe (the "cosmological arrow"). The arrow is not tied necessarily to the increasing value of the numbers in the chain. Cosmological time may reverse because the evolutionary process reverses direction (its unidirectionality works indeed for very long periods of time, or many evolutionary changes, but not for ever). If periods of one direction in time alternate with periods of the opposite direction, then a time interval chosen such that it covers time going both directions might show a general direction either way or even no direction. However, the numbers in the chain always increase to show the order of the time instants that form the chain.

Such a model reflects a position in the issue of the essence of time, which is that there is an underlying "mathematical time" that supports the "physical time." Mathematical time is an abstract model made to reflect our understanding of physical time. It is analogous to geometrical figures: it has idealized properties and makes a good analysis tool. For example, since the mathematical model of time is not tied to a specific physical process, it does not have to change its rate of flow with changes in the process rate; the model can keep a perfectly constant unit of time. This is similar to the idea of analyzing

the properties of a (physical, e.g., wood) triangle using a geometrical model made of “perfect” straight line segments.

A number of physical interpretations of time can be accommodated with such a model; in particular it may accommodate unidimensional or multidimensional time, unidirectional (either direction) or bidirectional, uniform (constant rate) and non-uniform flow, and so on. The assumption of mathematical time implies that physical time *can* be modeled using mathematical tools. Without the modeling tool, any reference to time would be a reference to some specific physical process or processes that would severely limit the development of our concept of time. As an example, if time had been defined by planetary motion only, the issue of time would have been “closed” by classical mechanics, relativity would never be considered an option, and motion at subatomic level would have a different description. The use of the model allows us to detach time from any specific process and revise it to include new properties. The revisions of the model we have in the light of newly understood physical (and non-physical) processes allow us to develop a deeper understanding of what time “is.”

The traditional description of the macroscopic world is consistent with information provided by our senses and with a possible inclination to “see” the world this way. Euclidean geometry and Newtonian mechanics are common-sensical. They lead to chains represented by sequences of numbers that grow indefinitely and at a constant pace; that is the nature of Newtonian time (and its arrow), and of forward causality, especially in a deterministic context.

A particular causal chain is formed by a particular succession of pairs of events, each pair consisting of one cause (C) and one effect (E). Causal relations tend to be more complex requiring a network of links in which an event can belong to different chains and connected to more than two other events in the same chain. Still, at any level of complexity, the causal chain can be conceived, and possibly described and characterized

without reference to time, and vice versa. One does not necessarily imply the other. The causal chain is a succession of changes in the system state, each of which is identified to be the effect of the previous event and the cause of the next one. The succession is not generated by chronological order but by cause/effect order. Time and time order might take part in causal relations but need not to be assumed as such.

A highly simplified version of a causal chain is shown in Figure 1 below; each event in the chain is both the effect of the previous event and the cause of the succeeding one, and nothing more. The particular location of an event in the sequence defines only its causal relationship to other events (not the time relationship).

Figure 1: Illustration of causal and time chains

Here is an everyday example of a sequence of 3 events:

<position of moon> is sequentially prior to
<sea level goes up> which is sequentially prior to
<fisherman prepares boat>

A causal chain can be conceived from this ordered set of events, which does not require reference to time. The phrase "is sequentially prior to" would mean in this case "causes." A time chain can be conceived as well, based on the same 3 events, and in a

similar manner the time chain needs no reference to causal order. "Is sequentially prior to" would mean in this case "precedes in time."

To be sure, the way in which causal connections are identified in this example is not complete. It is a short-form of cause-effect relation identification which is, to my knowledge, the most used way. The complete story contains the rest of the variables that sufficiently explain the effect. I am taking here Mill's side who says "the cause is the sum total of the conditions positive and negative taken together . . . which being realized, the consequent invariably follows."⁹ This list of conditions can be very long, possibly infinite, and if any item on the list is missing then the identification of the cause is incomplete and therefore vague. The example above is not absolved from having a certain amount of vagueness. Most identifications of causal relations are like that.

For instance, one omitted factor in this example is the fisherman making a prediction, scientifically based or not, about the expected sea level. This might be a significant factor, leading to the event "fisherman prepares boat." Other variables that can participate in the causal relation, such as the fisherman health during that time, his other commitments, his boat being available, etc., do not change or are causally insignificant, and therefore they are not identified as causes. They are included in what I refer to as "the relatively stable state of the system," the system being composed of (at least) fisherman, boat, sea and moon. It is also clear that the short-form identification of the cause is not unique. Moreover, even a complete explanation of a given event is not necessarily unique.

As mentioned, a sequence of events can be entirely ordered by causal relations alone or by time relations alone, and they do not necessarily match. Using the last example, causal relations might order the sequence as follows:

⁹J. S. Mill, *A system of Logic* quoted in Donald Davidson, *Essays on Actions and Events*, (New York: Oxford University Press Inc., 1980), 150.

1. position of moon causes
 2. sea level goes up which causes
 3. fisherman prepares boat

while the time order might be different:

1. fisherman prepares boat (today)
 2. position of moon (tomorrow)
 3. sea level goes up (tomorrow)

In this model of numerical sequences time travel or causal travel could be thought of as a phenomenon (capability) to jump along the sequence of numbers, without paying attention to its inherent order.

2 APPROACH

The thesis includes a survey of the meanings of causal relations with an emphasis on backwards causation, the meanings of time relations, time reversal and time travel, and some ways in which causality and time can be correlated. I shall begin by outlining my approach:

1. After an examination of the different meanings of causal relation and of backwards causality with a closer look into physical and non-physical causality I claim that causal chains can be logically defined and conceived without an appeal to time reference frames. In order to maintain a consistent distinction of causal vs. non-causal processes, causality cannot be inverted. Divorcing causal connections from spacetime, especially time, would mean that they are also independent of the physicality of physical events, all of which take place in spacetime. This will be explained later; as an example one can think of parapsychological-like events that cannot be explained in scientific terms, but can form a causal chain of events. A number of possible meanings (different shades of causality) can result. We can devise a context for each one of the shades based on the ways each shade is tied to the physical laws. Backwards causality, as presented in literature, is also discussed; it seems that a major part of the work done on this subject equates the term backwards causality with some sort of change in the normal evolutionary process of the universe as a function of time.

2. An examination of the concepts of time reversal, negative time and time travel. Here I would like to claim that the meaning of negative time in the mathematical description of the microscopic world of particles cannot be applied to the macroscopic world without violating its own model. Therefore, macroscopic time travel is quite incoherent. Thought experiments with time machines are inconsistent with the assumptions made in order for the machines to exist.

3. Introduce time or spacetime into the causality concept. Of course, once we are doing that, we might be limiting our scope to some sort of physical causality. Still, there are quite a few critical issues to be cleared up in order to understand the underlying connection between causal processes and the "arrow of time." One of the most interesting issues for this thesis is the investigation of the supposedly four possible combinations of cause/time directions.

4. A brief reference to the change in the meaning of the concept of causality when Quantum Mechanical effects are included, and the meaning of time/spacetime when relativistic effects are included.

3. CAUSAL ORDER AND ITS RELATION TO TIME

3.1 Survey of existing views

3.1.1 Hume

Hume claimed that (when dealing with matters of fact) a "conclusion beyond the impressions of our senses can be founded only on the connexion of cause and effect."¹⁰ This requires the most serious inquiry into causal relations. Hume's critique of some of the possible meanings of cause was fundamental. He wrote:

Here is a billiard ball lying on the table, and another ball moving toward it with rapidity. They strike; the ball which was formerly at rest now acquires a motion. This is as perfect an instance of the relations of cause and effect as any which we know either by sensation or reflection. Let us therefore examine it. It is evident that the two balls touched one another before the motion was communicated, and that there was no interval betwixt the shock and the motion. *Contiguity* in time and place is therefore a requisite circumstance to the operation of all causes. It is evident, likewise, that the motion which was the cause is prior to the motion which was the effect. *Priority* in time is, therefore, another requisite circumstance in every cause. But this is not all. Let us try any other balls of the same kind in a like situation, and we shall always find that the impulse of the one produces motion in the other. Here, therefore, is a *third* circumstance, viz., that of *constant conjunction* betwixt the cause and the effect. Every object like the cause produces always some object like the effect. Beyond these three circumstances of contiguity, priority, and constant conjunction I can discover nothing in this cause.¹¹

Hume's analysis is obviously framed in the mechanist, Newtonian world of macroscopic bodies and events. His identification of the necessary and sufficient conditions of a cause-effect relationship in that type of world, even if accepted, is still subject to a clear understanding of contiguity, priority, and the statistics of repetitions,

¹⁰David Hume, *A Treatise of Human Nature*, ed. L. A. Selby-Bigge (Oxford: Clarendon Press, 1978), 74.

¹¹David Hume, "An Abstract of *A Treatise of Human Nature*," *An Inquiry Concerning Human Understanding* (Indianapolis: Bobbs-Merrill, 1955), 186-7.

which are quite vague concepts. Moreover, when the three conditions are projected into processes analyzed with the tools of modern physics, two of them cannot survive when applied to microscopic phenomena. For example, fields of forces (e.g., the electromagnetic field) seem to make the condition of contiguity unnecessary. A charged particle in an electric field would change its motion without the need for what Hume calls an "impulse" from another particle. Hume must have been aware of magnetism at the macroscopic level. It is easy to demonstrate how one magnet moves pieces of metal from a distance - no contiguity by physical contact is required. This would supply a counterexample to his account of necessary conditions for a causal relation. Here we experience an identifiable causal connection between the movement of the magnet and that of the piece of metal, but we must allow for "distant contiguity" (a contradiction in terms) in order to be consistent. One might argue that contiguity should be defined by a range of distances, from zero (contact) to some small finite distance. The problem is that it is always possible to find a stronger magnet that can move pieces of metal outside this contiguity range.

The contiguity issue can be developed into a much wider discussion within modern physics when the field is represented by its own type of particles, which mediate the interaction between fields and particles. This would seem to be a reduction of all known physical interactions (between fields and particles of matter/energy) to the interactions of (smaller) particles, which represent both what we are used to call particles and what we are used to call fields. Now, apart from getting too far away from the original idea (and not knowing how Hume would adjust his claims), there is one more piece of information which Hume did not know: the duality of wave-particle. The concept of particles striking each other is different at the subatomic level. Contiguity should be redefined since the location of a particle-wave has a new meaning, adopted in the concepts and equations of Quantum Mechanics.

To go back to Hume's example, priority in time is another necessary condition. This condition has been best preserved through the scientific and philosophical developments. In science it is part of the definition of causal systems. Although some physical models of particle behavior use the idea of negative time¹², they also modify other parameters of the particle (charge for example) to make it equivalent to a particle that travels in positive time, and therefore the negative time description could be interpreted as not more than a mathematical exercise that reduces the complexity of analysis. In philosophy it seems to be widely agreed that priority in time in respect to effect is one of the attributes of cause.

The third condition identified by Hume, is repetitive behavior. However, it cannot count as necessary because on any possible physical time scale there could be a single pair of events that are causally connected and never repeat. It is obviously not a sufficient condition since there are many examples of successions of events that are repetitive but not causally related, e.g., night-day succession, eating-sleeping succession, etc.

The main point in Hume's critique remains that a causal process is a process empirically identified and must contain all three necessary conditions which together lead to the belief in a cause-effect relationship. Hume recognized that an underlying connection should be responsible for the perceived causal relation but such a view seems difficult to support within the empiricist frame. The empiricist view can allow for a deeper (non-observable) connection between events, but that connection should remain essentially out of reach for the human mind.

In my view Hume's account of necessary and sufficient conditions for identifying causal connection is incomplete, and actually does not include the most essential features. The contiguity Hume is talking about is good for the interaction of billiard balls, but not a necessary condition to bend light in a gravitational field. To require a (ever) lasting

¹²Richard Feynman, "The Theory of Positrons," *Physical Review* 76 (1949): 749-59

repetitive behavior is to require the works of a law of nature. He says: "Tis the constant conjunction of objects, along with the determination of the mind, which constitutes a physical necessity: And the removal of these is the same thing with chance."¹³ The physical necessity or natural law would have to state some relation(s) between the events analyzed, and be represented by a mathematical expression which has the power to express relations in an absolute way (as required by laws of nature). Of course, we should use the term "absolute" carefully; mathematical expressions are absolute, but as representation of physical reality they hold only in a limited way. Other representations would have been possible if we knew other mathematics-like languages.

In the frame of Newtonian physics the billiard balls would collide in an elastic type of collision, under the laws of conservation of energy and of momentum. Balls A and B would have each an initial energy and momentum before the collision, and a final energy and momentum after the collision. If the experiment is repeated with exactly the same initial energies and momenta, the final values will also repeat. Time after time the experiment will lead to the same pair of events: the initial state S_i , where A and B have given initial energy and momentum and the final state S_f . Suppose now we change the conditions of the experiment by making a slight change in S_i . Based on the law-of-nature account, the new S_f would be easily calculated and predicted. Using Hume's account however, there is no way to make any prediction. Only after a number of trials with the new S_i , a statistical expected value can be derived which would be reinforced or weakened by subsequent trials. (Hume does not claim this; he agrees that the mind leaps to acknowledge a necessary connection even after one successful and clearly understood experiment.¹⁴) The superiority of the law-of-nature is quite evident. Its strength comes from its predictive power which covers both a wide range of initial conditions and the accuracy of

¹³David Hume, *A Treatise of Human Nature*, ed. L. A. Selby-Bigge (Oxford: Clarendon Press, 1978), 171.

¹⁴Ibid, 104.

the predicted values, and I believe that cause-effect relations are identifiable and meaningful only when viewed from a perspective that starts with a set of contextual laws.

3.1.2 From Hume to others: meanings of cause and causal connections

Early in his life Bertrand Russell had followed Hume's critique by warning philosophers about any appeal to causality¹⁵:

All philosophers. of every school, imagine that causation is one of the fundamental axioms or postulates of science, yet, oddly enough, in advanced sciences such as gravitational astronomy, the word 'cause' never occurs. . . To me it seems that . . . the reason why physics has ceased to look for causes is that, in fact, there are no such things. The law of causality, I believe, like much that passes muster among philosophers, is a relic of a bygone age, surviving, like the monarchy, only because it is erroneously supposed to do no harm.

Later in his life Russell recognized the fundamental role of causality in science and scientific knowledge¹⁶.

The nature of the relation of causality and the relata involved in the relation is controversial. A survey of the various approaches to causality is given by Mackie¹⁷. Some maintain that propositions rather than events should be the entities involved in causal relations. Individual events cannot be said to participate in such relations directly, but only through their membership to a specific class of events that is covered by the propositional causal relation.¹⁸

Another question relates to the meaning of cause as a condition for the effect. Is it necessary, sufficient or both? Alternatively, perhaps the cause of an effect is neither a

¹⁵Bertrand Russell, *Mysticism and Logic* (New York: W. W. Norton, 1929), 180.

¹⁶B. Russell, *Human Knowledge, Its Scope and Limits* (New York: Simon and Schuster, 1948), 487-96.

¹⁷J. L. Mackie, *The Cement of the Universe* (Oxford: Clarendon Press, 1974).

¹⁸Wesley C. Salmon, *Scientific Explanation and the Causal Structure of the World* (Princeton: Princeton University Press, 1984), 138.

necessary nor a sufficient condition for the effect since causality is a statistical correlation. Mackie proposes the term "INUS condition," which is an abbreviation for *insufficient but non-redundant parts of unnecessary but sufficient* conditions. The idea applies to causality of events (as opposed to causality of propositions) and may be illustrated as follows: there are many sufficient conditions that can account for a house to burn down, e.g., smoking in bed, electrical short circuit, arson, etc. None of these conditions is necessary, but in order to be sufficient they must contain a complex set of auxiliary conditions that are non-redundant. For example the smoker must fall asleep, while the cigarette falls on something flammable, and so on. All these components are by themselves necessary for the scenario to take place, and for some philosophers they qualify as causes themselves.

Salmon¹⁹ opposes the standard view of event-oriented causality; he proposes a new approach based on the distinction between "causal propagation" and "causal production." Causal production is a more or less direct causal relation: a horse pulling a cart, a hammer driving a nail, etc. Causal propagation is mediated only through memory. Early events affect current behavior. Similarly, the propagation of signals through space and time (by the means of electromagnetic waves for example) lead to causal propagation. In a most general form causal propagation is the influence of events at a given place and time on other events at a different place or time.

. . . According to this standard approach, events enjoy the status of fundamental entities, and these entities are 'connected' to one another by cause-effect relations.

It is my conviction that this standard view, in all of its well-known variations, is profoundly mistaken, and that a radically different notion should be developed. . . . The two basic concepts are *propagation* and *production*, and both are familiar to common sense. . . . When we say that a horse pulls a cart, we mean that the force exerted by the horse produces the motion of the cart. . .

¹⁹Ibid, 135.

Causal propagation (or transmission) is equally familiar. Experiences that we had earlier in our lives affect our current behavior. By means of memory, the influence of these past events is transmitted to the present (see Rosen, 1975). A sonic boom makes us aware of the passage of a jet airplane overhead; a disturbance in the air is propagated from the upper atmosphere to our location on the ground. . . As all of these examples show, what happens at one place and time can have significant influence upon what happens at other places and times. This is possible because causal influence can be propagated through time and space. Although causal production and causal propagation are intimately related to one another, we should, I believe, resist any temptation to try to reduce one to the other.²⁰

Salmon is correct in distinguishing causal propagation from a straight causal relation as described by Hume. Causal propagation through memory is experienced by everyone. Childhood experiences are among the factors that build up our behavior as grown ups. Let's look at an even simpler example. After I am introduced to somebody and remember her name, I will call her name the next time I see her. Now, what is the cause of me calling 'Ann'? It is reasonable to include the memorized name as one of the components of the cause of the event. But memorized information cannot count as contiguous in spacetime to a specific effect. Although one might argue that memory is a physical device that has spatio-temporal existence and continuity, what counts for causal connection is the information and not the storage device or the transmission device. Put in a more general way, the components of a cause are not necessarily contiguous in time and place to the effect.

Salmon proposes to use processes instead of events. Events are localized in time and space, while processes can extend over space and periods of time. On a space-time diagram events are represented by points and processes by lines. Space-time diagrams will not be discussed in detail in this thesis. It suffices to point out that they are used as

²⁰Ibid, 138-9.

graphic tools in science and the philosophy of space and time. The following is a brief description of how to use them.

Figure 2: Space-time diagrams and world lines

Essentially every (physical) event can be located in spacetime, and consequently represented by a point on the diagram. Each point P can be associated with two cone-like patterns that define the extent (in space and time) of all the events that could affect P (the past light cone) and the events that could be affected by P (the future light cone) - see Figure 2. The shown space-time diagram is a two-dimensional graph. The horizontal axis measures the distance from origin and the vertical axis measures the time interval from the origin. (A complete diagram should be 4-dimensional to include time and three space dimensions.) An event called "P" at the origin serves as the reference time and location. Any item on the graph follows a "world line" which shows its distance from P at all times. An item can be anything we would like to represent, such as a sub-atomic particle motion, a laser beam trajectory, or a running puppy. As time passes, the world line will have to move at least in the vertical direction. An item that comes into existence at P and does not change its distance in respect with P will follow a world line along the

vertical axis ("A"). If the distance from P increases with time, the item can follow a line such as B, C, or D, depending on its speed. C corresponds to the speed of light and it is arbitrarily shown at 45° . D moves at a speed higher than the speed of light. A world line along the horizontal axis (not shown) implies infinite speed since the distance changes in zero time.

The past and future light cones assume that the time has an arrow, at least locally in P's vicinity, and that causality is constrained by space and time, and by the arrow of time. Only events represented by points inside the cones can be causally connected or causally relevant to P. This follows from the absolute limitation posed by the speed of light that, regardless any specific frame of reference, no signals can be communicated faster than the speed of light. (The issue of tachyons, theoretical particles that move faster than the speed of light, which might have a use in the realization of a time machine is briefly mentioned in section 4.3.)

Understanding causal relations as involving processes instead of events makes the transition from cause to effect smooth and continuous, and that provides a strong physical context to the question of identifying the cause of an event. The event E is caused by the set (the totality) of one or more world lines coming from the past light cone of E and which intersect at E. One can track the causal connection back indefinitely, or might, for simplicity purposes, identify one event on each of the world lines involved, and call them the cause of E. However, the assumption that the world lines participating in the birth of E are all from its past (light cone) is not necessary. It is normally assumed in all physical systems, as explained in the next section. Another assumption is that there is at least one world line that leads to E. This is a translation of the principle "every event has a cause" on a space-time diagram. Events cannot occur on the diagram without a continuous trace into their past.

Salmon and others treat causality from the scientific explanation perspective, which is the direction I would like to take in this thesis. Van Fraassen equates (scientific) explanatory knowledge with answering a “why” question.²¹ The classic “*covering-law model*” of explanation (see for example Hempel²²) is based on two elements: the contextual background of laws (and beliefs), and the specifics of the event that needs to be explained, which are specific facts that relate to the event through the background laws. I tend to agree with this view. The cause can be identified as a set of facts that are part of the explanation, preferably the most relevant changes in a relatively stable state of the system. Cause-effect is not only an empirical-based, statistical correlation, but is also a way of explanation why the effect happens. The (scientific) explanation does not have to be absolutely true. It has to be true or accepted as true within the existing scientific paradigm. Then when I say that C causes E, I mean that given the scientific background and the specific conditions, C which implicitly contains all of them is sufficient to cause E. E is a predictable effect of C.

3.1.3 Causality in physical systems

Literature about time travel and backward causation tends to blend the temporal order with the causal order. Many authors talk about a necessary connection between the two. As an example of the strong ties between the two concepts, I would like to point out that in the technical literature of science and engineering a “causal system” is defined as a system that reacts to any input disturbance only after the disturbance occurs. More precisely, the output reaction to an input occurring at time zero ($t=0$ is arbitrary) exists only for $t \geq 0$. A system which displays any output prior to $t=0$, that is a reaction to the input at $t=0$, is considered non-causal, and is normally ignored by the models built to

²¹Bas van Fraassen, “The Pragmatics of Explanation” in *The Philosophy of Science* edited by Richard Boyd, Philip Gasper, and J. D. Trout (Cambridge: The MIT Press, 1992), 317-27.

²²Carl G. Hempel, *Philosophy of Natural Science* (Englewood Cliffs: Prentice Hall, 1966)

represent real, or physical systems. See Figure 3: the time relation between a generic input signal and the output caused by it is illustrated in both cases of causal and non-causal systems. It should be also noted that there is no other relation accompanying the cause-time relationship (as defined) that would be involved in distinguishing causal from non-causal. It is not surprising that neither the scientist nor the engineer deal with non-causal behavior. They cannot afford to analyze systems that respond to non-existent input signals. Non-existent input signals are, of course, to be understood as non-identifiable as present at the time of the output. A (physical) system is always causal. Therefore, the presence of an output is always a response to (and a proof for) a preceding input in time. The route of identifying the cause is as follows: suppose we witness an event, which is the effect of some cause (in virtue of the principle "every event has a cause"). Then using the scientific criterion for causal, we disregard any inputs later than the output. From the remaining candidate inputs for the position of "cause," all of which are prior to the output, we now have to isolate the winner. There must be at least one more criterion for selection because the number of candidates is indefinitely large. This other criterion has nothing to do with priority in time.

Such a criterion is independent of the scientific criterion of "cause-precedes-effect" (CPE). One does not depend on, or involve the other. The use of both as the sufficient condition for identifying the cause is arbitrary. It is not a requirement posed by any physical law or philosophical argument. Implicitly physical laws and philosophical arguments might assume the CPE criterion. As such, they are not in the position to prove or support the assumption because of the possibility of a circular argument. My claim is that assuming CPE is only a matter of convenience. It is a valuable tool since it makes many good predictions, but the assumption has not been appropriately proved or supported on philosophical grounds.

Figure 3: Time relations between Input and Output

Figure 3 shows the input and the output wave forms with notable different shapes. One might wonder about the relation between the two shapes. Although in many cases the shape of the output resembles that of the input, it is not necessarily so. The following is in support of this claim, which is contrary to the way most people tend to think (namely that the wave form at the output must resemble the input). Without knowing the system, the shape of the output wave form is not predictable. I would like to use two examples to illustrate the lack of correlation between the two shapes. The first has to do with echo. A natural echo generator, say a mountain, is our example system. An input to the system can be an acoustic impulse (e.g., a short sound of a horn). The output is going to be a series of impulses with decreasing intensity, and at time intervals that depend on the distances between the natural walls that act as sound mirrors (see Figure 4 on the next page).

This repetitive wave form is hardly predictable from the single impulse at the input if the system is not known. However, although the shapes are quite different, one can

reasonably argue that some correlation can be found. My second example involves more complex systems. Such systems perform elaborate processing on their input, and produce an output having no resemblance to the input that has initiated the processing. (I cannot say “caused by the input” because the input is only a piece of the puzzle called cause, as will be explained later.)

Figure 4: Waveforms and time relations between Input and Output of an echo generator

A laser will convert some electrical energy into a very special beam of light. The input and the output are different in many ways; for one thing, we cannot detect both with the same human sense (which was possible in the case of the echo system) or even the same piece of measuring equipment. The same holds for an FM radio receiver, a tape recorder, a cat, a computer, etc. In general, the output wave form shape or its

resemblance to the input cannot be considered as necessary indications of causal relations.

Imagine now a repeatable experiment in which two events X and Y happen within a very short time interval, first X then Y. This by itself is not sufficient to justify attributing a causal connection between X and Y. The scientist could suspect that a causal connection is present, and try to explain the occurrence of Y within the existing scientific frame of knowledge (laws of physics) given that X happens. If he or she succeeds, then the causal connection is established and incorporated in the scientific knowledge. If Y cannot be explained, then some modifications (minor or major) are introduced to the existing frame of knowledge so as to allow for the explanation. But there is another way to go, which is never explored in science: explain X by Y. In the terms I would like to use in this thesis this is not backwards causation (as explained in the next section 3.2), but simply a case in which the effect precedes the cause in time. The reason this path of possible explanation is never explored is because it leads to a dangerous road: the road of non-causal systems. I would imagine that a great deal of scientific knowledge would be changed in order to provide an explanation of Y by X before the scientific community would give up and accept an explanation of X by Y.

The puzzle of backwards causation is generated when one takes a scientific stand on the matter of how the time relationship between cause and effect should be, and examines the possibility of an inverse relation. The next section is devoted to the question of backwards causation under the context of time relationship.

3.2 Backwards causation

Two of the most common meanings of backwards causation are time related. I will show below that the implicit relation between causal flow and time flow does not lead to a consistent concept of backwards causation. One type of backwards causation deals with

time reversal, and the other is about effect preceding cause. Both have to assume a preferred direction of time, or the natural arrow of time, which is the direction we perceive as a result of (so-called) irreversible processes. A simple illustration is a playback situation of a tape which contains a description of all physical processes in the universe. Our universe seems to have a specific direction of playback: it always plays Side A. Time reversal is reversing the direction of playback, not to hear Side B of the tape but to hear the same side, Side A, in reverse. All processes in the universe will happen backwards in terms of their initial order, without changing any other detail of any process. The reverse playback is supposedly continuous, so that the processes, the components of the processes, the components of the components, etc., are all inverted, microsecond by microsecond, even to the scale of infinitesimally small time intervals. This seems to raise a number of questions, some of which are discussed in section 4.2.

A second way in which backwards causation is understood is by having a specific cause-effect pair reversed in time with the effect preceding its own cause, and without the need for universal time reversal. The analysis in this thesis finds this to be possible in principle. I could imagine a few ways in which this phenomenon takes place, but I think it is wrong to identify it as backwards causation.

The traditional objections to backwards causation uncover logical contradictions that are reached when the assumption of effect preceding cause in time is made. The contemporary philosophical debate is exemplified in an article by Michael Dummett and Anthony Flew.²³ Dummett claims that it is possible to conceive an apple that jumps off the ground to the tree as an example of backwards causation, but that such events do not occur because there is an objective asymmetry in nature and in the direction of causation in time. I should point out that, as far as my analysis goes, this example does not

²³Michael Dummett and Antony Flew, "Can an effect precede its cause" in *Belief and Will*, Aristotelian Society Supplementary Volume 28 (London: Harrison and Sons, 1954), 27-62.

illustrate causal reversal. The movement of the apple is a time process. The apple moving upwards illustrates time reversal (see section 4.2). In my terms the correct description of the causal relation in this example is:

Cause: gravitational pull of Earth (in conjunction with many other implicit conditions)

Effect: apple moving toward the Earth ("falling")

Backwards causation would, in this context, be correctly described as:

Cause: apple falling

Effect: gravitational pull

This is a reversal of the sequence of events in the causal chain (a reversal in the causal flow) and does not involve time. Such a reversal leads in most cases to cause-effect relations that are not consistent with any experience, and even as thought-experiments they are not justifiable; more about that in section 3.2.2 below.

The view Dummett and others hold is different. For them backwards causation would be displayed when the apple returns to the tree. Dummett does support the notion of backwards causation (in time), although he argues that changing the past by present actions seems to be absurd. He identifies a set of conditions under which a later event can be a sufficient condition of an earlier event, and if the conditions are met and the causal connection established, he calls the later event a "quasi-cause" of the earlier event. At least one of the three conditions seems to be extremely difficult to satisfy. This condition requires that the occurrence of the earlier event would have to be inexplicable by reference to simultaneous and precedent events, which is, as I have mentioned in 3.1.3, a most difficult task for any physical event. A positive classification of an event as being inexplicable by events in its past requires the exhaustion of all scientific theories, old

and new, with no success. How could all new theories be tried if many of them are not even known yet?

The second condition is the existence of some reason that an inverse causal connection does not exist. Presumably, Dummett believes that two events are being identified as connected to each other because statistics of occurrence. Given the connection, the causal arrow from early to late needs to be ruled out or shown as improbable. The third condition is the existence of a causal account of the later event without involving the earlier one. Dummett also requires an explanation of the causal mechanism that connects the later event with the earlier one.

Dummett's position is that although neither the past nor the future can be changed (undone), it is possible to affect the past in the same way it is possible to affect the future. His idea, I think, is that by doing something now I might be able to affect future events as well as past events (probably in different ways, using different tools and connections between events). The difference between undoing the past and affecting the past is as follows: the past has already happened and cannot be undone. If I look at past chains of events from the future, I can only get a rerun of an already finished movie. However, in the movie I might see an event (that has already happened) that was caused by an event in the future, which relative to my time, could be past, present, or future. If an event does not happen, it means that I haven't taken the action that was needed for it to happen, and not that I could not take that action. Similarly, when affecting the past, an event that has not happened only proves that I am not taking the necessary action but not that I could not take it. Dummett's illustration of such a causal connection is a weather-expert magician who casts a spell today for having nice weather in Liverpool yesterday. The magician does not know the weather situation before casting the spell, but learns later that the weather was indeed nice. Dummett claims that any argument against this type of affecting the past will also preclude affecting the future.

As I have already mentioned, there is an important distinction between my interpretation of backwards causation and the one in the philosophical debate of Dummett and others, in which causation is mixed with time. For them backwards causation is the situation in which time flows in one direction, with effect preceding its cause on the given time sequence.

In later articles²⁴ Dummett reiterates his belief that backwards causation does not occur naturally but is conceivable. Prayer to God can be for both events in the future and past. Dummett maintains that since God foreknows prayer and can act at the time of the event in question, past or future, retrospective prayer can make sense. Dummett parallels the fatalistic argument to backwards causation. The standard argument for fatalism is analogous to the objection to retrospective prayer. His test examples are of two kinds. One is about the impossibility of changing the past: either your friend has drowned or he has not. Let's suppose you don't know and you try to justify prayer in order to save your friend's life. If he has drowned, your (present) prayer will not be and cannot be answered. If he has not drowned your prayer is pointless.

A second example involves future events. If you are going to be killed, any precautions will be ineffective. If you are not going to be killed, any precautions will be superfluous. Dummett does not agree with the second statement. He thinks that if one is not killed, this may be due to the precautions taken. However, for Dummett the knowledge of the reason why you escaped killing will be ultimately not known.

Although I do agree with Dummett's conclusion that the concept of effect preceding cause is logically consistent, or "affecting the past from the future" is logically equivalent to "affecting the future from the past," I find a problem in his illustration. Since the causal process of affecting weather is within the frame of the physical world, the causal connection between the spell and the weather has to be at least partially

²⁴Michael Dummett, "Bringing about the past," *Philosophical Review* 73 (1964), 338-59.

contained within the laws of physics (nature). A causal connection between two physical events (spell, nice weather), should somehow be explained. As has already been mentioned, all scientific explanations assume causal systems (cases of CPE), and cannot take care of any phenomenon in which effect precedes cause (EPC). If finding a cause-effect relation includes (or is equivalent to) finding an explanation for an event considered as effect, then the explanation cannot be scientifically supported, and therefore regarded as doubtful, to say the least. The other alternative is to connect cause and effect through a non-physical "channel," but a non-physical dimension in the explanation still has to be able to connect two physical ends, the spell and the weather, which are separated in time and place.

Dummett's position has been challenged by a number of people. Flew²⁵ is quite clear in saying that causes bring about effects, and what has been done cannot be undone. He emphasizes the time aspect of what I believe to be the essential claim, which is to say that once the pair of events takes place, the cause-effect process that connected them is somehow irreversible. I find this position similar to the position I take in 3.2.2 in the sense that the relationship is unidirectional and the reversal of it cannot be consistently conceived (see my interpretation of Dummett's example of apple jumping off ground at the beginning of this section). Scriven²⁶ argues that the issue at stake is not altering the past; rather it is whether the past can be determined by what we do now. This would also have some similarity to my perspective on the issue. "Affecting the past" is a second, weaker interpretation of backwards causation in terms of time. Unlike "undoing the past," which has to do with major changes in the already existing set of events that constitute *the past* (e.g., deleting established facts), affecting the past has to do with minor changes in the history. But, no matter how we rationalize the difference, the result

²⁵Michael Dummett and Antony Flew, "Can an effect precede its cause" in *Belief and Will*, Aristotelian Society Supplementary Volume 28 (London: Harrison and Sons, 1954), 45.

²⁶Michael Scriven, "Randomness and the Causal Order," *Analysis* 17 (1957): 5-9.

is the same: we need to deal with an already existing past, although possibly unknown to the agent causing the alteration, which is going to be altered. In both cases philosophers found logical impossibilities.

My perspective is event-based. A present event might, under certain conditions, affect events in the past. Effects of present causes can be situated in the past. The causal process is not necessarily initiated by an intelligent creature, nor it is intentional with some goal in mind (undoing the past), nor extraordinary such as reversal of irreversible. It is simply an event now affecting the past or an event in the future affecting the present. The idea can be grasped and made consistent by taking the following two perspectives:

a. It is not logically impossible that a present effect that we experience now is caused by an event in our future that somehow has that causal capability. In the same manner it is not logically impossible for an event in our present to have had some effect in the past through the same kind of capability. Physics cannot directly explain such occurrences; on the other hand physics cannot and does not formally reject them either. Some communication channels through which chunks of spacetime can be bypassed, such as black holes, worm holes, tachyons, can be conceived. A quite credible scenario is based on the essential probabilistic behavior that is promoted by the Quantum Mechanics, together with the inseparable dependence on the observer. Such a probabilistic effect is consistent with and could be explained by causes found in the future (see also 3.3.2).

One detail that might help to see things under a different perspective, and overcome the traditional view, is to think about a future time that is only one second away. If that is still not close enough to present, one can try one thousandth of a second or less. The future meets the present (and the present meets the past) as the time separation between the two approaches zero. For the macroscopic world and human senses, any separation in time that is on the order of one millisecond or less is not discernible. Therefore one can

easily be wrong in assigning events to past, present, or future if the events are closer in time than one millisecond. How can we be sure that the CPE principle is correct at this time scale?

One might argue that using advanced tools and equipment one can discriminate very short time intervals and thus correctly assessing occurrence of events in time. However, this type of empirical support is mixed with circular reasoning because the time measuring equipment is built on principles that are exclusively based on CPE. But even if we ignore this, we find out that no matter how advanced the technology there is always a small but finite gap in time that is not discernible. Events within this time scale cannot be timed correctly because equipment limitations; moreover, at an even smaller timescale, events cannot be timed correctly in principle because of Heisenberg's Uncertainty Principle.²⁷ Since the laws of physics at the microscopic scale of subatomic particles are symmetrical in time, it is conceivable that events are determined through EPC as well as through CPE. I will discuss the issue of symmetry in time in section 4.5.

b. The issue of undoing the past: let's look at some modified examples first.

1. Cause₁ (C₁) causes effect E

2. Cause₂ (C₂) undoes E

First, it would be acceptable to undo effects in the normal flow of time. Of course, effects that are irreversible cannot be undone. As far as we are concerned, death seems to be a good example of an irreversible effect; there is no known C₂ capable of undoing death. There are, though, an infinite number of effects that are reversible, and with the correct C₂ we could undo each one of them. Now, I would like to distinguish two possible meanings for "undo." The more trivial one is to cancel the effect by returning the system to its state before the action of C₁. Under this meaning if the effect is that the apple falls

²⁷Werner Heisenberg, "The Development of Quantum Mechanics" in *The world of physics*, vol. II, ed. Jefferson Hane Weaver (New York: Simon and Schuster, 1987), 353.

to the ground, then C₂ has to replace the apple in the tree in its original position. It seems to me that this should be a relatively easy task. A second, more demanding meaning of "undo" is to return the system to the original state and to make it look as if C₁ and its effect never took place. I believe that the discussion between Dummett, Flew, Scriven and others turns on this meaning to "undo." My position here is that the requirement posed by "never took place" is meaningful only in one sense. If that would be possible, it would be an example of time reversal, which would have the effect of reversing the evolution of the universe, bringing it back to the same state it had before C₁. This is really the only way the requirement of the more demanding backwards causation can be satisfied. Any other type of interpretation will be vulnerable in the sense that it will allow for some kind of recording that C₁, E have happened. But since we are talking about an operation on the universe, it can only be performed by an entity outside the universe, and presumably powerful enough; something like a God. Such a God has the capability of remembering the dead-time spent by the universe to evolve from C₁ through E through C₂ and back to C₁, and which he actually has to remember in order to be able to reverse the universe to the correct point in time. So, in principle there is no way to completely erase the past, but as far as our universe is concerned, using the works of such a God would leave no records inside the universe.

Now that we have introduced a God in the discussion, we may want to take another look at irreversible processes. The most demanding flavor of backwards causation seems to be: undo the past as if C₁ and E never happened even if E is irreversible. A God with the power of reversing the universe evolution path would be able to undo death, but again it takes no less than such a God to perform time reversal.

One cannot take a softer position which is performing time reversal only to a (small) part of the universe that will return the state of that part to pre-C₁ state, and will not affect the rest of the universe. In order to bring the apple back in the tree I could

perform time reversal only within my backyard. There is no need to involve the solar system, nor any galaxy. In fact even my neighbors will never know. But that's not possible. A record of such time reversal will have to remain since the time for the backyard is now different than before. The discrepancy will affect the spacetime around the backyard, changing its geodesic structure in order to take care of, say for example, the cosmic radiation that had to travel through the yard. The generation of a record in every case of partial time reversal precludes from bringing the state of the universe, even locally, to the pre-C₁ condition.

The softest form of requirement from time reversal would be: perform local time reversal, and given that a record will always exist, we should be satisfied if the state of affairs seems to be as before C₁. It is a subjective criterion. The result is considered effective backwards causation phenomenon if it passes the criterion.

An objection raised to backwards causation is the fact that there is no way to tell when it takes place. A random but scientifically inclined witness of an event produced by a cause in the future will be at least amazed, and looking for explanations available from his or her contemporary science. Even if a miracle occurs, i.e., an event that is incompatible or even contradicts a physical law, neither the scientist nor the rest of the public will suspect causes from the future (although relatively many people would believe in the existence of divine intervention for example).

3.2.1 A tour of the logical structure of backwards causation

As already stated, the principle of universal causality, "every event has a cause," will be here accepted as true. It is not within the scope of this thesis to discuss epistemological aspects of this principle such as how it should be justified and the famous synthetic a priori issue. It is interesting though, to reflect a little on the importance of the truth value of the principle of universal causality. If this is not a true statement, it seems to me

that the issue of effect-preceding-cause (EPC) is even more complicated by events that can show up without having a cause. This will make the EPC question valid only for the cases where it is known a priori that the specific event in question does indeed have a cause. The physicist-philosopher-parapsychologist will have a two-stage puzzle: a) Is this event caused or not? b) If the event is caused, then could be this a case of EPC?

When the principle of universal causality is accepted as true, the physicist assumes the existence of a cause and he or she needs only to identify it correctly. On the assumption that universal causality is true, there is no need to add the condition of cause-precedes-effect (CPE), as Hume does, in order to claim a causal relation. The question of backwards causation as EPC is open to many possible roads of discussion.

If the principle of universal causality is not assumed true, then it is possible for an event to happen without a cause. Answering the first stage of the puzzle must be empirically based because no (analytic) principle or set of principles can completely support the existence of the particular causal connection without being inconsistent with the assumption that the principle of universal causality is false. The causal connection has to be at least partially identified empirically. For instance, assuming that a principle, that was analytically derived, would state that all events starting with the letter 'E' are caused, then the minimum required empirical information is that the specific event we are investigating does or does not start with an 'E.' When the principle of universal causality is assumed false, it seems to me that the concept of cause-effect relation is somewhat closer to Hume's empiricist spirit. To identify a causal relation one has to observe that a set of requirements has been satisfied. It is quite possible, as in Hume's case, that the set of requirements contains the condition CPE, in which case the question of EPC makes no sense. However, it is also possible that the CPE condition is not included in the definition of causal relation, and the time relation can be either way.

To summarize:

a) If the principle of universal causality is assumed as unconditionally true, then the time relation between cause and effect is independent of the causal relation, and in principle can have either polarity. This is consistent with my position in this thesis.

b) If the principle of universal causality is assumed to be false, then the causal relation is not known a priori. It must be identified empirically. If CPE is one of the necessary conditions in causal relation identification, then an EPC situation is meaningless. If CPE is not a condition, then the time relation is an independent variable and can have any polarity.

A second underlying aspect is related to the order of events in time as a sufficient condition for causal connection. Some will argue that CPE is a sufficient condition: if a set of events A precedes an event E in time, then A constitutes the cause of E. The only logically consistent interpretation of this claim is to accept that the universal past (the totality of events that took place prior to E) is a sufficient condition for E to happen in the (universal) present. As stated before, any incomplete identification of some particular event(s) as the cause of E necessarily contains some degree of vagueness that cannot be accepted. If allowed, any partial set of events from the past of E is a sufficient condition for E, which is obviously false. Every event that happened before the effect in question has to be part of its cause and cannot be removed without affecting E. A partial set of events from the past cannot be sufficient because the rest of the universe had to be in some state (and not in some other state) which is part of the cause and cannot be neglected.

In this holistic approach, "every event has a cause" is replaced by "every event has a past," because the past is identified with the cause. The past supplies laws of nature, specific meaningful events, etc. The whole past light cone is identified with the cause. This position is not contradictory to my position in this thesis. If the universal past can supply a sufficient condition for E, it does not eliminate the possibility of EPC, where C is another sufficient condition for E found in E's future. In general, the position that CPE is a

sufficient (but not necessary) condition for cause-effect relations allows also for an EPC condition to be sufficient but not necessary. Only if one of them is identified as a necessary condition (normally this would be CPE), it will exclude the other because they cannot be both true.

3.2.2 Cause-effect is unidirectional

In my view, a causal chain necessarily has one direction. The meanings of 'cause' and 'effect' do not allow for backwards causation; as soon as we try to force that, we use the words ambiguously. The causal chain is unidirectional, from cause to effect, and not the other way. If in a causal chain that develops among events, items X and Y are located such that X is sequentially encountered right before Y, then X is the cause of Y and Y is the effect of X. The notation I would like to adopt is $X \gg Y$ (see also Figure 1). If an arrow goes from Y to X, then Y is the cause of X, and in the causal chain Y is prior to X. That's perfectly understandable without the need of the backward-causation concept.

Before continuing the discussion, I would like to point out that the use of abstract events as X, Y, etc. is intentional. Concrete examples would require some reference to physical events, or thoughts, ideas, etc. that are subjectively perceived in time. Either the event is framed in time or our subjective acknowledgment of the event is framed in time. The explosion of a bomb and the bomb hitting the ground form a physical chain of events that are clearly framed in time. The cause occurs first (bomb hits the ground) and the effect occurs afterwards (explosion). If we try to think about it without involving time, we would describe backwards causation as the explosion being the cause of bomb hitting the ground. In most physical examples, backwards causation would make no sense, not because of the missing time relation but because of the missing explanatory connection when reversing the order of events. For example, there is nothing in our

knowledge of the physical world to explain why an explosion of a bomb would lead to the event of the same (unexploded) bomb to hit the ground.

Similarly, a thought or an idea can cause another thought (idea) to occur. The mind might be able to keep a record of all the ideas, a record of their causal relation (which idea caused this idea), and a record of their time succession. It is likely though that the mind would tend to associate the order of ideas with their time succession. Some questions may arise: What if the time order recorded in the mind for a succession of thoughts is not accurate? Is it possible that thought order could be inverted? Moreover, is it possible, for whatever reason, that the thought order is recorded correctly in time but is not correctly recorded as a thought order? In both cases, if one knows the true thought order then he or she records it first as X and then as Y, which means that $X \gg Y$, and no backwards causation issues arise. However, both orders (thought order and time order) and their keepers are frequently challenged generating the philosophical questions of backwards causation and/or time reversal.

An abstract symbolic notation has the advantage of avoiding the association with physical phenomena in our macroscopic everyday life, phenomena which are undeniably causally connected and have a definite order in time. As I mentioned, causal connections of physical phenomena through the scientifically established laws of nature will automatically assume CPE, which will limit the usefulness of such phenomena in this thesis.

3.2.3 Causal loops

Some confusion arises when both causal directions are allowed: there is an arrow from X to Y and an arrow from Y to X. It is the only form of backwards causation that I would like to allow, and I will try to show that this has little to do with backwards causation as EPC. The causal chain leads to, say X first, which leads to Y, which leads to X,

etc. In this case I would suggest we have a loop (a *causal perpetuum mobile* or *circular causality*), which will oscillate and never stop - see Figure 5. Even if an output branch connects Y with some other stage in the causal chain, the loop XYX will remain active.

Figure 5: Loop in a causal chain

A simple example of a physical form of a causal loop is a system consisting of one atom inside a “box” that perfectly reflects all radiation. Eventually one of the electrons of the atom would jump from a higher orbit to a lower orbit, and the atom will emit a photon of electromagnetic energy when that happens. As explained in 1.2, an event is defined as a set of changes in the state of the system. Event X will be defined as the atom changing its state from HIGH to LOW and the emission of the photon. Since the box is perfectly reflective, the photon will be bounced back and forth inside the box for a while until it is thrown in the “direction” of the atom. The atom is likely to catch it and use it for elevating the same electron back to exactly the same original orbit. Now the state of the system has been changed again: event Y is the absorption of the photon by the atom in the box. $X \gg Y$ and $Y \gg X$ form a loop that is not only causally closed, but also closed in terms of the objects in the system that take part in each of the events. Event X lowers the state of atom A from HIGH to LOW and frees photon P. Event Y returns the same photon P to the same atom A, and raises A from LOW to HIGH.

The limiting factor which will ultimately prevent the existence of a physical perpetuum mobile is, in this case, the imperfection of the mirror, not only as an

experimental "fact," but required by the Second Law of Thermodynamics. The mirror cannot reflect energy perfectly, without absorbing some of it, and eventually the photon will disappear which will cancel the causal branch $Y \rightarrow X$.

The second example is based on a slightly different system: the same reflective box from the previous example contains now two atoms, one in the HIGH state and one in the LOW state. The system state is characterized by the states of both atoms, and the status of the photon. Atom A can be either HIGH or LOW, atom B can be either HIGH or LOW, and the photon can be either bouncing within the box or non-existent. A minimal description of the system state needs no reference to the photon since the information can be derived from the state of atoms. The system as a whole has two distinct states: a) both atoms are in the LOW state (P is free), and b) one atom is in the LOW state and the other in the HIGH state (P does not exist). We assume the system to start in the latter state. Event X is the change of the system state from "one atom in the HIGH state and the other in the LOW state" to "both atoms in the LOW state (and the emission of the photon)." Event Y is the opposite change which also includes the absorption of the photon. It is important to note that the causal loop is identical to the one in the first example. Using the same definitions for X and Y, but a slightly different system, the objects involved in each of the events may now change. As the causal loop progresses, some X, Y pairs will have atom A absorbing and emitting the photon, and some others will have atom B doing that. Under the definitions, X and Y remain indifferent to the identity of the particular atom.

One other example is the chain reaction in, say the atomic bomb. Within the system that includes the radioactive critical mass and some other accessories, a specific type of nuclear reaction (event "X") generates N neutrons (event "Y"), which produce one reaction X, which produce N neutrons, etc. Again, the way we define the system and its states and events, determines which objects are involved in the causal loop. For example, the state of the system can be characterized by three factors: the number of nuclei before

reaction (that have not been fissioned yet), the number of nuclei that have been already fissioned, and the number of free neutrons. Since X is the change in the system state that happens when one nucleus is fissioned (with the help of a neutron), the event X can involve any nucleus. The system state will change because the number of the unfissioned nuclei decreases by one, the number of fissioned nuclei increases by one, and the number of neutrons decreases by one. Y will change the state of the system by increasing the number of neutrons by N. In reality X produces more than one Y and Y produces more than one X, and the process develops as a rapid grow of the number of loops. That is a characteristic of this chain reaction, but is not required to sustain the causal loop. The original loop that starts the chain reaction can continue indefinitely if there is an infinite supply of nuclei, and if the rest of the conditions do not change. In that case, X would have fissioned exactly one nucleus and Y would have caused the emission of exactly N neutrons. However, in either of the cases, the unrestricted fission chain reaction in a bomb or the controlled reaction where only causal loop is present, physical occurrences of causal loops are limited by the amount of energy available, which eventually acts as a change of the causal relation. Either $X \gg Y$, $Y \gg X$, or both change, and the loop cannot exist anymore. In my example, when the amount of nuclei is exhausted, new reactions cannot be triggered by the neutrons, which is equivalent to have the branch $Y \gg X$ removed.

In a more general case, the causal loop need not be minimal (e.g., $\dots X \gg Y \gg X \dots$), but may have one or more intermediate branches (e.g., $\dots X \gg A \gg K \gg Y \gg T \gg I \gg B \gg N \gg X \dots$ - the pattern repeats indefinitely, and A, K, T, I, B, N are arbitrary, causally connected events). As long as it is closed (starts and ends with precisely the same event - X), it is capable to sustain itself with no help from outside branches, and therefore it is a Causal Perpetuum Mobile.

It seems to me that the possibility of causal loops ties to the question of time. It is not a necessary connection since the causal chain (loop) can be conceived independently, as

explained in section 1.3. Still, the causal loop can take interesting physical forms as explained below:

1. Physical Perpetuum Mobile. Under the assumption “cause precedes effect” (CPE), a Causal Perpetuum Mobile will produce a Physical Perpetuum Mobile. This is a “scientific” exemplar of the causal loop. A mechanical pendulum will oscillate indefinitely under a gravitational field (of the Earth or other planet), if no loss of energy in the form of friction occurs. For the sake of simplification, we will look at two out of many possible physical (geometrical) states: state L and state R. These are the end points of its movement. Each state is characterized by a certain amount of potential energy that the pendulum holds and then uses to reach the other point. In the system containing a pendulum oscillating in a gravitational field with no energy loss, the event LR, which is the change in the system state from L to R, causes event RL, which is the change in the system state from R to L - see Figure 6.

Figure 6: Causal and Physical Loop - the pendulum

The pendulum can be in many other states, such as the shown mid-point, but they are not relevant here. As far as the mathematical analysis

of the pendulum goes, it is conceivable that in principle this system could produce a Physical Perpetuum Mobile. However, physical reality does not allow this or any other system to be a Physical Perpetuum Mobile because of the Second Law of Thermodynamics which imposes a restriction by heat loss on any energy conversion, the same exact law that is also one of the main contributors to the arrow of time - see section 4 on Time. Therefore, the incarnation of the Causal Perpetuum Mobile into Physical Perpetuum Mobile is not allowed due to the same principle which defines a direction in time. This should not be surprising; the existence of a Physical Perpetuum Mobile would make the direction of time ambiguous since the changes in the system would be perfectly symmetric in both time directions (to go from R to L forward or backwards in time would be exactly the same). This needs a little more discussion. Since we are dealing with a physical system that operates in time, the two directions in time are not, strictly speaking, identical. The system reaches the L state at different times, or equivalently in a sequence that can be recorded; the same goes with the R state. So the system passes through ... $L_{i-1}, R_{i-1}, L_i, R_i, L_{i+1}, R_{i+1}, L_{i+2}, \dots$. However, an observer inside the system cannot tell the difference between this sequence and the opposite one, which would represent a time reversal. Only an observer outside the system would be able to distinguish the direction by relating the sequence to other physical changes that take place in parallel.

2. Time reversed Causal Perpetuum Mobile. This is a mirror in time of the preceding example. If the causal loop happens to be formed by two events X, Y for which causal connections have also an associated time relation in the form of EPC (both are caused by events in the future), then

the Physical Perpetuum Mobile is going to be running backwards in time. $X \gg Y$ while X is in Y 's future, and $Y \gg X$ while Y is in X 's future. Therefore, Y will happen before its cause X , which will happen before its cause Y , etc. It is a perpetuum mobile that goes back in time indefinitely - a mirror in time of the physical perpetuum mobile above. If such a Causal Perpetuum Mobile actually exists, the chances to be observed are very slim both because the scientifically unpopular EPC principle, and because the traces into the past would be easily lost. In other words, if the idea of such a causal chain running into the past crosses some scientist's mind, and if he or she does not reject it on scientific grounds, research to confirm or reject such a conjecture will be nearly impossible because historical documentation and evidence is almost always CPE based. Events are noted and recorded mostly as explanations to subsequent events. If they do not have significance under the CPE principle they tend to be left out as unnecessary details. Research looking for effects in the past would probably need to look at all these undocumented details.

An idealized illustration of such a loop is the "atom in the box" system mentioned at the beginning of this section. Since the system includes only the atom and the box, and only two causally connected events are defined, the time relation can go either way. With both events being either the EPC or CPE type, the result is the same: in the causal chain $X \gg Y$ and $Y \gg X$, and the system evolves through an infinite series of $[X, Y]$ successions. We, the observers, cannot tell the arrow of time only from looking at this system; we cannot tell if a particular Y is caused by the preceding X or by the following one. As far as we can tell, this system may evolve backwards in (our) time and what we observe, as our time passes, is the past of the

system. Again, this is only an idealized experiment. It cannot be actualized without some loss of energy. Although X, Y are well known physical events, the effect of the Second Law via the mirror is not negligible and will break the loop.

3. Another interesting combination is: $X \gg Y$ is a CPE and $Y \gg X$ is a EPC. Suppose for a moment that the two events X, Y are the only events in the universe. X precedes Y as Y's cause, and also precedes Y as Y's effect. Let's assume that the time interval required for both functions is identical. Since the time conditions are always satisfied, X and Y continuously exist. After the first time interval when the loop is started, which, by the way, has no (time) direction, the time passage will essentially stop because the universe will freeze in time showing the events X and Y continuously. There will be no way to tell that the frozen appearance of the universe is static (no events) or made up of 2 or more events, other than the passage of the first branch(es) in the causal loop until the loop closes.

In the more general case, the time intervals for $X \gg Y$ and $Y \gg X$ are not necessarily equal, and that will cause the causal chain to develop in time into the future or the past depending which time interval is larger. Events will hop both into the future and into the past. Suppose $X \gg Y$ is CPE and takes 1 hour; $Y \gg X$ is EPC and takes 45 minutes. Suppose event X happens; after an hour Y will happen, which will cause another event X 45 minutes before that, or 15 minutes after the first X. The third X will show up 30 minutes after the first X, etc.; the loop develops into the future in respect with the first X. Locally, X shows in Y's "past" (before Y), and Y shows in X's future, but every loop cycle, from X to Y and back to X has a net balance of 15 minutes into the future.

The way to halt the causal loop is to inject a branch that partially distorts or entirely annihilates the original branch from X to Y or from Y to X.

3.3 Analysis of the causal relationship

3.3.1 Definition

When considering any specific pair of events X, Y, the following definition will hold (X, Y can represent also sets of events):

If $X \gg Y$, then X is an event or a set of events that, together with the existing scientific paradigm, including all sciences, provide the best explanation for Y.

A complete explanation is a mixed set of background context and specific events that together are sufficient to explain why and how Y occurred (the “covering-law” model).

The selection process of X has two main dimensions:

1. Selecting the best explanation among available ones. Best is normally taken to mean: simplest and with maximum coherence. Logical and nomological coherence within the scientific paradigm is probably more important, at least in the early selection. Simplicity, which is determined relatively to the same scientific background as coherence is, will be assessed if two or more explanations have the same degree of coherence, or if an explanation with a low degree of coherence (i.e., revolutionary) but simple is among the candidates. Most times simplicity with no or very little coherence would hardly account as an advantage. The explanations that have a better chance to be considered seriously are those based on coherence. However, at times of impasse, coherent explanations cannot be found, and science becomes sensitive to simplicity.

2. A delineation of the set of events that will ultimately count as the cause X, and which would be separated from the rest of the explanation that contains what would count as context or background. The choice of X is somewhat subjective but only in terms of which part of the explanation we call "cause" and which part we call "background."

What will count as the best explanation has to rely on the scientific context, the frame through which we understand the world around us. However, in many cases the background context is not even mentioned and counts merely as a language most people should understand.²⁸ (If one does not understand the language, one will not in some cases understand why X causes Y). In some cases, when the causal relation is complicated, e.g., low-probability events following a hidden law, an appeal is made to the underlying laws or principles which are explicitly attached to the explanatory structure.

I will use the example of the falling apple. What is the cause of the event Y, which is an apple A falling from the tree? First we select the best explanation which includes Newton's mechanics and some biological facts about apple trees and their fruit, the specific conditions about A (weight, location, etc.), the weather before the fall (temperature, wind speed), and so on. Then we select what part of the explanation remains in the background and what counts as the cause X. Newtonian mechanics, for example, is considered context, although it wasn't before Newton. As a side comment, Newton asked the question in a slightly different way, emphasizing the fall of the apple and not the separation of the apple from the tree. It is safe to say that today Newton's laws are part of the language we speak and can be counted as background. The selection is also relative to what the perceived stable state was before Y and what is to count as the main disturbance. For example, if the apple had been hanging for a long time, then even if wind

²⁸This is a normative "should". People who want to be involved in the explanatory journey must learn the language of science.

was maybe present at the time of the fall we would select the cause to be "maturity." If the apple had not matured but strong winds were present, then X will be selected differently.

There is going to be a gray area - information that could belong to either background or X. Furthermore, some philosophers and scientists take an extremist position which reduce all specifics to the context of natural laws that, through complex causal chains running from the past, have caused the specifics of the event. I think that the exact partitioning into context and specifics is not significant here. What is important is the strong correlation between cause-effect relation and explanation, which is the path that Van Fraassen, Salmon, and others took. Y is caused by X if and only if Y is best explained by X and its epistemological background.

For obvious reasons X cannot be only a necessary condition for Y because that does not ensure the causal connection (Y might not happen). To be sure, the word 'cause' is used with more than one connotation. One connotation of 'cause' is as the background context only (e.g., the fall of A is caused by the law of gravitation), while another refers to the particular specific conditions only. It is clear though, that neither one, although being necessary, can fully explain a specific Y, and the people who use either of these connotations assume the missing part implicitly. When somebody says "an apple falls because of the gravitational force," the statement makes sense only as a general statement about apples. It does not imply that gravitational force is necessary for the apple to fall, or that under gravitational force every single apple will fall. It is a generic statement about a reality we came to know on Earth: that apples, under a variety of specific conditions, tend to fall down from trees, and that the underlying force that is capable of pulling the apple down is gravitational force. Similarly, to say "the apple fell down because of the storm" is an incomplete account. The storm by itself is not a sufficient

condition; neither for the general behavior of apples, nor for the fall of apple A specifically.

Do the background context or the specific conditions necessarily include a time dimension? The answer is yes for the physical phenomena, for the scientific frame of reference is a spacetime frame. Every time the laws of physics are invoked, time is introduced in the explanation, and therefore in the causal relation. Does the spacetime frame of reference necessarily imply a cause-precedes-effect (CPE) relation? No. The laws do not imply that, but physical systems are always assumed to be causal and analyzed as such. What about non-physical phenomena? Do they require a time dimension? Some of these issues are discussed below (see 'c' of 3.3.2).

3.3.2 Causal connections under different reference backgrounds

What would be the criterion of connecting two events in a causal chain? We start by looking at the conditions required for some effect E to happen.

a. In the context of (standard) logic, the conclusion of a deductive argument can be said to be "caused" by the premises and the (correct) application of the appropriate inference rules. It seems that although we do not usually refer to causal relations in logic, we could identify the rules of inference as the contextual background, and the set of premises as the specifics. Together they form the "cause" of the conclusion, they explain the conclusion. Within the frame of logic, time is not associated with arguments or their structural parts. If time is not associated with logical relationships, then the requirement of cause preceding effect in time is not necessary. This is exactly the spirit in which I would like to apply causal relations to events outside logic.

A causal chain contained entirely within a given frame of reference may not indicate the frame as part of all causes. The frame is assumed to be present. For

example, deductive arguments are usually presented as consisting of a set of premises leading necessarily to the conclusion; the frame is not mentioned. In cases where the causal chain under consideration goes across different frames, the set of sufficient conditions defining cause should include frame-related items. For example, when a physiological event is identified to be the cause of a psychological event the causal explanation needs to show how the two frames can be connected, the principles under which biochemical-chemical events can be translated into states of mind.

b. In a physical environment, cause-effect connections or chains are the rule rather than the exception. Physics is about finding causes, with the underlying aim towards generality, laws. After a set of laws is adopted as the correct description of how natural phenomena are connected, they tend to shift into the background. Just like in the logic environment, a set of specific conditions is said to be the cause of E, while the laws are hidden in the background. Using the definition in the model above where the cause is a sufficient set of conditions, then the cause must include both the applicable laws and the specifics.

c. In a non-physical environment, cause-effect connections can be deliberately set to be in agreement or not with physical laws. One example I have in mind is cartoons. Although they seem to show a physical world, they actually break the physical laws, but the causal connections seem to make sense in a broader context which we normally accept if logic still holds. The most incredible things can happen to a character, such as free falling from 10,000 feet and either stopping in mid-air, or hitting the ground and walking away "alive." Those are either very improbable or technologically impossible outcomes, but certainly not logically impossible in principle. Two events that are presented as causally connected might make very little sense scientifically, as for example Popeye

eating spinach and growing muscles in a matter of seconds because of his eating the spinach, but are still acceptable as cause-effect connection for a cartoon story.

From this example I would point out two issues: a) cause-effect relations are perceived and accepted or rejected within a given frame of reference, and in this case the cartoonesian frame is more tolerant than the Cartesian frame; b) no matter how incredible the cartoons might be in their virtual reality, they could never invert the time relationship between cause and effect. Popeye will never eat his spinach after growing the muscles (as a cause for that). Actually, maybe he should not do that in his case, but the fact I am emphasizing is that sometimes a cause could be allowed to come after the effect but it is never done.

At this point it seems to me that I have a good non-physical example of a timeless frame of reference (logic), but I do not have a good non-physical case of EPC, and I think that the main reason for that is that any example has to somehow connect with the physical world in a way we think it should, which brings the CPE back.

d. Before dealing with time order (section 4), some consideration needs to be given to the type of causality utilized by Quantum Mechanics. Quantum Mechanics managed to bring a new perspective to the concept of causal processes. It turns out that, as far as physics can tell today, sub-atomic processes behave quite strangely in terms of our taste for well-ordered behavior (as developed through the classical physics). Quantum Mechanics tells us that particles and systems of particles exist in essentially unknown physical states. Observation through experiments of a physical state of a system leads to a phenomenon called "collapse of the state-vector" from its (unknown) state to a state that is detected by the experiment results. The collapse is a probabilistic phenomenon, which introduces an element of chance into Nature's behavior. This should not be confused with a

statistical analysis of complex systems due to their complexity. There the considerations are pragmatic, i.e., not having the computational power to deal with the complexity of the system in a deterministic manner. In Quantum Mechanics the chance effect is fundamental in that the observation triggers at random the decision of the outcome. In order to account for quantum mechanical effects any causal relation should allow for a range of possible effects (instead of a specific one), and for a random selection of the actual effect.

In section 3.2, while claiming that EPC is conceivable, not as a case of backwards causation, but as a case of inverse time relation between cause and effect, I mentioned Quantum Mechanics as a theory that brings some support to this claim. Quantum Mechanics does not really attempt to explain events through EPC; however, it does not really explain them through CPE either. At some point in the explanation a coin is tossed, but the “physics of the coin movement” is unknowable, and the outcome is probabilistic. It is conceivable, as one of the possible ways to bridge the probabilistic gap in the explanation, to allow a causal connection with an EPC time relation as part of the explanation.

4. THE ARROW OF TIME

Some of the issues related to the concept of time are traditionally discussed with very little reference to causal effects. Time by itself is puzzling enough to be “independently” investigated, but this is outside the scope of the thesis. Among those issues that are perceived to have a strong relation to causality, the direction of time is a major one. A review of this issue is given in 4.1 and 4.5. The rest of section 4 is dedicated to two major issues, time reversal and time travel, both in the context of time (spacetime) and that of causality.

The perceived asymmetry of time flow is one of the oldest and still major puzzles. The issue of time flow, as psychologically perceived by the human observer, is approached in a few different ways in the literature of space and time theories in the philosophy of science. A number of terms are being used to refer to the concept of time flow. A relatively weak term is the “asymmetry of flow” to point out a deterministic or probabilistic preference in the direction of flow.²⁹ A stronger term is “the arrow of time” which is currently a three-valued concept: the cosmological arrow, the thermodynamic arrow and the psychological arrow.

The idea of time flow represented as a “moving now” was challenged and rejected by McTaggart³⁰ as being contradictory. Nevertheless, when we try to approach the concept of time, some aspects of it indicate an asymmetry. For example³¹, the knowledge about the past and present seems to be cast in stone. The past is overdetermined as opposed to the future which is underdetermined. A second aspect is the issue of time reversal of processes. Some processes might be considered irreversible in principle (nomologically

²⁹Adolf Grünbaum, “Time, Irreversible Processes, and the Physical Status of Becoming” in *The world of physics*, vol. III, ed. Jefferson Hane Weaver (New York: Simon and Schuster, 1987), 865.

³⁰John E. McTaggart, “The Unreality of Time” in *Mind*, vol. 17 (1908), 457

³¹See a good review in Paul Horwich, *Asymmetries in Time* (Cambridge: The MIT Press, 1992)

irreversible) because asymmetric physical laws, and some are irreversible as a matter of fact although the governing laws are symmetric in time. Both types of irreversibility generate an asymmetry in the time flow. Other aspects include the issue of truth value of statements about the future (do they have one?) and those about the past, and causation.

4.1 Survey of some of the ideas related to the direction of time

The scientist faces the following problem: starting with the reductionist assumption that the laws governing elementary particles can explain all physical processes, why can't these laws explain the cosmological and thermodynamic arrows of time (which are also scientifically accepted phenomena)? A number of roads are open for trying to supply an answer to this question, and probably most of them have been tried already. The apparent irreversibility of some processes is at the heart of time asymmetry. Since all processes can be completely described by elementary particle interactions (physicalism and reductionism), the reason for irreversibility must lie either in time-asymmetric laws about elementary particle interactions, or in the specific conditions under which the processes take place. There are three types of conditions used in modeling physical processes: initial (time) conditions, boundary (place) conditions, and symmetry conditions.

The two, experimentally accepted, arrows of time are the cosmological and the thermodynamic arrows. The cosmological arrow is associated with items in the physical world that retain some of the "historical memory." Geological transformations in the Earth crust are one example. Another example is the evolution of stars and galaxies. The cosmological general direction of development (the "cosmological envelope") seems to point out a directional time flow. The thermodynamic arrow has to do with the interactions, processes within the universe. It has to do with energy conversion and conservation. In any closed system containing a finite amount of energy, every process

that involves energy exchange or conversion ends up raising the amount of thermal energy (or heat) in the system. A closed system evolves always towards the state in which all its energy is in the form of heat (the state of "thermal death"). This universal behavior of closed systems defines a time direction, the thermodynamic arrow of time.

In general, all processes that lead to more or to less order within a system (order is also referred to as information) are processes that point to some direction of time. Historical processes of the type indicated by the cosmological arrow lead to more order or information. Galaxies, planets, life, etc. all presumably start from a material soup that has no order in it and advance towards more organization and information. An opposite type of process defines the thermodynamic arrow: it destroys information and decreases order. Examples are sugar dissolving in a cup of hot water, diffusion, heat generation. These are all manifestations of the Second Law of Thermodynamics which states that all natural processes generate entropy (more disorder) by increasing the amount of thermal energy. A closed system (which, in principle, could be the entire universe), starting with a certain amount of order, will inevitably progress toward a final state in which the amount of order is zero (maximum entropy).

Those two types of time arrow are not supported by any (known) laws in particle physics. In the world of elementary particles, the concept of order does not exist. Particles change their states but there is no parallel to the macroscopic order. Physical laws have no requirements regarding a preferred direction. Let's consider an example: if we open a bottle of perfume in a closed room, eventually molecules of perfume fill up the room (the scent can be detected anywhere in the room). This process is invariably unidirectional at the macroscopic level, although if we try to follow any specific molecule, we will find out that its movement is perfectly reversible. If the motion of a molecule is captured on film using a movie camera, and the movie is run backwards, the motion of the molecule will look as natural as in the original direction. The motion of the

molecule while time is reversed seems to be consistent with all applicable laws.

However, at the macroscopic level the asymmetry is obvious. Even if the theory allows in principle for the unlikely event of all molecules coming back into the bottle, the chances for the forward process are many orders of magnitude larger.

One attempt to reconcile the microscopic symmetry with the macroscopic asymmetry is taken by David Layzer.³² One of Layzer's claims is that the amount of information required to describe a system, e.g., the room with the bottle of perfume, does not change as the system evolves from lower to higher entropy. The amount of information is measured by the number of bits (binary digits) required to specify the state of the system. Layzer's point is that although entropy increases in any system, the parallel (and opposite) concept of order does not simply decrease; it is shifted towards the microscopic scale. Therefore, the thermodynamic arrow of time is not only an expression of entropy increase, but also an expression of the level at which the system contains some order.

Using the same idea of order in a system, Layzer then analyzes the cosmological arrow of time. The original "cosmological principle" (so named by Einstein in 1916) states that the distribution of matter in the universe is homogeneous and isotropic (on average). The strong cosmological principle states that no statistical property of the universe defines a preferred position in space. With the help of this symmetry principle Layzer argues that it is impossible to find microscopic differences between two different representations of the universe. The cosmological principle provides statistical information, but not microscopic behavior. At birth, the initial state of the universe is characterized by the presence of microscopic information and the absence or almost absence of macroscopic information. Expansion generates macroscopic structure without microscopic information, and that defines the direction of the cosmological arrow.

³²David Layzer, "The arrow of time," *Scientific American* 234 (1975): 56.

The summary of Layzer's position is that a combined cosmological/thermodynamic arrow of time can be argued through the change in entropy of any closed system and the loss of microscopic information due to perturbations coming from outside the system. This is a valid line of reasoning but it does not, I believe, answer the why question about the arrow of time. It shows a way to associate the existence of the arrow with physical processes in a system, and their effects on the information about the system, but it does not explain the arrow. Such an explanation needs to teach why the system evolves in a "preferred" direction - why the processes that take place are the ones that take place. In the example of the bottle of perfume, why do the molecules spread throughout the room? Or, at a deeper level, why is the thermal energy (heat) that imprecise and unattached?

The existence of the arrow is not assumed for my claims in this thesis. Since time is only used as an epistemological tool, and it is mainly based on and derived from a mathematical model, it can be required to have any direction (and even more than one dimension). Nonetheless, most examples in the thesis are tied to physical events in which time plays its traditional role.

4.2 Time reversal

"Time-reversal" is described as the reversal of all motion in the universe. First, imagine a macroscopic universe of celestial bodies that is evolving in time governed by some physical laws (gravitation, the Newtonian three laws of dynamics, etc.). Since the laws are known and the positions can be measured at any given time, it becomes quite easy to predict the future and the past of all bodies positions (the prediction of the past, although a linguistic deformation, it is quite meaningful).³³ In other words, the state of

³³Bohr's famous related remark: "predictions are increasingly harder to make, especially about the future"

the universe is completely defined, measurable and predictable. This situation is at the heart of Laplace's "hard determinism":

An intelligence knowing, at any given instant of time, all forces acting in nature, as well as the momentary positions of all things of which the universe consists, would be able to comprehend the motions of the largest bodies of the world and those of the smallest atoms in one single formula, provided it were sufficiently powerful to subject all data to analysis; to it, nothing would be uncertain, both future and past would be present before its eyes.³⁴

What should happen after the moment of time reversal is that the universe will be played in reverse through all the states it has passed through already, from the last backwards to the first (if there was a first). An eclipse that occurred 1000 years before the reversal of time, will occur 1000 years from the moment of time reversal, and in the opposite direction of movement. The concept of time reversal is allowed by the fact that the laws of motion are indifferent to the direction of time.

Another traditional example is the billiard balls collision. I have already discussed this in connection to causal relations. As we know it, the movement of the balls proceeds from an initial state through a collision to a later state. If the time reverses, the balls will follow their trajectories backwards through the collision to the initial state. There will be no breaking of any laws of physics. Indeed, if the motion of the balls is filmed, time reversal would be equivalent to running the film backwards. A person watching the film running in either direction, would not observe any motion or interaction that is not in accord with the physical laws.

An extension of the concept of time reversal to the subatomic world is somewhat difficult. If we take the reductionist position and grant that all phenomena in the universe are reducible to actions and interactions of elementary particles, then quantum mechanical effects with their probabilistic essence cannot be played in reverse through

³⁴Pierre Simon Laplace, *A Philosophical Essay on Probabilities* (New York: Dover, 1951).

the same series of states. The universe might take a different pattern at random, which makes the concept of time reversal meaningless; if the sequence of states during time reversal does not match exactly the (inverse) sequence during time forward, then how do we know that the time is reversed? Therefore, I claim that the reductionist view and universal time reversal are *not compatible*. We might want to consider either rejecting reductionism or give up universality by saying that time reversal can work only for limited systems that are essentially deterministic. That kind of statement is going to face criticism because the concept of time does not allow for isolated systems to enjoy qualitatively different time frames; characteristics of time that apply to one system, should apply to others as well.

It seems to me that the concept of time reversal is inconsistent. It was conceived in the macroscopic and deterministic world, but it cannot be extended to subatomic processes because of quantum mechanical effects. Therefore, it is not applicable in an universal way to spacetime as a frame for physical processes. A limited version of time reversal is inconsistent with its own definition which is the reversal of *all* motion in the universe. A limited version might take the form of some isolated system showing reverse motion, as in the example of the apple moving back up to the tree. If we grant the possibility of such a situation without involving particle physics, I suppose that this could be explained by some anomaly in the spacetime around the particular process. However, in order to grant that, we must first reject reductionism as false, which implies that some physical events are not reducible to subatomic processes.

Time reversal cannot be a reasonable explanation for the traditional backwards causation, which is the phenomenon of EPC, because it would require the assumption that the chain of events to be explained contains only processes that are not reducible. Such an assumption is difficult to defend.

4.3 The idea of time travel at the macroscopic level

4.3.1 About the idea

Time travel is most often described as an event that requires some apparatus - a chamber, a hand watch, a DeLaurean car, etc. The operation is quite simple: the tool is normally set to the desired (historic) time and the machine takes care of the rest. As far as the traveler is concerned, the transport (delivery) time is negligible. Some machines can deliver only the desired time with poor control on the place of delivery; more sophisticated machines do both. However, both types are called time machines. It seems that the human imagination is not as excited about the possibility of space travel as it is for time travel. The reason must be that space travel is already here, although slow and rudimentary. Our imagination can easily accept the idea of an increase in the speed of space travel, even orders of magnitude of increase. It seems almost a given that we will move faster, closer to the speed of light and all kind of weird things will happen, but the (only) result in terms of travel is that we will cover bigger distances almost instantaneously. On the other hand, time travel is not here. Nobody can prove that it cannot be done, but nobody has done it yet, even at the "beginner level" - traveling one minute into the past or future.

Time travel is strongly related to at least some of the causal chains in the world. As explained below, any traditionally conceived travel leads to some changes in the spacetime structure, which affect causal chains in the physical world. My claim in this thesis is that the concerns raised by the possibility of time travel are not justified because the concept of time travel itself is quite incoherent at both sub-atomic and macroscopic levels. The concept has to be scientifically sound, and it is not. Some critique to the macroscopic scale time travel is brought below. At the sub-atomic scale it faces the same difficulties as time reversal (quantum mechanical effects), as discussed in the previous

section. In light of granting that time travel seems to be an impossible development within spacetime as we know it, I claim that its implications in the realm of causally connected chains can be ignored.

An intuitive way to look at a time machine operation is to talk about the time interval that the person in the machine is going to skip. Negative intervals represent trips into the past and positive ones are trips to the future. A time machine presumably calculates the time interval between the present time and the desired time, and performs the time leap. A note of warning: the leap must take less time than the desired time interval. If the leap is into the future, I would not want to sit in the time machine chamber the same or longer time than the desired interval because I can get there without the machine. The “natural time machine” takes me into the future anyway, at least for some period of time. If the leap is into the past, which is the more difficult task for the machine because no other machine including the natural one has done it yet, I would distinguish three values of leap time:

- a. Leap time equals the desired time interval. This could be done using time reversal (not necessarily), by reversing the time when the machine is turned on and reversing it again when the desired time is reached (in order to return the world back to its original evolutionary direction). The previous section describes some problems with universal time reversal.

- b. Leap time is longer than the time interval to the desired past. This is rather an inefficient way to leap into the past. As an example let's assume that the efficiency is not more than 50%; for any desired interval, the leap time takes twice as much. If I want to leap now (1994) into the year I finished high school (1964), I would have to wait 60 years for the leap to be completed. In the year 2054 the machine door will open and I will be welcome to the world of 1964. Or

will I? This might be a too long journey. One could not ask for leaps into a past that is farther back than half the number of years left for him or her to live.

c. Leap time is shorter (even much shorter) than the time interval. Here we have the ideal situation, which is normally the way people assume time travel happens, and that includes negative and positive time travel.

A time machine, as imaginary as it seems, can be conceived of, at least at a very superficial level. Its performance may be limited by (imaginary) technological considerations; for example the time intervals cannot be larger than a day or a month, but this is not a limitation in principle since the operation can be performed repetitively until the desired time interval is reached. However, some limitations are more subtle and serious. It has been already pointed out in the literature³⁵ that possible personal identity problems arise as long as the analysis accepts the scientific explanation for how life begins and ends.

4.3.2 Machine limitations

If the setting on the machine shows zero, or time interval = 0, then the machine and its content stays in the present. Any number other than zero will require macroscopic bodies to leap through spacetime. Since supposedly a person is part of the leaping system, the machine should be able to take care of bodies that are human size. This does not necessarily mean that the machine has roughly the same size, but it means that the organization of the macroscopic body needs to be preserved.

4.3.2.1 Partial past

Obviously we cannot leap back or forth in time within the spacetime structure in which we live or exist. That is because, as far as physics goes today, a body can only use

³⁵Christopher Ray, *Time, Space and Philosophy* (New York: Routledge, 1991), 153.

world lines (trajectories) that are contained in its past and future light cones at any point. The radiation that existed a week ago in San Jose has been either absorbed or propagated through space at the speed of light. The part that is gone cannot be reached anymore, even if we could, through the time machine, reach the speed of light. (To move faster than the speed of light is not allowed within the physical world to which we belong at the point when we enter the machine.) So, if I try to go into any past, recent or remote, using the 4-dimensional spacetime in which I and the machine exist, I could only get a partial replay of that time, that lacks a portion of the energy at that time.

4.3.2.2 Hyper space and a non-identical past

In order to leap through spacetime a machine should be able to reach other (physical) dimensions, that can give shortcuts to the desired destination on the existing physical dimensions. (The classic illustration is a Flatland world of two-dimensional things, a planar world; a spacetime leap there would be a trip through the third dimension, which no flatbody can perceive.) Even with such an advanced machine, as long as relativity and Quantum Mechanics limitations hold, I believe that the result is a partial physical reality of the past or future. As an example, imagine a flatbody removed through the third dimension and put back into its past. Flatobservers would see Mr. F. disappear and others see him reappear at a different spacetime location, in its past. Can this be the *same* past? Even if everything else is neglected, the "new past" contains something the original past did not have: the time machine. The machine has to exist in the spacetime of the target location in order to deliver the cargo.

4.3.2.3 The meaning of body organization in other dimensions

Suppose we ignore other limitations and assume that the leap time is very short; for any selected time interval there is a shortcut that takes you there through a hyper space

of, say 64 dimensions. A macroscopic body, such as the time machine or its content (passenger is probably a better word) is made from a huge number of identifiable microscopic parts (molecules, atoms, subatomic particles, etc.), all of which belong to this physical world. Somehow, the macroscopic body needs to be converted into a parallel thing that exists on other dimensions, transported through the shortcut, and reconverted back to our own spacetime after it has reached the desired time. (It is quite clear now that the travel cannot take place in the existing spacetime because of the limitations posed by the physical laws.)

The converter that comes to mind is the famous “transporter” in Star Trek. The converter takes a good look at the body to be transported, identifies structure, features, etc. and produces an equivalent body on unperceivable hyper space dimensions. I assume a moral transporter that does not generate multiple copies. There is only one copy made, and it is built from the original body who stops to exist in its original spacetime.

4.3.2.4 Holes in spacetime

The time machine occupies a closed spacetime slice before the conversion. If the machine is designed as a chamber or a car then the volume enclosed inside the room together with the room itself will travel in time. If the machine is more like a watch then the volume of space that travels has to be defined in a different way. Since the travel is no simple task, and each atom or molecule predetermined to travel has to be known and converted, it is reasonable to expect that the border in space between the region supposed to be traveling and the surrounding region that does not, will be very accurately determined (to every single atom and even subatomic particle). Neither the machine nor the passengers can afford to lose or gain molecules with every little travel they take. Similarly, the spacetime region that travels leaves behind a hole, which affects the remaining spacetime. Here the picture gets even more complicated. If spacetime is a

separate reality, then it make no sense to transport spacetime through spacetime (time). If spacetime is only a tool for dealing with matter and energy, then what is being transported is (only) matter/energy. The travel affects its relationship to the rest of matter/energy in the world. At this point I can say that since the mechanism of reducing spacetime to matter/energy distribution is not understood, nor accepted as true, the problems existing at the level of spacetime don't go away by accepting this reductionism. They might, but this cannot be proved without knowing the actual relations.

4.3.2.5 Getting in hyper space, driving through it and leaving it

Finally, I would like to go back to the difficulty of our reaching spacetime dimensions other than our own. It seems to me that this operation is a logical inconsistency. Even if it is conceivable for us to exist on a different set of spacetime dimensions, there is nothing we can do in order to make a transition. The only way to switch from one set of spacetime dimensions to another is with the help of beings that have access to both sets. The same reasoning applies to the issue of how the time machine determines the end of the trip. There are two possible ways of driving this time machine: internally and externally to the machine. In both cases the driver has to watch the road and stop the machine when the destination has been reached. An external driver that sits only in the spacetime frame of the departure or arrival location seems unreasonable because the machine would not be controllable during the trip. To keep the travel under control, the driver has to be able to reach both sets of dimensions.

I conclude that all we can do regarding time travel is to wait for communication from beings with access to spacetime dimensions we can't reach (although they can reach ours), and ask for assistance. When that happens I believe we will be turned down because of the impossibility of converting to other dimensions. If we are not turned down,

then the best we can hope for is to travel into a *modified* past, different than the *original* one (lacking some of the features).

4.4 Spacetime as a frame for understanding the physical world

Spacetime is primarily a frame of reference that is required for any modeling, measurements and transfer of knowledge connected to the physical world. It was one of Kant's main epistemological claims that it is our nature to perceive physical events in space and time. But, is spacetime only an epistemological tool? Since spacetime is so useful in physical sciences and fits so well the rest of the physical entities that are taken to exist objectively, one should inquire about the objective existence of spacetime, its ontological status.

Portraying spacetime only as a mathematical tool would in fact invalidate the philosophical problems associated with the meaning of spacetime existence. There are no similar problems with other mathematical tools. To take just a simple example from Number Theory: there is a nice correspondence between natural numbers and the physical world. Sets of physical (or other) objects can be associated with natural numbers. On the other hand, irrational and complex numbers have no direct correspondence in the physical world. They are efficiently used in the modeling of the physical world, but there are no parallel concerns about their physical existence as it is with time. Mathematical models of physical reality are not necessarily by themselves physical reality. In addition, the existence of most of the models beyond being mathematical objects is not that crucial or debated as spacetime is. Tools in general can be very valuable in modeling the physical world without themselves being part of the physical world.

On the other hand, an acceptance of physical spacetime (the tool of understanding and modeling is actually a physical entity) poses a series of interesting problems. We

understand the physical world in terms of energy distributed in spacetime, and laws expressing relations about this distribution. It seems to me that energy and spacetime are taken to be the fundamental physical entities which can explain all other physical items. One view is that energy and spacetime are irreducible, form a set of independent entities. We cannot express one by the other. This by the way does not mean that they are the only possible minimum set of independent entities. Nor would this mean that we are not supposed to try to understand their meaning better. However, in such a minimum set we cannot expect to get a better understanding of spacetime in terms of energy and the other way around.

Einstein managed to find a connection between them, a dependency. The General Theory of Relativity claims that spacetime is distorted by and around concentrations of energy (mass). Therefore we no longer deal with spacetime on one hand and energy on the other, independently. The spacetime location of a mass is now dependent also on the mass itself; but as far as I understand, the inverse relationship, namely that the amount of energy (mass) depends also on its location is not mentioned. The problem becomes then: how should we understand the existence of spacetime in the presence or absence of energy?

This question brings me back to the issue of time or spacetime travel. Time travel by macroscopic bodies necessarily involves the presence of mass, which eliminates the need to deal with a massless spacetime. On the other hand, the topology of the spacetime is very much dependent on the distribution of mass in it, which means that the time traveler would have to use different maps for different mass distributions. Since the time traveler or the machine cannot know all the distributions and redistributions of mass in the universe on a continuous basis because that requires infinite capability, i.e., at least one of them is God, and God's time travel is assumed possible anyway, then their travel destination, their path and their accuracy of arriving is limited, sometimes unknown before the trip.

4.5 The direction of time

Time is somehow related to change. The connection between them becomes apparent if we try to imagine a universe without change, a frozen universe at the temperature of absolute zero. With no energy available, there will be no physical events. Under my definition of "event" this implies that the universe as a system undergoes no changes at all. It is in a perfectly stable condition. Since such a singular state escapes available mathematical models for description, and even available imagination, it cannot be used to derive statements about time. Time might not exist in this universe, but so is the universe itself. If there is anything material in this universe, then there is energy; the assumption of zero energy cannot allow for any matter or energy in this universe.

One might argue that although time intervals cannot be measured within the universe, they can be measured from outside the universe, which implies a physical basis for the existence of time associated with the frozen universe. That would indicate that time exists as long as any observation of physical events can be made. But before this is accepted too easily I would like to point out that such a thought experiment might not be feasible. In fact any observation about the frozen universe would need some energy coming from the frozen universe or bouncing from it. In other words it would need energy from a universe that was assumed to have no energy.

It is also fair to assume that we will have no communication with creatures from a different universe anytime soon. Therefore, I would claim that we should develop our arguments as if there is one universe only, and in which we happen to live. If this universe has intermittent time periods of freezing to absolute zero ($T = 0^0\text{K}$), there is no way for us to measure or acknowledge the time spent at $T = 0^0\text{K}$. It follows that energy is a necessary condition for the existence of time.

Time starts being a physical factor only when $T > 0^0\text{K}$, which also means that there is energy in the system (universe). Given its existence, in what ways can we talk about directions of time? One description of time either as a separate dimension or as one of the four dimensions of spacetime, is a line - a sequence of (real) numbers. This type of linearization of time has also generated the terms of direction, negative time, etc.

An abstract sequence of numbers ordered on a line is not necessarily a time sequence. The added meaning of time is given by some other thing. Here I would like to bring up an example: the tool for measuring time - the clock. What does the clock do? It has some kind of pendulum, or means for generating a periodic movement (electronic watches can be said to move electrons). As the pendulum oscillates, another mechanism counts the number of oscillations and records it. What we represent as time on a geometric line is the result of the count. The essence of time is in the acknowledgment and recording of one or more events (changes) in an already existent reality. In my example time is part of the oscillation event. The oscillation time is the unit of time or the minimum time interval that can be measured. This is represented on the line as the interval between two consecutive numbers.

Suppose now that the clock is the universe. The only physical events are the oscillation of the pendulum and the recording of the number of periods. The oscillation event represents the unit of time, but it has no direction. What does it mean to say that the time has no direction? Presumably it means this: if the recording of the period count is stopped, then the maximum time interval that can be measured (known) is also the minimum one and equals the period of oscillation. Because of that, at the end of each period there is no way to say if the last oscillation was made to the right or to the left.

The universe that has a direction in time records the number of counts (in the thermodynamical sense by an ever increasing entropy). At the end of each clock period

the total entropy in the universe is calculated; if it is found to be bigger than the total entropy a period ago, the time is said to move in the positive direction and one count is added to it. If the entropy is found smaller than before, the time moves back or to the left and one count is subtracted. A true thermodynamic time must be though aligned with entropy rate changes. If the entropy changes faster, then the time has to flow faster; if the entropy does not change, then the time count should stop.

Although the direction of time is attributed among other things to entropy and its irreversible direction, the time is not aligned to the changes in the entropy. In practice we use the cosmological alignment and a linear time that flows at a constant speed determined by star/planet motion; thermodynamics introduces a qualitative arrow without making requirements on how the counting is done.

Presumably, the cosmological arrow of time has been determined at the beginning of the universe. During the first few fractions of a second some of the initial conditions had been established and through them a significant part of the universe and its motion were defined. Looking at the evolution of the stars, background radiation, galaxy motion, etc. an evolutionary time direction can be established.

The so-called irreversible processes that generate a cosmological and a thermodynamical direction of time can be reversible in principle, only with a very long periodicity. To reverse the cosmological time is to reverse the evolutionary process of the universe: galaxies will move closer to each other, all planets will change both spin, and direction of revolution, and the universe will progress towards a Big Bang. The meaning of time in this sense is "how far we are from the Big Bang" (counted as the number of oscillation events from the closest next Big Bang). If the count is positive the motion is away from the (last) Big Bang, as we are counting our regular time. If the count is negative then we are approaching a Big Bang. To reverse time is equivalent to a change in the sign of the count. It is interesting to note that the universe being now on a

positive count (away from the Big Bang) is not a necessary condition, only an empirical fact. The universe could have been on either time polarity without violating any underlying laws.

The concept of time, as an idealized mathematical tool, does not necessarily have a direction. Moreover, physical time, independently or as a part of the spacetime frame, is not clearly and uniquely directional. Its direction comes through an association with physical changes, events and processes that can be proved to have a “count” that increases or decreases consistently. Since physical time is associated with two main processes in the universe, it is not uniquely determined; the physical time that we accept is a uniformly flowing time, which is not accurately tied to the two processes. As explained before, I chose not to claim any status for the physical time in this thesis; time flow and its relation to causal processes refer to the mathematical model for time as accepted.

CONCLUSIONS

Time and causality can be conceived as separate concepts. As far as any cause-effect relation is identified to be part of an explanation, and time is part of the spacetime physical frame or a mathematical model of it, there is no need to tie causality and time in a necessary way. Causal chains should be able to develop untimely, and time should be able to exist without causal relations. For the specific cases that form most of the physical world as we know it, causal relations are taken to include a time dimension. The explanation of how the cause causes the effect includes a time relationship between the two. However, this is only one possible explanation.

The physical description of the world considers the principle CPE (cause precedes effect in time) true, and it associates CPE with forward causation. Then, given the (assumed) necessary relation between causality and time, the question of backwards causation cannot be considered without any change in the time flow or direction. Similarly, the questions of time reversal and time travel have to be accompanied by a change in all causal chains imbedded in that time interval. However, the traditional analysis of such topics isolates the causal order from the time flow, which seems to be inconsistent with the assumption of a necessary connection between them.

This thesis has analyzed both aspects of CPE and EPC of causal chains, and concludes that the non-scientific EPC aspect is not contradictory in principle. It is possible to imagine instances of EPC, but it is quite difficult to bring concrete examples from the physical world because CPE is an underlying rule embedded in it.

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