THE ORDER OF TIME

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RIVERHEAD BOOKS NEW YORK 2018

10 PERSPECTIVE

In the impenetrable night
of his wisdom
a god closes
the strip of days
that's to come
and laughs
at our human trepidation. (III, 29)

The entire difference between past and future may be attributed solely to the fact that the entropy of the world was low in the past.[90] Why was entropy low in the past?

In this chapter I will give an account of an idea that provides a possible answer, "if you will hear my answer to this question and its perhaps extravagant supposition."[91] I am not sure that it is the correct answer, but it's the one with which I have become enamored.[92] It might clarify many things.

WE ARE THE ONES TURNING!

Whatever we human beings may be specifically, in detail, we are nevertheless pieces of nature, a part of the great fresco of the cosmos, a small part among many others.

Between ourselves and the rest of the world there are physical interactions. Obviously, not *all* the variables of the world interact with us, or with the segment of the world to which we belong. Only a very minute fraction of these variables does so; most of them do not react with us at all. They do not register us, and we do not register them. This is why distinct configurations of the world seem equivalent to us. The physical interaction between myself and a glass of water—two pieces of the world—is independent of the motion of the single molecules of water. In the same way, the physical interaction between myself and a distant galaxy—two pieces of the world—ignores what happens in detail out there. Therefore, our vision of the world is blurred because the physical interactions between the part of the world to which we belong and the rest are blind to many variables.

This blurring is at the heart of Boltzmann's theory.[93] From this blurring, the concepts of heat and entropy are born—and these are linked to the phenomena that characterize the flow of time. The entropy of a system depends explicitly on blurring. It depends on what I *do not* register, because it depends on the number of *indistinguishable* configurations. The *same* microscopic configuration may be of high entropy with regard to one blurring and of low in relation to another.

This does not mean that blurring is a mental construct; it depends on actual, existing physical interactions.[94] Entropy is not an arbitrary quantity, nor a subjective one. It is a *relative* one, like speed.

The speed of an object is not a property of the object alone: it is a property of the object in relation to another object. The speed of a child who is running on a moving train has a value relative to the train (a few steps per second) and a different value relative to the ground (a hundred kilometers per hour). If his mother tells the child to "Keep still!," she does not mean that they have to throw themselves out of the window to stop *in relation to the ground*. She means that the child should stop *with regard to the train*. Speed is a property of an object with respect to *another object*. It is a *relative* quantity.

The same is true for entropy. The entropy of A with regard to B counts the number of configurations of A that the *physical* interactions between A and B do not distinguish.

Clarifying this point, which frequently causes confusion, opens up a seductive solution to the mystery of the arrow of time.

The entropy *of the world* does not depend *only* on the configuration of the world; it also depends on the way in which we are blurring the world, and this depends on what the variables of the world are that *we* interact with. That is to say, on the variables with which our part of the world interacts.

The entropy of the world in the far past appears very low to us. But this might not reflect the exact state of the world: it might regard the subset of the world's variables with which *we*, as physical systems, have interacted. It is with respect to the dramatic blurring produced by our interactions with the world, caused by the small set of macroscopic variables in terms of which we describe the world, that the entropy of the universe was low.

This, which is a *fact*, opens up the possibility that it wasn't the universe that was in a very particular configuration in the past. Perhaps instead it is us, and our

interactions with the universe, that are particular. We are the ones who determine a particular macroscopic description. The initial low entropy of the universe, and hence the arrow of time, may be more down to us than to the universe itself. This is the basic idea.

Think of one of the grandest and most obvious phenomena: the diurnal rotation of the skies. It is the most immediate and magnificent characteristic of the universe around us: it turns. But is this turning really a characteristic of the universe? It is not. It took us thousands of years, but in the end we managed to understand the revolving of the heavens: we understood that it is *we* who turn, not the universe. The rotation of the heavens is a perspective effect due to our particular way of moving on Earth, rather than a mysterious property of the dynamics of the universe.

Something similar might be true for time's arrow. The low initial entropy of the universe might be due to the particular way in which we—the physical system that we are part of—interact with it. We are attuned to a very particular subset of aspects of the universe, and it is *this* that is oriented in time.

How can a particular interaction between us and the rest of the world determine a low initial entropy?

It's simple. Take a pack of twelve cards, six red and six black. Arrange it so that the red cards are all at the front. Shuffle the pack a little and then look for the black cards that have ended up among the red ones. Before shuffling, there are none; after, some. This is a basic example of the growth of entropy. At the start of the game, the number of black cards among the red in the first half of the pack is zero (the entropy is low) because it has started in a *special* configuration.

But now let's play a different game. First, shuffle the pack in a random way, then *look at* the first six cards and commit them to memory. Shuffle a little and look to see which other cards have ended up among the first six. At the start, there were none, then their number grew, as it did in the previous example, together with the entropy. But there is a crucial difference between this example and the previous one: at the beginning of this one, the cards were in a *random* configuration. It was *you* who declared them to be particular, by taking note of which cards were in the front half of the pack at the beginning of the game.

The same may be true for the entropy of the universe: perhaps it was in no particular configuration. Perhaps

we are the ones who belong to a particular physical system with respect to which its state can be particular.

But why should there be such a physical system, in relation to which the initial configuration of the universe turns out to be special? Because in the vastness of the universe, there are innumerable physical systems, and they interact with each other in ways that are even more numerous. Among these, through the endless game of probabilities and huge numbers, there will surely be some that interact with the rest of the universe *precisely* with those variables that found themselves having a particular value in the past.

It is hardly surprising that there are "special" subsets in a universe as vast as ours. It is not surprising that *someone* wins the lottery: someone wins it every week. It is unnatural to assume that the entire universe has been in an incredibly "special" configuration in the past, but there is nothing unnatural in imagining that the universe has parts that are "special."

If a subset of the universe is special in this sense, then for this subset the entropy of the universe is low in the past, the second law of thermodynamics obtains; memories exist, traces are left—and there can be evolution, life, and thought.

In other words, if in the universe there is something like this—and it seems natural to me that there could be—then we belong to that something. Here, "we" refers to that collection of physical variables to which we commonly have access and by means of which we describe the universe. Perhaps, therefore, the flow of time is not a characteristic of the universe: like the rotation of the heavens, it is due to the particular perspective that we have from our corner of it.

But why should *we* belong to one of *these* special systems? For the same reason that apples grow in northern Europe, where people drink cider, and grapes grow in the south, where people drink wine; or that I was born where people happen to speak my native language; or that the sun which warms us is at the right distance from us—not too close and not too far away. In all these cases, the "strange" coincidence arises from confusing the causal relations: it isn't that apples grow where people drink cider, it is that people drink cider where apples grow. Put this way, there is no longer anything strange about it.

Similarly, in the boundless variety of the universe, it may happen that there are physical systems that interact with the rest of the world through those particular

variables that define an initial low entropy. With regard to *these* systems, entropy is constantly increasing. There, and not elsewhere, there are the typical phenomena associated with the flowing of time: life is possible, together with evolution, thought, and our awareness of time passing. There, the apples grow that produce our cider: time. That sweet juice that contains all the ambrosia and all the gall of life.

INDEXICALITY

When we do science, we want to describe the world in the most objective way possible. We try to eliminate distortions and optical illusions deriving from our point of view. Science aspires to objectivity, to a shared point of view about which it is possible to be in agreement.

This is admirable, but we need to be wary about what we lose by ignoring the point of view from which we do the observing. In its anxious pursuit of objectivity, science must not forget that our experience of the world comes from within. Every glance that we cast toward the world is made from a particular perspective.

Taking this fact into account helps to clarify many things. It clarifies, for instance, the relation between what a geographical map tells us and what we actually see. In order to compare the map with what we see, it is necessary to add a crucial piece of information: we must identify on the map our exact location. The map does not know where we are, at least when it is not fixed in the place that it represents—like those maps in mountain villages showing routes that can be walked with a red dot next to which is written: "You Are Here."

A strange phrase: how can a map know where we are? We might be looking at it from afar, through binoculars. Instead, it should say "I, a map, am here," with an arrow next to the red dot. But there is also something curious about a text that refers to itself. What is it?

It is what philosophers call "indexicality": the characteristic of certain words that have a different meaning every time they are used, a meaning determined by where, how, when, and by whom they are being spoken. Words such as "here," "now," "I," "this," "tonight" all assume a different meaning depending on who utters them and the circumstances in which they are uttered. "My name is Carlo Rovelli" is true if I say it, but untrue if someone else not also called Carlo Rovelli uses the same phrase. "Now it is September 12, 2016" is a phrase that's true at the moment that I am writing

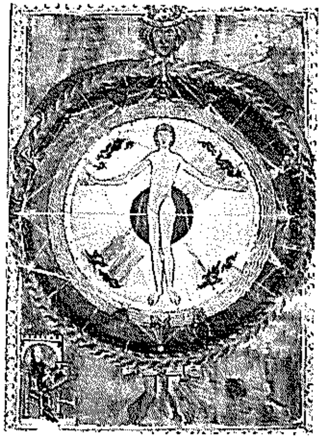
this but will be false just a few hours later. These indexical phrases make explicit reference to the fact that a point of view exists, that a point of view is an ingredient in every description of the observable world that we make.

If we give a description of the world that ignores point of view, that is solely "from the outside"—of space, of time, of a subject—we may be able to say many things but we lose certain crucial aspects of the world. Because the world that we have been given is the world seen from within it, not from without.

Many things that we see in the world can be understood only if we take into account the role played by point of view. They remain unintelligible if we fail to do so. In every experience, we are situated within the world: within a mind, a brain, a position in space, a moment in time. Our being situated in the world is essential to understanding our experience of time. We must not, in short, confuse the temporal structures that belong to the world as "seen from the outside" with the aspects of the world that we observe and which depend on our being part of it, on our being situated within it.[95]

In order to use a geographical map, it is not enough to look at it from the outside: we must know where we are situated in relation to what it represents. In order to understand our experience of space, it is not enough to think of Newtonian space. We must remember that we see this space from inside it, that we are localized. In order to understand time, it is not enough to think of it from outside: it is necessary to understand that we, in every moment of our experience, are situated *within* time.

We observe the universe from within it, interacting with a minuscule portion of the innumerable variables of the cosmos. What we see is a blurred image. This blurring suggests that the dynamic of the universe with which we interact is governed by entropy, which measures the amount of blurring. It measures something that relates to us more than to the cosmos.



Universal man at the center of the cosmos, in *Liber Divinorum Operum* by Hildegard of Bingen (1164–70).

We are getting up dangerously close to ourselves. We can almost hear Tiresias, in *Oedipus*, saying: "Stop! Or you will find

yourself" . . . Or Hildegard of Bingen, who in the twelfth century seeks the absolute and ends up by putting "universal man" at the center of the cosmos.

But before getting to this "us," another chapter is required, to show how the growth in entropy—perhaps only an effect of perspective—might give rise to the entire, vast phenomenon of time.

Let me summarize the hard ground covered in the last two chapters, in the hope that I have not already lost all my readers. At the fundamental level, the world is a collection of events *not* ordered in time. These events manifest relations between physical variables that are, a priori, on the same level. Each part of the world interacts with a small part of all the variables, the value of which determines "the state of the world with regard to that particular subsystem."

A small system *S* does not distinguish the details of the rest of the universe because it interacts only with a few among the variables of the rest of the universe. The entropy of the universe *with respect to S* counts the (micro)states of the universe undistinguishable *by S*. The universe appears in a high-entropy configuration *with respect to S*, because (by definition) there are more microstates in high-entropy configurations, therefore it is more likely to happen to be in one of these microstates.

As explained above, there is a *flow* associated with high-entropy configurations, and the parameter of this flow is *thermal time.* For a generic small system *S*, entropy remains generally high along the entire flow of thermal time, perhaps just fluctuating up and down, because, after all, we are dealing here with probabilities, not fixed rules.

But among the innumerable small systems *S* that exist in this extraordinarily vast universe where we happen to live, there will be a few special ones for which the fluctuations of the entropy happen to be such that *at one of the two ends* of the flow of thermal time entropy happens to be low. For *these* systems *S*, the fluctuation is not symmetrical: entropy increases. This growth is what we experience as the flowing of time. What is special is not the state of the early universe: it is the small system *S* to which we belong.

I'm not sure if we are dealing with a plausible story, but I do not know of any better ones. The alternative is to accept as a given of observation the fact that entropy was low at the beginning of the universe, and to leave it at that.[96]

It is the law announced by Clausius, $\Delta S \geq 0$, and deciphered by Boltzmann that is guiding us: entropy never decreases. Having lost sight of it, in search of the general laws of the world, we rediscover it as a possible perspective effect for particular subsystems. Let's begin again from there.