7. Does Time Flow?

“It is as if we were floating on a river, carried by the current past the manifold of events which is spread out timelessly on the bank,” said one philosopher trying to capture time’s flow with a helpful metaphor. Santayana offered another: “The essence of nowness runs like fire along the fuse of time.” We seem to be speaking of the flow of time when we say space dimensions are different from the time dimension because we can always go forward or backward in a space dimension, but we can go only forward in the time dimension. The philosopher’s goal is to clarify the idea of time’s flow, the passage of time. Everyone agrees that the passage of time appears to us humans to flow, but not everyone agrees that it actually does.

There are two categories of theories of time’s flow. The first, and most popular among physicists, is that the flow is an illusion, the product of a faulty metaphor. Time exists, things change, but time does not flow objectively. There may well be some objective feature of our brains that causes us to believe we are experiencing a flow of time, but the flow is not objective. This kind of theory is sometimes characterized as a “myth-of-passage” theory. That theory is normally the one adopted by those who believe McTaggart’s B-series is more fundamental than his A-series.

The second category of theories of time’s flow contains theories implying that the flow is objective, a feature of our mind-independent reality that is to be found in, say, today scientific laws, or, if it has been missed there, then in future scientific laws. These theories are called “dynamic theories” of time. This sort of theory of time’s flow is closer to common sense, and has historically been the more popular theory among philosophers.

One dynamic theory implies that the flow is a matter of events changing from being indeterminate in the future to being determinate in the present and past. Time’s flow is really events *becoming* determinate, so dynamic theorists speak of time’s flow as “temporal becoming.” A second dynamic theory implies that the flow is a matter of events changing from being future, to being present, to being past. This is the kind of flow associated with McTaggart’s A-series of events.

Opponents of these two dynamic theories complain that when events change in these senses, the change is not a real change in the event’s essential, intrinsic properties, but only in the event's relationship to the observer. For example, saying the death of Queen Anne is an event that changes from present to past is no more of a real change in the event than saying her death changed from being approved of to being disapproved of. This *extrinsic* change in approval does not count as a real change in her death, and neither does the so-called second-order change from present to past. Attacking the notion of time's flow in this manner, Grünbaum said: "Events simply are or occur…but they do not 'advance' into a pre-existing frame called 'time.' …An event does not move and neither do any of its relations."

Instead of arguing that events change their properties, a third dynamic theory says time's flow is the coming into existence of facts, the actualization of new states of affairs. A fourth dynamic theory suggests the flow is reflected in the change over time of truth values of a sentence or pro position
. For example, the sentence "It is now raining" was true during the rain yesterday but has changed to false on today's sunny day. It is these sorts of truth value changes that are at the root of time's flow. In response, critics suggest that the indexical (or token reflexive) sentence "It is now raining" has no truth value because the reference of "now" is unspecified. If it can not have a truth value, it can not change its truth value. However, the sentence is related to a sentence that does have a truth value. Supposing it is now midnight here on April 1, 2007 in Sacramento, California, then the indexical sentence "It is now raining" is related to the complete or context-explicit sentence "It is raining at midnight on April 1, 2007 in Sacramento." Only these non-indexical, non-context-dependent, complete sentences have truth values, and these truth values do not change with time. So, events do not change their properties because complete sentences do not change their truth values.

There are other dynamic theories of time. John Norton (Norton, 2010) argues that time's flow is objective but so far is beyond the reach of our understanding. Tim Maudlin argues that the objective flow of time is fundamental and unanalyzable. He is happy to say "time does indeed pass at the rate of one hour per hour." (Maudlin, 2007, p. 112)

Regardless of how we analyze the metaphor of time's flow we also need to analyze the metaphor of time's flow in some direction or other.

8. What Gives Time Its Direction or "Arrow"?

a. What Needs to be Explained

The arrow of time is what distinguishes a group of events ordered by the happens-before relation from those ordered by its converse, the happens-after relation. Time's arrow is evident in the process of mixing cool cream into hot coffee. You soon get lukewarm coffee, but you never notice the reverse–lukewarm coffee separating into a cool part and a hot part. Such is the way this irreversible thermodynamic process goes. Time's arrow is also evident when you prick a balloon. The air inside the balloon rushes out; air never rushes into the balloon. So, the pricking starts an irreversible process. The *arrow* of a physical process is the way it normally goes, the way it normally unfolds through time. If a process goes only one-way, we call it an "irreversible process." (Strictly speaking, a reversible process is one that is reversed by an *infinitesimal* change of its surrounding conditions, but we can overlook this fine point because of the general level of the present discussion.) The amalgamation of the universe's irreversible processes produces the *cosmic arrow* of time, the master arrow. Usually this arrow is what is meant when one speaks simply of "time's arrow." By convention, we say the arrow is directed toward the future.

There are many goals for a fully developed theory of time's arrow. It should tell us (1) why this arrow exists; (2) why the arrow is apparent in macro processes but not micro processes; (3) what it would be like for the arrow to reverse direction; (4) what the relationships are among the various more specific arrows of time–the various temporally asymmetric processes such as entropy increases [the thermodynamic arrow], causes preceding their effects [the causal arrow], light radiating from its source rather than converging into it [the electromagnetic arrow], and our knowing the past more easily than the future [the knowledge arrow]; (5) what are the characteristics of a physical theory that pick out a preferred direction in time; and (6) why the process of falling into a black hole is irreversible according to the theory of relativity, yet every quantum process has an inverse process.

Because the physical processes we commonly observe do have an arrow, you might think that an inspection of the basic physical laws would readily reveal time's arrow. It will not. With very minor exceptions, all the basic laws of fundamental processes are time symmetric. (It is assumed here that the second law of thermodynamics is not basic but somehow derived.) This means, according to a principal definition of time symmetry, that if a certain process is allowed by the laws, then that process reversed in time is also allowed, *and* either direction is as probable as the other. Maxwell's equations of electromagnetism, for example, can be used to predict that television signals can exist, but the equations do not tell us whether those signals arrive before or arrive after they are transmitted. In other words, these basic laws of science do not imply an arrow of time.

Suppose you have a movie of a basic physical process such as two electrons bouncing off each other. You can not actually create this movie because the phenomenon is too small, but forget that fine point for a moment. If you had such a movie, you could run it forwards or backwards, and both showings would illustrate a possible process according to the basic laws of science, and they would be equally probable processes. Unlike in a macroscopic movie, in this movie you could not tell from just looking at it whether you were looking at it in the order it was filmed. So, time's arrow is not revealed in this microscopic process.

The “disappearance” of time's arrow in microscopic process, does *not* show that time itself fades away as you look at briefer and smaller processes; this is because there are still events happening, and so time still exists there. Also, it is important to note that, although it is interesting to explain how we humans are able to detect the arrow, the more challenging philosophical question is to explain why time *has* an arrow.

b. Explanations or Theories of the Arrow

According to physicists, the most likely explanation of the arrow of time is that the arrow is a matter of the way entropy changes, entropy being a measure of the randomness or disorganization of the universe as a whole. At the time of the Big Bang, the universe was in a very organized state, for some unknown reason, and it has been running down and getting more disorganized ever since.

In the 19th century, the new kinetic theory of gases was supposed to provide the foundation for all gas behavior, yet this foundational theory is time symmetric. That is, the theory is insensitive to the arrow of time, to the distinction between past and future–because, for any system with all molecules moving as they are, there could be a system of the same molecules in the same positions but with the corresponding molecules moving in the reverse direction. The theory allows any system to go forward in time or backward in time. How were the physicists to resolve this apparent contradiction of having a temporally symmetric theory at the foundation of a theory that is supposed to account for irreversible gas processes such as the escape of gas from a balloon pricked with a pin? The first clue was discovered in the mid-19th century by the German physicist Rudolf Clausius. He devised an early version of the 2nd law of thermodynamics, which, speaking informally, is the claim that an isolated system will evolve so that some of its more useful energy is converted to heat. [An isolated system is a system left to itself; it is a region isolated from outside influences, a region where energy can not come in or go out.] That is,

(a) 2nd Law: In an isolated system, entropy never decreases.

Entropy is Clausius's word for the measure of this conversion of useful to "useless" energy by irreversible processes. Sometimes, but not in general, entropy increase is an increase in disorder. For example, when we build a house on a bare lot we increase the order in the neighborhood, but this organization is at the expense of a greater degree of disorganization elsewhere such as the depletion of natural resources and the digestion of food by the house builders and, ultimately, the degradation of the sun. The new house is created via a net loss in the available useful energy of the universe.

Why should there be *more* entropy in the future? The Austrian physicist Ludwig Boltzmann had an answer in 1872. Boltzmann claimed that it is a matter of probability because, for complex systems, that is, systems with many particles, even distributions of particle positions and velocities are more probable than uneven distributions. That is, it is very probable that the system will naturally end up in the most generic possible macrostate. Boltzmann redefined the concept of entropy in terms of the statistics of molecular motion, and he deduced a revised 2nd law from probability theory:

(b) 2nd Law: In an isolated system, entropy is *likely* not to decrease.

His treatment of entropy as being basically a statistical concept was broadly accepted, as was the claim that time's arrow, or at least its thermodynamic arrow, is to be explained in terms of entropy increase.

Boltzmann's achievement soon had to confront two objections, one raised by Ernst Zermelo and one raised by Josef Loschmidt. Zermelo appealed to a recurrence theorem proved in 1890 by Henri Poincaré. A dynamic system is a system defined by the values of the positions and velocities of all the system's particles–such as the places and speeds of the molecules in a cup of coffee. Poincaré's recurrence theorem in statistical mechanics says every isolated dynamical system will *eventually* return to a state as close to the initial state as we might wish. Wait long enough, and the lukewarm coffee will separate into hot coffee and cool cream. This reversal would be expected to take 10^N seconds, where N is the number of molecules involved. The number is staggering, but still finite; so, strictly speaking, there are no irreversible processes and no long term entropy increase. Whenever entropy rises it will eventually fall. That implies there is an apparent contradiction between Poincaré's theorem and Boltzmann's.

To avoid this Poincaré problem, physicists redefined the second law:

(c) 2nd Law: In an isolated system, entropy is likely not to decrease for any period of time that is short compared to the Poincaré period for that system.

Josef Loschmidt pointed out another problem with Boltzmann's approach to the arrow of time, a problem first discussed by Lord Kelvin in 1874. Loschmidt mentioned to Boltzmann that his statistical mechanics predicts for any point in time not only that entropy should be higher in the future but also that it should be higher in the past. However, we know that it was *not* higher in the past.

The conclusion to be drawn from this is that entropy increase is only part of the story of time's cosmic arrow.

Loschmidt suggested that the low entropy in the past must be explained by what the initial conditions happened to be like at the beginning of the universe. Boltzmann agreed. Among cosmologists, this is now the generally accepted answer to the origin of time's arrow.

Yet this answer leads naturally to the request for an explanation of the initial configuration of our universe. Is this temporally asymmetric initial boundary condition simply a brute fact, as many physicists believe, or are there as yet undiscovered laws to explain the fact, as many other physicists believe–either to explain it as necessarily having had to happen or to explain it as having been highly probable? Objecting to inexplicable initial facts as being unacceptably ad hoc, the Swiss physicist Walther Ritz and, more recently, Roger Penrose, say we must not yet have found the true laws (or invented the best laws) underlying nature's behavior. We need to keep looking for basic, time *asymmetrical* laws in order to account the initial low entropy and thus for time's arrow.

The low entropy appears to be due to the microscopic Big Bang region having just the right amount of homogeneity or smoothness so that galaxies would eventually form. If it were intially smoother, then there would be no congealing of matter into galaxies; if it were intially less smooth, then most all the matter would have long ago ended up in large black holes. So, the issue of how to explain the thermodynamic arrow is the issue of why the Big Bang region had just the right smoothness.

c. Multiple Arrows

The past and future are different in many ways that reflect the arrow of time. Consider the difference between time's *arrow* and time's *arrows*. The direction of entropy change is the thermodynamic arrow. Here are some suggestions for additional arrows:

1. We remember last week, not next week.
2. There is evidence of the past but not of the future.
3. Our present actions affect the future and not the past.
4. It is easier to know the past than to know the future.
5. Light and radio waves spread out, but never converge.
6. The universe expands in volume rather than shrinks.
7. Causes precede their effects.
8. We see black holes but never white holes.
9. B meson decay, neutral kaon decay, and Higgs boson decay are each different in a time reversed world.
10. Quantum mechanical measurement collapses the wave function.
11. Possibilities decrease as time goes on.

Most physicists suspect all these arrows are linked so that we can not have some arrows reversing while others do not. For example, the collapse of the wave function is generally considered to be due to an increase in the entropy of the universe. However, the linkage of *all* the arrows may require as yet undiscovered laws. And even if all arrows are produced by the thermodynamic arrow, the origin of this arrow is still a mystery.

d. Reversing the Arrow

Could the cosmic arrow of time have gone the other way? Most physicists suspect that the answer is yes, and they say it actually would have gone the other way if the initial conditions of the universe at the Big Bang had been different.

Unfortunately, it is still an open question in philosophy as to what it even *means* for time's arrow to reverse. For a technical introduction to the debate, see Savitt, pp. 12-19.

Supposing the cosmic arrow of time were to reverse, presumably our past would be re-created and lived in reverse order. This re-occurrence of the past is different than the re-living of past events via time travel. With time travel the past is re-visited in the original order, not in reverse order.

Philosophers have asked interesting questions about different scenarios involving the reversal of time's arrow. Suppose the cosmic arrow of time were someday to reverse in a distant, populated region far away from Earth. Imagine what life would be like for the time-reversed people. First off, would it be possible for them to be conscious? Assuming consciousness is caused by brain processes, could there be consciousness if their nerve pulses reversed, or would this reversal destroy consciousness? This is a difficult question, but supposing the answer is that they would be conscious, and supposing that anyone's future is what *will* happen, not what has happened, then what would their experience be like? It has been suggested that if we were able to watch them in their region of space, they would appear to us to be pre-cognitive. Could they use this to win gambling bets on, say, the roll of the dice? Probably not, say other philosophers who argue that the inner experience of time-reversed people must be no different than ours.

If Aristotle were correct that the future, unlike the past, is undetermined or open, then the future of people in the time-reversed region would be open, too. But it is like our past. What can we conclude from this? Do we conclude that our past might really be undetermined and open, too? That our past could change?

And there are other questions. Consider communication between the two regions. If we sent a signal to the time-reversed region, could our message cross the border, or would it dissolve there, or would it bounce back? If they successfully sent a recorded film across the border to us, should we play it in the ordinary way or in reverse? If the arrow of time were to reverse in some region, would not dead people in that region become undead, but is that metaphysically possible?