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# The Arrow of Time

**John:** Welcome back from vacation.

**Naomi:** Thanks. Are you still eating leftover turkey sandwiches like me?

**John:** No, I'm on an all-chocolate diet. It's not as effective as exercise, but I figured it wouldn't hurt to try.

**Naomi:** Good luck with that. My mom sent me back to L.A. with a ton of leftover turkey like she does every year. I had so much in my suitcase I probably made the airport's bomb-sniffing dogs go crazy. But anyway, how about you? Did you enjoy your vacation?

**John:** Yeah, but it's wasn't as good as when I was nine years old.

**Naomi:** How's that?

**John:** When I was nine, I caught my first fish using a rod that was only two feet long. My very first cast was a huge success. I hauled in a thirteen-inch trout.

**Naomi:** What luck!

**John:** When I was in the boat on the river last weekend, I was dreaming of a repeat. Didn't happen. But I had fun anyway. While I was there on the bank watching things float downstream, it reminded me of being in time with the events of my life passing by.

**Naomi:** Those events never stop coming. The arrow of time points upstream, but did you ever think about why it points that way instead of the other way around? Why do you think the arrow points toward the future instead of the past?

**John:** It's just a conventional truth. What's not conventional is that the universe behaves as if it has an arrow.

**Naomi:** Without an arrow, there'd be chaos.

**John:** Definitely. In class today one of the students said the arrow should point the way it does independently of how events go in the world. Other students complained that he didn't understand the arrow.

**Naomi:** I'm not surprised. Most people would say the arrow depends on events happening—first-order changes, as you call them.

**John:** Mehlberg said one of the big problems with the direction of time is to figure out just what the problem is. Some people say the problem is to show that there's an intrinsic difference between time flowing to the future and time flowing backward to the past, but other people say that's not the problem because we simply define "future" as how time flows, and the real problem is to decide why there's asymmetry. Others object to describing the arrow with the word "flow" because they believe in the arrow but not in its describing the direction of flow.

**Naomi:** I'm one of those people who don't like the word "flow," but what did you mean just now by "intrinsic difference" in the two directions?

**John:** Oh, like a leaf's being green is an intrinsic quality of the leaf. Its being west of New York isn't, because that's just a relationship the leaf has with some other thing. There's an intrinsic difference between its being green and being brown. And the question is whether there's an intrinsic difference between time flow to the future and time flow to the past.

**Naomi:** OK, that's what I thought "intrinsic difference" meant.

**John:** So what do physicists say about the arrow?

**Naomi:** That there are arrows, and then there are arrows. The arrow of a specific physical process is the way it normally goes. A lit wooden match normally goes from wooden match to ashes and never from ashes to unburned wooden match. If a process can't be reversed without altering the surroundings, physicists call it an "irreversible process." Imagine what you'd have to do to the surroundings to produce a wooden match starting with ashes. Most processes you can think of are irreversible. The amalgamation of the universe's irreversible processes produces the cosmic arrow of time, the master arrow. Usually this arrow is what we mean when we say "time's arrow." And physicists would say it exists regardless of whether you accept the substantivalist theory of time or the relational theory.

**John:** Yeah, but even reversible processes are changes in time, aren't they?

**Naomi:** True, but they can't be used to define an arrow. The process of several molecules bouncing off each other is a good example of a reversible process. Here's why. Suppose during a microsecond I were able to take a series of photographs of the molecules as they collide and bounce away. Then I shuffle the photographs and ask you to unshuffle them. You could order them properly, but there'd be two sequences to choose from, the sequence with time going forward and the one with time going backward. Which to choose? That indecision is a sign that the arrow of time can't be found in this process. You have to look for the arrow on a bigger scale.

**John:** OK, the arrow isn't detectable by examining reversible processes for short time periods, but surely the arrow is still there even if it can't be detected. You believe things can exist without them being detected, don't you?

**Naomi:** Yes, but if it's never, ever detectable, why believe it's there? If somebody tells you they have an invisible friend who's a rabbit, but who can't ever be detected by you, then why believe them?

**John:** Hmm . . . OK, so your point is that it's not that time fades away in small regions for short times, but just that the arrow does. And you're saying the arrow of processes is a collective property that emerges only on a larger scale in processes involving many particles.

**Naomi:** That's a good way to put it. You'd think that an inspection of the laws of nature should reveal why directed processes go one direction and not the other. Well, when it comes to the very basic physical laws, nobody can find an arrow.

**John:** When a match burns, doesn't the law of match burning say that over time there has to be more charcoal rather than less, so isn't that a direction inside the law?

**Naomi:** Yes, but you're looking at the situation too macroscopically. At the microscopic level where we have more basic laws about molecules, the laws explaining burning allow for the process to go either way. The match can unburn. Essentially, all the basic laws of fundamental processes are time symmetric. This means 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, as far as you could tell just from the laws themselves. Since the history of the world is the history of all those processes, this means that if the world has one history, then it could have had the reverse history.

**John:** That's odd. If the laws of science don't make time have the arrow it does, then I wonder if this shows the laws are defective.

**Naomi:** Maybe it does. Or maybe it shows that time doesn't have an intrinsic arrow after all.

**John:** But how about entropy? I don't really have a good sense of what it is except that it's some measure of the disorganization of a system, but isn't it associated with the arrow? I mean, doesn't the second law of thermodynamics require an increase in entropy over time for isolated systems, so isn't entropy's overall increase the same thing as time's arrow? In your class last year we learned that increase in entropy is why matches burn but never unburn, why cans rust but never unrust, and why engines are never perfectly efficient. Is that right?

**Naomi:** Yes. This law does describe the arrow, but it's not fundamental. It's really a law that can be explained in terms of the statistics of molecular processes that are more fundamental. If you have an isolated system of just a few particles, then the processes involving those particles can go either way, but if you have zillions of particles, then the more probable direction reveals itself. It's not that it can't go the other way but that it won't. The high probability of a process going one direction rather than the other is what makes entropy very probably increase, and it's what makes us say the process is "irreversible." But the fundamental laws are always reversible; that means, if the process went in the improbable direction, then the process could still be obeying the same laws.

**John:** I think I need an example.

**Naomi:** OK, instead of thinking about a chemical process, let's think about processes involving the mixing of air molecules of different speeds. Suppose we have an isolated box with hot air in its left half and cold air in its right half. The box is very ordered, we say. As the molecular particles interact by bouncing off each other, there are many possibilities for a final distribution of the molecules ten minutes later, but most of the possibilities are ones in which the molecules are nearly evenly distributed. in both halves and the original order is gone. The most probable distribution after ten minutes is one in which you have molecules of the same speed distributed uniformly throughout the box. It would be extremely improbable to find after ten minutes that the left half of the box was even hotter than when we started. The measure of this directedness toward the probable is what physicists call "entropy's increase." It's the direction of increased disorder. That's the thermodynamic arrow in action. To detect the arrow, you can't look at only a hundred molecules. You have to move out to the level of generality of millions of molecules. These molecular mixing processes go the way they do because nature is producing probable states from improbable states.

**John:** So that's what physicists think the arrow of time is? Some urge toward the probable? Entropy change is a measure of this urge?

**Naomi:** Yes. Well, almost. That's just the thermodynamic arrow because entropy change is an idea that applies only to situations involving energy flow that can be measured as heat change. It's a big part of the story of the cosmic arrow, but there are other arrows of time that also point to the future and seem to have nothing to do with heat change. Effects happening after their causes and not before is called the "causal arrow." In order for this causal arrow to exist, normal causation has to be much more frequent than backward causation. The psychological arrow is the direction from our sensing of events to our having memories of those events. The psychological arrow is what marks our remembering the past rather than the future. Another arrow exists when possibilities decrease and actualities increase as time goes on, but I don't have a name for that arrow. Clusters of galaxies are receding from one another on average as time goes on; this is the cosmological arrow that indicates the universe's expansion. Light going out from a candle flame rather than converging into the flame indicates the electromagnetic arrow. And there are many other arrows. For most of the arrows, the physicists don't know why the arrows exist, but just that they do. Nobody knows why light doesn't converge into the flame instead of only shining out from it.

**John:** I'm really surprised that scientists don't know why.

**Naomi:** Science has a ways to go. Physicists don't know how the universe acquired its initial low entropy, and they don't know whether one arrow is more fundamental than the others or if they're linked somehow. I worry that maybe they aren't linked. Then wouldn't it be strange if no other arrow changed except that the psychological arrow reversed tomorrow morning and we started having true memories of events before we experienced them?

**John:** It'd be really strange.

**Naomi:** I know you'd disagree with me, but I'd say the arrow of time is objective and the feeling of time's flow is subjective. They both point the same direction because the feeling of flow is due to changing brain states, such as acquiring new memories, and these changing brain states are thermodynamic processes that move toward higher entropy just like all the other processes. This is why the direction that time seems to flow is also the direction the thermodynamic arrow actually points. So the thermodynamic arrow is more fundamental than the psychological arrow. How about that?

**John:** That would make sense if the flow were subjective and due to brain processes, but I still think it's objective. Maybe it's time's flow that forces time's arrow to have the direction it does. Anyway, think about all the processes reversing. I don't know how, but just think of it. Then the cosmic arrow would reverse and time would run backward. We'd be able to relive our past. Like, look, up ahead, there's the past! It would be like when you step out of a time machine and see the past.

**Naomi:** I don't think the experience of arrow reversal would be like the experience of time travel. With time travel, the past is revisited in the original order that the events occurred. With arrow reversal, the past is visited in reverse order, which would be much stranger, don't you think?

**John:** Yes, stranger. I guess you're right about time travel not being like time reversal. OK, but suppose the universe were divided into two regions, one like ours with a normal arrow and one with the arrow reversed from the way it goes in our region. If people there were built just like us, with the same kinds of bodies and minds and civilization, then they'd usually walk backward up stairs, and food would come out of their mouths when they ate. Their past would look like our future.

**Naomi:** Wouldn't you say that their future, like ours, is by definition what will happen, not what has happened?

**John:** Yes. If we were able to watch them in their region, they might appear to us to be precognitive. I can imagine how they could easily win gambling bets on the roll of the dice. The un-roll.

**Naomi:** I'd have agreed with you about gambling a minute ago, but now I don't think someone's experience of a time-reversed world would be strange at all compared to our experience. Even if the people in the time-reversed region did know the numbers on the dice before they were rolled, their experience of dice wouldn't be different from ours because their brain processes would be reversed, too.

**John:** Uh . . . The reversal of their brain processes wouldn't remove the fact that they'd have access to the result of the roll before they placed their bet on the roll. That's all they'd need to easily win the bet. Reversing the cosmic arrow would require people to remember events in their future, and the future is what hasn't happened yet.

**Naomi:** Who'd accept the bet if it was common knowledge what the outcome is? Maybe there couldn't be true gambling as we know it.

**John:** It's so hard to imagine what their experience would be like. Mehlberg said that if we lived in a time-reversed world, we'd discover the same scientific laws we have now. Really odd.

**Naomi:** Different arrow; same science.

**John:** If Aristotle is correct that our future is undetermined or open, then because our future is like their past, the past of people in the time-reversed region would be open, too. And if their past could be open, why not ours?

**Naomi:** That's a dangerous deduction.

**John:** I know. Do you think we could communicate with the time-reversed people? If we sent a signal, could our message cross the border, or would it dissolve there, or would it bounce back? I'm not sure what would happen. I guess all the molecules involved in the signal would reverse direction at the border, and that should be enough to make their region impenetrable, like a perfect mirror. Odd.

**Naomi:** Just because the processes in the other region are the reverse of ours, that wouldn't make our own processes go in reverse as they arrived at the border. I think our signals would simply enter an odd, dark world where light is converging into lamps and people in the cemetery are rising out of their coffins and becoming undead.

**John:** Yeah, I think I was wrong about that mirror idea. If we were able to send a message to an inhabitant of the time-reversed region, maybe they couldn't remember our message because it would become part of their future. No, they remember the future, don't they?

**Naomi:** Memory is always about retaining traces of what's happened. So the message would enter their past while they played it. They'd just need to play the message backward, that's all.

**John:** No, that definition of memory you're using works only in our own region.

**Naomi:** I'm not sure.

**John:** How about this? Forget about regions. Suppose the whole universe contained people who were just about as good with foreseeing experiences as with remembering experiences. They have noninferential, direct knowledge of their future experiences just as we do of our past experiences. Their world wouldn't have any psychological arrow of time, would it?

**Naomi:** First off, you should distinguish whether they could or couldn't tell the difference between memory and precognition. Suppose they couldn't. Their world would still have the usual cosmic arrow, but they wouldn't be any good at detecting it naturally. We normal people use our memory and our ignorance of the future to detect the arrow and to distinguish between before and after. You know, if, while you're eating the apple, you truly remember buying the apple, then the buying was first and the eating is second. If we lost this detector of the arrow, that wouldn't wipe out the arrow itself.

**John:** OK, it wouldn't wipe out the cosmic arrow, but what about the psychological arrow?

**Naomi:** I'm not sure, but here's a thought. Abnormal people who are as good with the future as the past, but can't immediately tell the difference, could build an entropy detector and then rely on entropy increases to tell them which direction the future is. More generally, when these abnormal people are faced with two candidates for time order for a sequence of events and both orders look natural to them, they would find that only one of the two was consistent with the second law of thermodynamics.

**John:** Imagine living your life relying on an entropy detector machine to work out whether your mental image of falling in a mud puddle is a thought of what might happen or instead of what has already happened.

**Naomi:** An insane way to live.

**John:** Do you think the arrow in our normal universe can reverse? I don't see why not.

**Naomi:** It can't happen. I mean it can't happen everywhere. The cosmic arrow can disappear but not reverse. If causality goes wild, then it will disappear, but it isn't allowed to reverse.

**John:** Why not?

**Naomi:** Having the whole universe reverse all its processes at once would be like having the whole universe change into its mirror image. There'd really be no difference. If all there is in the universe is a single hand, then it can't be either a right hand or a left hand. The difference between left and right wouldn't make sense. So, if all the processes reversed, it wouldn't make any sense to say the universe had a right hand but then everything reversed and it turned into a left hand.

**John:** You just made sense saying it, so why did you say it doesn't make sense?

**Naomi:** I was speaking loosely. I should have said there'd be no detectable difference, so by Leibniz's Law there'd really be no difference.

**John:** God would know the difference, Leibniz or no Leibniz. Also, I can think of how the cosmic arrow could reverse and there'd be a detectable difference. Imagine that our universe contains nothing but people who shuffle playing cards. Their arrow of time shows itself in the fact that when people begin with a deck in perfect order, a few shuffles will always destroy that order. Continued shuffling won't restore the order. But now suppose one day the shufflers were to start noticing that in a few shuffles they could go from a disordered deck to a perfectly ordered one. Then they'd be justified in saying, "Look, the arrow of time must have reversed today!"

**Naomi:** I can understand what you're saying, but this scenario only works because you're imagining the people in the universe not being involved in those processes that reverse.

**John:** I don't see the problem. OK, let the people reverse, too. Let *all* the processes in the universe stop and then start going the other way.

**Naomi:** What do you mean by "then"?

**John:** Well, I . . . OK, you got me there. . . . No, you don't! Time can go forward even though the arrow reverses.

**Naomi:** Now you've got two arrows. You're imagining God's absolute arrow of time going forward while he reverses the arrow of time of his creation.

**John:** That's right.

**Naomi:** But without absolute time, the reversal would be described very differently by someone living during the reversal. I'd guess they'd say the arrow disappeared but is back again. They'd never notice the reversal because it would be analogous to our not noticing our waking up into a mirror-reversed world.

**John:** Are you distinguishing between saying people couldn't notice the reversal and saying there's no reversal?

**Naomi:** I made a mistake and forgot to make that distinction, but now that I think about it, if a reversal is not detectable even in principle, then it makes no sense to say there's been a reversal. It's all about Leibniz's Law of the identity of indiscernibles. A mirror-reversed world remains the same world.

**John:** I'm not sure. We seem just to be clarifying our difference rather than removing our difference.

**Naomi:** Well, we still have the issue of whether there's any physical property of the universe that gives time its direction. I think the property is causation. I want to define directed time order as causal order, but now I'm worried that we can't explain what causal order is without presupposing we already know what time order is. Maybe I'm going in circles. Time is really difficult to think about. Space is so much easier.

**John:** Mehlberg mentioned that Hans Reichenbach had an original idea about this back in 1924. Two events can be put in the proper time order if you can figure out which one of them could have caused the other, but not vice versa. Reichenbach used that idea, and his definition was something like this. Event A is earlier than event B if either A was part of the cause of B, or an event simultaneous with A was part of the cause of B, but not vice versa.

**Naomi:** That's fine, but I think Reichenbach's definition doesn't work if there's a possibility of backward causation.

**John:** He probably ruled that out.

**Naomi:** I'm still waiting for a good reason for doing this.

**John:** OK, but putting that aside where are we? The idea is that A happens before B if A could have caused B. Now Reichenbach's next problem is to avoid circularity by somehow defining what it means for A to cause B without presupposing that, if A could have caused B, then A must happen before B.

**Naomi:** This won't be easy. We know the laws of science are time symmetrical, which means that in principle if A is followed by B, then B can be followed by A. If a hammer dropping on an egg can be followed by the egg cracking, then in principle the egg cracking can be followed by the egg being whole and the hammer rising. I suppose somewhere Reichenbach has to start talking about statistics or else give up on an objective description and say causation is something the mind projects onto reality.

**John:** His tactic here does involve statistics. He defines causal order in terms of an asymmetry due to outgoing processes from a common center tending to be correlated with one another, but incoming processes to a common center tending not to be correlated with one another.

**Naomi:** Outgoing and incoming?

**John:** Yeah. In class we talked about an example used by David Papineau. We know that obesity and high excitement are two causes of heart attacks. These are two incoming processes tending toward a common center of heart attacks. But these two causes are probabilistically uncorrelated in the sense that obese people aren't any more likely to be highly excited than nonobese people and highly excited people aren't any more likely to be obese than unexcited people. Now look at outgoing effects from smoking. Both lung cancer and having nicotine-stained fingers are effects of smoking. This causation *does* imply that lung cancer is correlated with nicotine-stained fingers; for example, lung cancer is more likely among people with nicotine-stained fingers than among people with ordinary fingers. So the two causes of heart attacks are uncorrelated, but the two effects of smoking are correlated. This is a clue to the difference between what causes are like *versus* what effects are like. Reichenbach's idea is that effects can be detected by their being correlated or probabilistically dependent on each other, unlike causes. Reichenbach's program is considerably more complicated than what I've just said, but that's his key idea for distinguishing causes from effects.

**Naomi:** Reichenbach is onto something.

**John:** I'm not so sure of that. It seems to me that there are better ways to distinguish causes from effects than in terms of probabilities and correlations. I think it's best to think of causes as the sorts of events you manipulate in order to get the effects. You can't manipulate the effects to bring about their causes. That's what really distinguishes causes from effects, not probabilities and correlations. Think about kinds of events instead of single events. One kind of event is the firings of a gun at targets on the practice range. The other kind of event is holes appearing in targets. How do you tell which causes which without making the decision by saying the cause is what happens first? Well, you can't manipulate the target to get the gun to fire, but you sure can manipulate the gun to get holes in those targets. That tells you how to distinguish causes from effects, and then you can declare by definition that the causes are first, that is, before their effects. So there's your direction of time, the overall flow from causes to effects. I know this is vague, but that's my general idea.

**Naomi:** Did you escape circularity? I think you might be surreptitiously presupposing you already know which occurred first. The holes in the targets might be stimulating the pleasure centers of gun owners so they go and point their guns at the targets. The holes might cause the firings.

**John:** You couldn't say that about a single event. A single bullet hole in the target couldn't stimulate someone to shoot the bullet.

**Naomi:** Why not?

**John:** Because we know that first you pull the trigger, and then the bullet . . .

**Naomi:** Oops! You said "first" and "then." You've just assumed you know the direction of time, so there's a circularity in your theory.

**John:** All right, but maybe I can revise my theory. How about this? Suppose some event has happened. You can explain it by citing its cause; you can't explain it by citing its effect, and this asymmetry in explanation might be the key to distinguishing causes from effects—to their being different, not just to our noticing that they're different. Back to the gun and the targets. You want to explain the holes in the targets. Well, the gun firings are what explain the holes, so they're the cause.

**Naomi:** No, you've got the same problem. How can you know not to explain the firing of the gun by the appearance of the bullet hole?

**John:** Well, the explanation would be so bizarre and unintuitive. . . . Oh, there's my bus stop.

**Naomi:** Time flies.

**John:** As they say, time flies like an arrow, and fruit flies like a banana.

**Naomi:** [laughs]

**John:** See you next week.

## DISCUSSION QUESTIONS

1. How do we know time's arrow doesn't point toward the past?
2. What's the difference between the arrows of time and the arrow of time?
3. Why do we remember the past but not the future?
4. What does entropy have to do with the arrow of time?
5. If the cosmic arrow of time went one way in our half the universe and the other way in the other half, and you received a verbal communication from the other region (presumably in English), what would your experience of it be like?
6. Discuss seriously the comments in the following dialogue between Alice in Wonderland and the Queen who lives backward:

> "Living backward!" Alice repeated in great astonishment. "I never heard of such a thing?"
>
> "–But there's one great advantage in it, that one's memory works both ways," said the Queen.
>
> "I'm sure *mine* only works one way," Alice remarked. "I can't remember things before they happen."
>
> "It's a poor sort of memory that only works backward," the Queen remarked.
>
> "What sort of things do *you* remember best?" Alice ventured to ask.
>
> "Oh, things that happened the week after next," the Queen replied in a careless tone.

7. How can causes be distinguished from effects?
8. What point is Reichenbach making in his discussion of the difference between incoming and outgoing processes and their correlations?
9. Is anything preventing the arrow of time from reversing?

## FURTHER READING

Davies, Paul. *About Time: Einstein's Unfinished Revolution*. New York: Simon & Schuster, 1995.

A physicist surveys the problem of time's arrow in chapter 9.

Gardner, Martin. "Can Time Go Backward?" *Scientific American* 216, no. 1 (1967): 98–108.

An informal exploration of how the reversal of time's arrow is treated in the literature of physics, science fiction, and philosophy.

Hawking, Stephen. *A Brief History of Time: The Updated and Expanded Tenth Anniversary Edition*. New York: Bantam Books, 1998.

Chapter 9, "The Arrow of Time," discusses why all the arrows of time point in the same direction. Hawking explores what experience is like in a time-reversed world. He claims "the reason we observe this thermodynamic arrow to agree with the cosmological arrow is that intelligent beings can exist only in the expanding phase."

Horwich, Paul. *Asymmetries in Time: Problems in the Philosophy of Science*. Cambridge, MA: The MIT Press, 1987.

A philosophical monograph devoted to the problem of understanding asymmetries in time and to the relationship of this problem to other problems in philosophy. Our dialogue lightly touches on the relationship between thermodynamics and entropy, but it is covered well and accessibly in Horwich's chapter 4.

Morris, Richard. *The Big Questions: Probing the Promise and Limits of Science*. New York: Henry Holt and Company, LLC, 2002.

Pages 12–28 contain a brief, easy-to-read explanation of current scientific knowledge about the arrows of time.

Newton-Smith, W. H. *The Structure of Time*. London: Routledge & Kegan Paul Books Ltd., 1980.

See chapter 9 for this philosopher's introduction to the problems involving the direction of time.

Papineau, David. "Philosophy of Science." In *The Blackwell Companion to Philosophy*, edited by Nicholas Bunnin and E. P. Tsui-James, 290–324. Oxford: Blackwell Publishers Limited, 1996.

See page 312 for how two causes of heart attacks are uncorrelated, but two effects of smoking are correlated, which is a sign of how to distinguish causes from effects in general.

Price, Huw. *Time's Arrow and Archimedes' Point: New Directions for the Physics of Time*. New York: Oxford University Press, Inc., 1996.

An analysis of time's arrow from a distant vantage point outside of time. Difficult reading.

Reichenbach, Hans. *The Direction of Time*. Berkeley: University of California Press, 1956.

An original attempt to explain why there are traces of the past but not of the future. He develops his causal theory of time and speculates about there being two regions of the universe with their arrows of time going in opposite directions. Difficult reading.

Sklar, Lawrence. "Up and Down, Left and Right, Past and Future." *Nous* 15 (1981): 111–29.

Argues that the meaning of the term "arrow of time" is not what needs to be explained; rather there should be a theoretical reduction of the arrow. Similarly, earlier scientists didn't want to know what the term "water" means, but they wanted a theoretical reduction of water to $H_2O$.