1.1: Time and Causality

Updating Plato's allegory of the cave, imagine two super-intelligent twins, Alice and Betty. They're raised entirely by a robotic tutor on a sealed space station, with no access to the outside world. The robot, in accord with the latest fad in education, is programmed to encourage them to build up a picture of all the laws of physics based on their own experiments, without a textbook to tell them the right answers. Putting yourself in the twins' shoes, imagine giving up all your preconceived ideas about space and time, which may turn out according to relativity to be completely wrong, or perhaps only approximations that are valid under certain circumstances.

Causality is one thing the twins will notice. Certain events result in other events, forming a network of cause and effect. One general rule they infer from their observations is that there is an unambiguously defined notion of *betweenness*: if Alice observes that event 1 causes event 2, and then 2 causes 3, Betty always agrees that 2 lies between 1 and 3 in the chain of causality. They find that this agreement holds regardless of whether one twin is standing on her head (i.e., it's invariant under rotation), and regardless of whether one twin is sitting on the couch while the other is zooming around the living room in circles on her nuclear fusion scooter (i.e., it's also invariant with respect to different states of motion).

You may have heard that relativity is a theory that can be interpreted using non-Euclidean geometry. The invariance of betweenness is a basic geometrical property that is shared by both Euclidean and non-Euclidean geometry. We say that they are both *ordered* geometries. With this geometrical interpretation in mind, it will be useful to think of events not as actual notable occurrences but merely as an ambient sprinkling of *points* at which things *could* happen. For example, if Alice and Betty are eating dinner, Alice could choose to throw her mashed potatoes at Betty. Even if she refrains, there was the potential for a causal linkage between her dinner and Betty's forehead.

Betweenness is very weak. Alice and Betty may also make a number of conjectures that would say much more about causality. For example:

i. that the universe's entire network of causality is connected, rather than being broken up into separate parts;
ii. that the events are globally ordered, so that for *any* two events 1 and 2, either 1 could cause 2 or 2 could cause 1, but not both;
iii. not only are the events ordered, but the ordering can be modeled by sorting the events out along a line, the time axis, and assigning a number tt, time, to each event.

To see what these conjectures would entail, let's discuss a few examples that may draw on knowledge from outside Alice and Betty's experiences.

- According to the Big Bang theory, it seems likely that the network is connected, since all events would presumably connect back to the Big Bang. On the other hand, if (i) were false we might have no way of finding out, because the lack of causal connections would make it impossible for us to detect the existence of the other universes represented by the other parts disconnected from our own universe.
- If we had a time machine[1], we could violate (ii), but this brings up paradoxes, like the possibility of killing one's own grandmother when she was a baby, and in any case nobody knows how to build a time machine.
- There are nevertheless strong reasons for believing that (ii) is false. For example, if we drop Alice into one black hole, and Betty into another, they will never be able to communicate again, and therefore there is no way to have any cause and effect relationship between Alice's events and Betty's.[2]

closed timelike curve (CTC)

[1] The possibility of having time come back again to the same point is often referred to by physicists as a *closed timelike curve (CTC)*. Kip Thorne, in his popularization *Black Holes and Time Warps*, recalls experiencing some anxiety after publishing a paper with “Time Machines” in the title, and later being embarrassed when a later paper on the topic was picked up by the National Enquirer with the headline PHYSICISTS PROVE TIME MACHINES EXIST. “CTC” is safer because nobody but physicists know what it means.

Since (iii) implies (ii), we suspect that (iii) is false as well. But Alice and Betty build clocks, and these clocks are remarkably successful at describing cause-and-effect relationships within the confines of the quarters in which they've lived their lives: events with higher clock readings never cause events with lower clock readings. They announce to their robot tutor that they've discovered a universal thing called time, which explains all causal relationships, and which their experiments show flows at the same rate everywhere within their quarters.

“Ah,” the tutor sighs, his metallic voice trailing off.

“I know that `ah', Tutorbot,” Betty says. “Come on, can't you just tell us what we did wrong?”

“You know that my pedagogical programming doesn't allow that.”

“Oh, sometimes I just want to strangle whoever came up with those stupid educational theories,” Alice says.

The twins go on strike, protesting that the time theory works perfectly in every experiment they've been able to imagine. Tutorbot gets on the commlink with his masters and has a long, inaudible argument, which, judging from the hand gestures, the twins imagine to be quite heated. He announces that he's gotten approval for a field trip for one of the twins, on the condition that she remain in a sealed environment the whole time so as to maintain the conditions of the educational experiment.

“Who gets to go?” Alice asks.

“Betty,” Tutorbot replies, “because of the mashed potatoes.”

“But I refrained!” Alice says, stamping her foot.

“Only one time out of the last six that I served them.”

The next day, Betty, smiling smugly, climbs aboard the sealed spaceship carrying a duffel bag filled with a large collection of clocks for the trip. Each clock has a duplicate left behind with Alice. The clock design that they're proudest of consists of a tube with two mirrors at the ends. A flash of light bounces back and forth between the ends, with each round trip counting as one “tick,” one unit of time. The twins are convinced that this one will run at a constant rate no matter what, since it has no moving parts that could be affected by the vibrations and accelerations of the journey.

Betty's field trip is dull. She doesn't get to see any of the outside world. In fact, the only way she can tell she's not still at home is that she sometimes feels strong sensations of acceleration. (She's grown up in zero gravity, so the pressing sensation is novel to her.) She's out of communication with Alice, and all she has to do during the long voyage is to tend to her clocks. As a crude check, she verifies that the light clock seems to be running at its normal rate, judged against her own pulse. The pendulum clock gets out of synch with the light clock during the accelerations, but that doesn't surprise her, because it's a mechanical clock with moving parts. All of the nonmechanical clocks seem to agree quite well. She gets hungry for breakfast, lunch, and dinner at the usual times.

When Betty gets home, Alice asks, “Well?”

“Great trip, too bad you couldn't come. I met some cute boys, went out dancing, ...”

“You did not. What about the clocks?”

“They all checked out fine. See, Tutorbot? The time theory still holds up.”

“That was an anticlimax,” Alice says. “I'm going back to bed now.”

“Bed?” Betty exclaims. “It's three in the afternoon.”

The twins now discover that although all of Alice's clocks agree among themselves, and similarly for all of Betty's (except for the ones that were obviously disrupted by mechanical stresses), Alice's and Betty's clocks disagree with one another. A week has passed for Alice, but only a couple of days for Betty.