Causation

Lecture 8: Does Time have an Arrow?

1. 2nd Law of Thermodynamics

- This tells us that entropy tends to increase. Since this ‘increase’ is understood as an increase over time it is temporally ordered; it is not symmetric with respect to time.
- Hence it looks as though there is here a fundamental law of nature which is not symmetric with respect to time, and thus that time has a ‘natural’ direction – from lower to higher entropy.

2. Entropy

- Entropy is a way of measuring how ‘untidy’ or ‘disorganised’ a system is. The higher the entropy the more untidy it is; but, equally, a system with high entropy is likely to be in equilibrium, whereas one with low entropy (i.e. very tidy) will not be in equilibrium – and will tend to change to a more disorganised state. there is are connections here with energy: maintaining low entropy requires extra energy, unlike maintaining the equilibrium state of high entropy.

3. From low to high probability

- Why is the tendency (for an isolated system) to change from low to high entropy not symmetric? In the 1870's Ludwig Boltzmann offered a way of thinking about this change, as one from a low probability state to one with a higher probability. If that is right, then we do appear to have an explanation of the asymmetry: for one would not expect a process which changes from low to high probability to be symmetric.

4. Macro- and microstates

- To make the connections here between entropy and probability, Boltzmann argued that we should think of the classification low vs. high entropy as a generic, macro, classification of a plurality of different molecular microstates each of which realises a macro state. Then the basic thought is this: high entropy macrostates are realised by vastly more microstates than low entropy macrostates. So: if there is a largely random process of change among the microstates themselves, there is a much greater chance of a microstate which realises low entropy being transformed into a state which realises high entropy, rather than vice-versa.

- The standard model is shuffling a pack of cards. Even if one starts from a pack of cards systematically ordered into suits etc. shuffling typically takes one quickly from order to disorder because there are vastly more ways in which a total pack of cards can be disordered than ways in which it can be ordered systematically. Of course it’s not ruled out that shuffling might take one from disorder to order; such a transformation has a finite, if small, probability. So, similarly, Boltzmann’s argument has to allow that there is a finite, though very small chance of a change from high to low probability. This is a qualification of the 2nd law of thermodynamics: it might be that a glass of tepid water divides into a couple of ice cubes and some warm water. But the chance of this is so remote that we can neglect it (and for our purposes what’s important is the denial of symmetry, which Boltzmann’s argument respects.

5. The process of change.

- Boltzmann's argument essentially draws on the assumption that the process of change at the microstate level involves a series of largely random transformations – molecules of one gas mixing with those of another via a series of random collisions, energy transfers via radiation of collision etc. But at this point a serious problem arises.

- Although these transformations are not individually predictable or controllable, it was also an assumption of statistical mechanics that in principle these transformations were governed by deterministic laws – Newton’s or extensions of them. Of course things are different once one moves to quantum theory and quantum electrodynamics; but in principle it would be good not to have to draw on this theory, which, of course, postdates Boltzmann’s work.

- So the challenge (set out by Loschmidt) is this: can Boltzmann’s argument survive determinism at the microlevel? And the particular challenge to confront is this: Newton’s laws are symmetric with respect to time – hence the transformation of a low entropy microstate into a high entropy microstate can in principle be reversed, and there seems no reason to hold that the transformation in one direction is any more probable than in the other.

- But if that is right, then Boltzmann's thought that the low-to-high entropy transformation is a change from low-to-high probability is in trouble.

6. Salvaging Boltzmann's argument

- We need to find a way to build randomness into the transformations at the microlevel despite the assumed symmetric determinism of the fundamental laws involved. The way to do this is to recognise that the transformations are dependent not only on the laws of nature but also on the initial conditions. In the cases in question these initial conditions concerning the location, velocity, direction, charge etc. of the molecules involved ware very sensitive to external influences.

- So if we can regard these external influences as random, then their effect upon the conditions under which the transformations from one microstate to another take place will be to introduce the requisite element of randomness into these transformations despite the assumption that the laws of nature are symmetric.
- So far as I can see, this gets us back to the substance of Boltzmann’s conclusion.

7. Entropy and time

- But now another issue arises. This resuscitated version of Boltzmann's argument tells us that the natural tendency of systems to move from low to high entropy is backed up the fact that such a transformation is one from a low probability state to one whose probability is much higher.

- But where is time in all this? Why should we suppose that this transformation is uniquely ordered as one which runs from past to future? Hard though it is to make sense of it, why not suppose that this transformation also runs in the opposite temporal direction – from future to past?

- On reflection that does not seem likely; for a transformation of this kind, viewed the other (normal) way, would be one from a high probability equilibrium state to a low probability out-of-equilibrium state; and that’s not at all likely, given random interventions which affect initial conditions at each stage, even assuming the fundamental laws are symmetric.

8. The universe as a whole – from low to high?

- But there is a different assumption in the general temporal application of the 2nd Law of Thermodynamics – which is that in general the universe has manifested low entropy, and – thanks to the 2nd Law – is moving towards high entropy. It is this assumption which fundamentally underpins the thesis that the 2nd law is one which runs from past to future.

- How is this assumption to be justified?

- Maybe on cosmological grounds: maybe the random perturbations in the Big Bang generated lots of low entropy systems (e.g. stars) whose ‘decay’ into red dwarfs is an example of a move to high entropy.

- So: perhaps it is cosmology plus the 2nd law which gives time its direction.

9. Finally: how does this connect with causation?

- If we agree that the transformations characteristic of the 2nd law have a temporal direction, then we can regard the causal processes involved as temporal too.

- And, more generally, any process of change from low to high probability looks to have a temporal order.

- But does this apply to all causal processes – e.g. interactions governed by time symmetric laws (e.g. clashing billiard balls)? I don’t see how it does; and to that extent, therefore, I don’t see why one has to suppose that causes cannot occur after their effects.