Anthropic Explanations in Cosmology

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1. Anthropic Explanations

Cosmologists often claim that our universe is "fine tuned" for life. A change by 1% in the strong nuclear force would have meant little carbon would exist, and carbon can seem biologically essential. Again, the riches of chemistry and biochemistry depend on the neutron's being heavier than the proton by no more than 0.1%. The early cosmic expansion rate may have needed fine tuning to one part in 10^{55} to prevent speedy recollapse and speedy disintegration. To prevent excess turbulence the "smoothness" perhaps needed fine tuning to one part in 10 raised to the power of 10^{123} (a number far greater than 10^{1230}). Etcetera (Leslie 1982, 1983a, 1985, 1986).

The list of such claims is very long. No doubt some of its items are mistakes. Others may be dictated by basic physics so that they are not fine-tunable. But it seems unlikely that all the items can be dealt with in these ways. And the very fact that cosmologists try to "deal with" them shows their discontent with treating natural constants and early conditions as essentially unpuzzling. They puzzle, for instance, over why there is more matter than antimatter, when they observe roughly 10^{80} matter particles and 10^{89} photons such as result from matter-antimatter annihilations. If you toss 2×10^{89} pennies there is slim chance of getting 10^{80} more Heads than Tails.

A divine Fine Tuner supplies one possible solution. Or there might exist vastly many "worlds" or "universes" with varied properties; life-encouraging conditions might then be expected in a few. (When "universe" means All That There Is, talk of many existing universes is absurd. But to cosmologists "our universe" often means something more limited, such as All With Which We Could Interact, all inside the horizon set by the speed of light.)

An attractive scenario is described by A.D.Linde, a leading investigator of the nowadays very popular Inflationary Universe. Space inflates to perhaps 10^{3240} cm in its first fractions of a second. (Compare this with the mere 10^{28} cm of our horizon.) The gigantic large-U Universe in which our small-u universe is embedded contains regions of

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greatly differing force strengths and particle masses, thanks to scalar fields whose values vary randomly from region to region. (During early phase transitions such fields can break the symmetries which may make all force strengths and particle masses identical at great temperatures.) The whole shebang is "a free lunch": it costs nothing since gravitational energy enters the accounts as a negative quantity. The scalar fields give "a lunch at which all possible dishes are available" (Linde 1982, 1983, 1984).

Regions inside the Inflationary Universe could count as separate worlds or small-u universes through being unable to interact now; they may however have interacted at the start. A more drastic separation between universes is offered by E.P.Tryon, originator of the "free lunch" theme. Tryon's universes arise as quantum fluctuations. They have entirely separate histories. Perhaps life exists only in few.

Other ways of getting many universes include J.A.Wheeler's. The cosmos oscillates: Big Bang, Big Squeeze, Big Bang, etcetera. Successive cycles could be very different, perhaps because "memory" of properties vanished during each compression. Each cycle might count as a new universe (Wheeler 1973).

Many Worlds Quantum Theory, originated by H.Everett, gives us a constantly branching cosmos; the branches could count as "separate universes". Particle masses and force strengths might vary from universe to universe thanks to random differences between early phase transitions.

Such scenarios need not compete. An Inflationary Universe could be one of many born as Tryon fluctuations. It might undergo Wheeler oscillations. It might branch, Everett-fashion.

The Anthropic Principle could be stated as follows: Any living beings must find themselves where life is possible. Though a tautology, this can be important when combined with belief in many universes; it can suggest that our universe could well be remarkably friendly to life. Note, first, that it concerns living beings in general, not just man; second, that its "must" is not the "must" of "God must have wanted to create life" or of "Every actual universe must be life-containing"; and third, that it does not say that our universe was from its first instant sure to become life-containing. Whether it would develop life-encouraging properties may have depended on probabilistic phase transitions at later instants. Finally, claiming that such properties are "a consequence of" our existence need not mean viewing us as their causes. Being a wife is a causal consequence, often, of being a woman. Being a woman is a logical consequence of being a wife. (The Anthropic Principle was so christened by B.Carter. Leslie (1983b) discusses problems in interpreting him.)

The Anthropic Principle suggests an observational selection effect. If only a few universes contain life, we must see one of those few. I find a story helpful here. You catch an eel measuring 19.6573 cm. Every eel must have some length; but what if your fishing apparatus would reject all except ones of almost exactly this length? You would have grounds for thinking the lake contained eels of many lengths. One needs many actual eels to make it at all likely that the apparatus can catch anything.

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It could be rash to claim that among all possible universes only a small range could support life. But no such claim need be involved. We need consider only universes in "the local area" of possibilities, universes with laws much like those we know but differing in, say, expansion rates. A second story may help. On a wall there sits a fly surrounded by a largish fly-free area. A bullet hits the fly. Conclusion: Either the firer is a marksman ("God") or the wall is being sprayed with bullets ("multiple universes scattered over the area of physical possibilities"). Whether distant areas of the wall are thick with flies, so that any bullet landing there would hit one, is irrelevant.

2. The "Inverse Gambler's Fallacy" Objection

Could the existence of other universes truly render ours less puzzling? I shall draw on two studies by Ian Hacking (1985, 1986), the second of them stemming from a debate with me.

Hacking sees nothing too wrong with anthropic explanations when at least one life-containing universe is guaranteed. In Everett's theory, for instance, all possible phase transitions occur, one in each branch into which the early cosmos splits. Did life depend on a phase transition's taking a particular form? That form was bound to be taken in some branch. Did it demand fortunate molecular combinations in primeval soups? Somewhere such combinations would arise. But, says Hacking, beware when mere probabilities enter in! The Anthropic Principle now cannot help us. Appeals to it commit The Inverse Gambler's Fallacy.

The Gambler's Fallacy goes like this. A gambler sees two dice thrown repeatedly. Deciding double-six "is long overdue", he bets his shirt on it. The Inverse Gambler's Fallacy occurs when the gambler, wandering into a room and seeing double-six thrown, bets his shirt that there were many earlier throws.

Were Hacking right, then the scope for "anthropic" reasoning would be small. P.Davies would commit a howler when writing (1983, p. 172) that when universes appear in sequence, their natures being settled probabilistically, this is for present purposes "identical" with the Everett situation. The identity would exist only were it guaranteed (perhaps because the universes were infinite in number, the possible variations only finite) that life would evolve some day. Yet if a howler occurs anywhere then I think it occurs everywhere. For I can see little difference between an absolute guarantee and a virtual guarantee supplied by vastly many universes. The gambler who states that double-six will occur at least once in a million throws is for practical purposes right. And when he argues that seeing double-six suggests an infinite number of throws, his howler can be as horrific as if he had said a million.

It seems, though, that no Fallacy occurs. For the right story does not have a gambler wandering into a room. He is instead called in because double-six ("life") has just been thrown.

However, Hacking says this makes no difference. The gambler, knowing his admission depended on double-six and finding that he is called in, may fancy he has *prima facie* grounds for believing that the dice were thrown repeatedly. (Only *prima facie* ones: the thrower might be bone

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idle and certain to have thrown once only.) But, Hacking protests, double-six was thrown on the throw which has just occurred. This was just one throw. Its chance of being a double-six was just as small whether or not it followed many throws.

Hacking's point would apply also to a hundred sixes. Again, imagine you are going into suspended animation. You will awake if and only if the monkey (who can grow very but not infinitely old) types an encyclopedia. Hacking's claim is that waking would not give you even *prima facie* grounds for believing in more than one encyclopedia-length bout of typing.

This seems too paradoxical. "Just one encyclopedia-length bout" can have only one chance of being correct whereas "more than one bout" would have many chances when the monkey could type for trillions of years, stopping only if the encyclopedia appeared; it could be correct on a second bout, or on a third, or on a fiftieth, etcetera. Yes, to speak of *the* second bout, *the* fiftieth, would beg the question against the idea of a devilish plan to allow the monkey only one bout. But on seeing the typed encyclopedia, who would believe in this plan? Such a plan would have made seeing it almost impossible, whereas a plan to allow vastly many typing bouts could have made it nearly inevitable.

Here are three places where Hacking may have gone wrong.

(1) The thrower may have decided to throw up to ten thousand times, stopping if double-six appeared. IF that had been his policy, double-six would have appeared almost certainly -- and it could of course appear only on the final throw. (Here "final" means "which ends the throwing" so this throw might be the very first throw, unlikely though that would be.) True, the IF is a big one; the thrower might be bone idle. Still, he might fail to be bone idle! We thus have no right to say that the chance of the final throw's being a double-six is only one in thirty-six. All we can say is that just before such a throw was made the chance that this specific throw (the tenth throw, perhaps) would become a double-six, as may have been necessary to its becoming the final throw, WAS only one in thirty-six.

Now, Hacking uses Bayes' Rule, writing

$$P(L|A) = \frac{P(L)\ P(A|L)}{P(L)\ P(A|L)\ +\ P(M)\ P(A|M)}$$

where L is a LONE throw, M is MORE THAN ONE, and A is ACTUALLY SEEING double-six; thus $P(L|A)$ might be read as "the probability that this observed double-six resulted from a lone throw". And he insists on substituting 1/36 for both $P(A|L)$ and $P(A|M)$. Since $P(L) + P(M) = 1$, it then follows that $P(L|A) = P(L)$; hence, he says, the gambler who sees double-six has no extra reason to prefer the many-throws hypothesis. Well, though this would make sense had the gambler entered the room at a time of his own choosing, or had the thrower decided to throw EXACTLY such and such a number of times, calling in the gambler if double-six appeared on the final throw, I think it breaks down in the case we are discussing. For here the thrower's policy is to throw UP TO such and such a number of times (where perhaps this is just once), calling in the gambler immediately if double-six appears. Here the

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conclusion that P(L|A) = P(L) suggests that even were the experiment repeated a million times, the gambler being called in every single time, he still would have no new grounds for supposing that the thrower usually threw more than once. Yet that seems incredible.

Just what can have gone wrong, though? Well, suppose the thrower were known to have the policy of throwing UP TO twice, i.e., of throwing again just once if double-six did not appear first time. P(A|L), if interpreted as the probability that double-six would lie on the table when the thrower had thrown once AND THEN ENDED THE THROWING, would now have to be not 1/36 but 1, since this policy would guarantee that the throw had been a double-six; otherwise throwing would have continued. Correspondingly, any tendency for the gambler to believe in such a policy would force his estimate of P(A|L), thus interpreted, upwards from 1/36 towards 1; for him to judge that P(A|L) was as low as 1/36 would therefore amount to a strange assertion that it was 100% sure that the thrower instead decided to throw once only. Now, of course the figure 1/36 is always correct for the chance of double-six on a throw exempt from any selection effect. But our gambler is considering a selected throw: not just some throw or other, but the last (meaning that it MARKS AN END TO THROWING -- a sense permitting it to be the first throw too). And this can be crucial; for might it not be a throw bearing a number (first, fiftieth or whatever) such that it could have become a last throw only if a double-six, that being the thrower's policy?

When the gambler's being called in depends on a double-six, a throw could of course be a seen last throw only if double-six. But this is not the point. The point is that its double-six-ness might be sole cause of its being last -- the alternative, naturally, being that throwing was in any case due to end then.

Let me insist that any double-six was sure to mark an end to throwing until our gambler had been called in. And one might just as well tell a story in which double-six ensured a final end to all throwing; for the gambler's calculation would be unaffected if (perhaps so that the experiment could be repeated) throwing were due to recommence later. Now, P(A|L) and P(A|M) must refer to the chances of his seeing double-six on the only kinds of throw on which he could possibly see it, namely, throwing-ending throws. For his purposes, therefore, P(A|L) should not mean "the probability of the first throw's being a double-six"; it has instead to mean the probability of a throwing-ending first throw's being a double-six; and remember, the thrower's policy might be that a first throw could be throwing-ending only if a double-six. Again, P(A|M) should not mean "the probability of double-six on any given throw after the first". It should mean the probability of double-six as the final throw in a series -- the thrower's policy perhaps being that only a double-six could end the series. So P(A|L) and P(A|M) can be calculated only after estimating the likelihoods of various dice-throwing policies.

Alas, the policies could have any degree of complexity. Attempts to capture the situation in a neat formula must therefore fail. (For every single throw which might be the last, one needs to estimate the probability that it could have last-ness only if possessing double-six-ness. Yet in the case of the seventy-fifth throw, for example, the thrower's policy might be to end throwing there only if it were a double-six; or he might have decided to end there whether or not it was a double-six;

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or else to end there if he managed to perform seventy-five press-ups; etcetera.) However, one quickly notices such facts as that the estimate of P(A|L) must rise to 1 when it is judged certain that the policy is of throwing for double-six up to twice. P(A|M), in contrast, would in this special case be estimated as only 1/36. When it is instead judged certain that up to 150 further throws would be made if the first were not a double-six, P(A|M) must be estimated to be $1 - (35/36)^{150}$, which is close to 1.

It is easy to check by experiments that when you throw two coins in an attempt to get double-Heads, your policy being to repeat the attempt if necessary another twice, then P(L) will be 1/4 but the figure for P(L|A), the chance that it was a lone throw which produced any double-Heads which you see, will be 16/37. Now, this is the figure given by

$$P(L|A) = \frac{P(L)\ P(A|L)}{P(L)\ P(A|L) + P(M)\ P(A|M)} = \frac{(1/4)\ (1)}{(1/4)\ (1) + (3/4)\ (1 - (3/4)^2)}$$

where P(A|L) is over twice P(A|M). And though someone who, knowing that your policy had been as stated and seeing double-Heads on the table, would rightly say, "Just before this throw was made the chance that it would be a double-Heads was exactly one quarter", he would also be right in refusing to give one quarter as the figure for either P(A|L) or P(A|M).

(2) True, Hacking himself stresses that the double-six was thrown, the encyclopedia typed, not just "at some time" but <u>last time</u>. This means, he insists, on one specific throw (perhaps it was the fifty-third) or during one specific typing bout. But I think this cannot help him. Suppose a red ball is drawn from an urn. This gives <u>prima facie</u> grounds for rejecting the idea that all the sixty others are black. The grounds remain even when one learns it was ball 53. For if all of the balls are numbered, whichever is drawn will bear some specific number. Hence one cannot fairly argue that the presence of additional red balls could not give <u>red ball 53</u> more likelihood of being drawn so that there is no ground for believing in them. Again, shooting an arrow at a forest you hit someone. You now have grounds for believing that the forest contains many people. The grounds do not vanish when you learn you have hit John Smith. You cannot argue that other people could not have given <u>Smith</u> more likelihood of being hit, etcetera.

Things would be different were Smith a famous hermit.

(3) "Was double-six more likely to be seen after some non-double-sixes?" might ask whether a series of non-double-sixes made seeing a double-six more likely on, say, the fifty-third throw. Answer: No. But it could instead ask whether a double-six was probably preceded by non-double-sixes; and then the answer can be Yes. (Claiming that success in throwing double-six was probably preceded by failures need not be to say that the failures helped the double-six to be thrown.)

3. A Tale involving Many Gamblers

It might be objected that the gambler can wait outside the room until double-six appears. But we are not able to stand outside a succession

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of universes, waiting for life-encouraging conditions.

Let us revise the story, therefore. If double-six appears on the first throw then Mr. One is called in; if on a second, Mr. Two; and so on. The Mr. labels are allocated randomly to a million gamblers. The dice are thrown; a gambler is called in. Is he Mr. One? Well, the chance of Mr. One's entering the room was only one in thirty-six. For this reason the gambler is unlikely to be Mr. One, unless there were likely to be two throws at most -- but, exactly as in the original story, the fact of there being any gambler in the room argues against that. Had ten sixes been required for entry, the argument would be still better. (Notice that if everything but double-six secured entry then the gambler would almost certainly be Mr. One even if there were a trillion Misters; the unlikelihood of being Mr. One through random allocation is irrelevant.)

Here the gambler must try only to reduce any puzzlement he might feel on being called in. Multiple throws could not make him any the less lucky to be called in. (Compare how the gambler in the original story could say that the throw which called him in was a lucky one.) He is like the lottery winner when there is only one winning ticket among a million, but almost all the million have actually been sold. Though blessing his luck such a winner has no clear ground for puzzlement. Almost certainly someone would be in his lucky shoes. Similarly with us, if our lives resulted from how a phase transition took a very unlikely turn. We could be very lucky while still finding our situation unpuzzling if there exist many universes.

4. Anthropic Explanations in the Inflationary Universe

Let us return to the Inflationary Universe.

Inflation reduces any need for the early expansion rate and smoothness to be fine tuned. Even if strongly curved an inflating space may become very flat, its flatness yielding a life-encouraging expansion rate; its initial inhomogeneities may be smoothed away. But before concluding that Inflation removes the need for anthropic explanations, consider the following points. (i) The enthusiasm with which Inflation has been greeted helps confirm that our universe's earliest conditions can reasonably be treated as needing explanation. (ii) There are many matters apart from expansion rate and smoothness which seem to have needed fine tuning. (iii) The large-U Universe resulting from Inflation has room for vastly many regions beyond our light horizon. These regions may almost all have properties hostile to life. (iv) Inflation rescues users of the Anthropic Principle from the "horizon problem" of how symmetry-breaking phase transitions, if delivering chance results, could have delivered results the same throughout the observable heavens: that is to say, throughout hugely many regions which could seem to have been causally unconnected when the transitions occurred. These regions, unconnected today, perhaps used to be connected prior to an inflationary period. (v) Probably Inflation can smooth away only small irregularities, and can occur only granted very special initial conditions. It is nowadays common to postulate a gigantic cosmos containing rare places where those conditions are met. (Some of this was discussed by F.Tipler at the 1984 PSA Meeting, but see also Barrow and Turner (1981) and

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Mazenko et al. (1985).) (vi) Inflation demands an appropriate choice among Grand Unified Theories. Anthropic selection effects may occur against a background of universes ruled by different GUT's.

Maybe life occurs more readily than Anthropic Principle writers tend to think. Perhaps it exists on neutron stars. But people who suggest this sort of thing and then accuse believers in multiple universes of fantastic theorizing are pots calling quite a clean kettle black.

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