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Puzzles of Anthropic Reasoning Resolved Using Full Non-indexical Conditioning

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I plan to make some further revisions in future.

Abstract. I look at four interrelated puzzles that involve "anthropic" reasoning, show how they can be resolved, and discuss the implications of this resolution for cosmological theories. I consider in particular the "Self-Sampling Assumption" (SSA), which states that one should reason as if one were randomly chosen from the set of all observers in a suitable reference class. The problem of Freak Observers might appear to force acceptance of SSA if any empirical evidence is to be credited. The Sleeping Beauty problem arguably shows that one should also accept the "Self-Indication Assumption" (SIA) — that one should take one's own existence as evidence that the number of observers is more likely to be large than small. But this assumption produces apparently absurd results in the Presumptuous Philosopher problem. Without SIA, however, a definitive refutation of the counterintuitive Doomsday Argument seems difficult. I show that these puzzles are satisfyingly resolved by applying the principle that inference should be based on probabilities that are conditional on *all* evidence — not just on the fact that you are an intelligent observer, or that you are human, but on the fact that you are a human with a specific set of memories. This "Full Non-indexical Conditioning" (FNC) approach usually produces the same results as assuming both SSA and SIA, with a sufficiently broad reference class, while avoiding their *ad hoc* aspects. I argue that the results of FNC are correct using the device of hypothetical "companion" observers, whose existence clarifies what principles of reasoning are valid. As one application, I apply FNC to the problem of how densely we should expect intelligent species to occur. I also examine recent anthropic arguments in inflationary and string theory cosmology, in which FNC's prescription for using all the evidence contrasts with "anthropic" arguments in which the fact that intelligent life exists is effectively ignored when evaluating the evidence for a theory.

* I have added new material to the introduction, and clarified some other passages, in order to avoid misinterpretions, particularly about what is meant by "conditioning". I have added a discussion of falsifiability in the Sleeping Beauty problem to the end of Section 3. I also have added a brief mention of a paper by Dyson, Kleban, and Susskind (2002) to the discussion of Freak Observers in Section 5. I've split the applications section in two, separating the stuff on Fermi's Paradox from the cosmology applications, and added a discussion of the "top-down" view of Hawking (2003) to the latter. Finally, I fixed ssome typos and made other minor modifications.

1 Introduction

Accounting for selection effects is clearly necessary when drawing conclusions from empirical data. A poll conducted by telephone, for example, will not tell us the opinions of people who don't have telephones. This simple observation has been seen by some, beginning with Brandon Carter (1974), as having profound cosmological implications, expressed as the Anthropic Principle — "what we can expect to observe must be restricted by the conditions necessary for our presence as observers". One typical cosmological application of the Anthropic Principle is in "explaining" the observed values of physical constants by assuming that they take on all possible values in a multiplicity of universes, but that we of course must observe values that are compatible with the existence of life. A related use of the Anthropic Principle is to deny that a cosmological theory in which life is common should be considered more probable (other things being equal) than one in which life is rare, as long as the latter theory gives high probability to the existence of at least one intelligent observer.

There is a large literature on the Anthropic Principle, much of it too confused to address. Even the purpose of some"'anthropic" arguments is difficult to discern — it seems they sometimes serve only to make the presenter of the argument feel more comfortable. In this paper, however, I assume that their purpose is to help decide between two or more scientific theories. These theories may differ very fundamentally, as with string theory versus some alternative, or they may be variations on an accepted theory, differing in the value of some parameter, or in which mathematical approximation can be regarded as adequate.

I will centre my critique on the coherent probabilistic account of some issues involving anthropic reasoning that has been presented by Nick Bostrom (2002, 2005). I also consider Ken Olum's (2002, 2004) views, which are sometimes closer to my own. Leonard Susskind (2006) and Leo Smolin (2006) have contrasting views on the cosmological implications of the Anthropic Principle, which I discuss at the end of this paper. Before this, I discuss the somewhat less ambitious question of how dense intelligent observers are in the universe — what has been called the "Fermi Paradox". I begin by considering several philosphical puzzles that relate to anthropic reasoning, and two principles that have been advanced for dealing with these issues.

1.1 Four puzzles and two assumptions

One formalization of the intuition regarding observer selection effects is what Bostrom calls the "Self-Sampling Assumption" (SSA):

> (SSA) One should reason as if one were a random sample from the set of all observers in one's reference class. (Bostrom 2002, p. 57)

Bostrom regards this as a preliminary formulation; in particular, he later considers more fine-grained "observer moments". However, all forms of SSA require some specification of an appropriate "reference class" (eg, all humans, or all intelligent observers), and hence are poorly defined if no precise basis for specifying such a class is given.

Despite this difficulty, something like SSA might appear to be essential in order to deal with the Freak Observers problem:

> How can vast-world cosmologies have *any* observational consequences *at all*? We shall show that these cosmologies imply, or give very high probability to, the proposition that every possible observation is in fact made. (Bostrom 2002, p. 52)

Bostrom argues that in a sufficiently large universe, brains in any possible state will be emitted as Hawking radiation from black holes, or condense from gas clouds as a result of large thermal fluctuations. We need not consider such extreme possibilities in order to see a problem, however. Scientific experiments commonly have some small probably of producing incorrect results for more mundane reasons. In a large enough universe, it is likely that *some* observer has made a misleading observation of any quantity of interest. So, for example, that some observer in the universe has made observations that with high confidence could be produced only if the cosmic microwave background radiation is anisotropic is *no reason at all* to think that the background radiation is actually anisotropic. If we are to draw any conclusions from observations we make, we need to see them not just as observations that have been made, but as observations that have been made *by us*. Bostrom argues that SSA together with the fact that most observations made are not misleading then allows us to conclude that our observations are likely to be correct.

However, if we accept SSA, we are led to the Doomsday Argument expounded by John Leslie (1996), who attributes it to Carter. The Doomsday Argument says that your ordinary estimate of the chance of early human extinction (based on factors such as your assessment of the probability of an asteroid colliding with earth) should be increased to account for an observer selection effect. It is claimed that the circumstance of your being (roughly) the 60 billionth human to ever exist is more likely if there will never be more than a few hundred billion humans than if there will be hundreds of trillions of humans, as will be the case if humanity survives and colonizes the galaxy. This argument implicitly assumes SSA. (If the reference class is all intelligent observers, the argument requires that uncertainty in time of extinction be shared with other intelligent species.)

Although Leslie (1996), Carter (2004), and some others accept the Doomsday Argument as valid, I take it to be absurd, primarily because the answer it produces depends arbitrarily on the choice of reference class. Bostrom (2002) argues that this choice is analogous to a choice of prior in Bayesian inference, which many are untroubled by. However, a Bayesian prior reflects beliefs about the world. A choice of reference class has no connection to factual beliefs, but instead reflects an ethical judgement, if it reflects anything. It is thus unreasonable for such a choice to influence our beliefs about facts of the world.

The challenge is therefore to explain exactly why the Doomsday Argument is invalid, without also destroying our ability to draw conclusion from empirical data despite the possibility of freak observers. Many refutations of the Doomsday Argument have been attempted, but as argued by Bostrom (2002, Chapter 7), most of these refutations are themselves flawed. In particular, it is not enough to adduce plausible-sounding principles that if correct would defuse the Doomsday Argument if these same principles produce unacceptable results in other contexts.

One way of avoiding the conclusion of the Doomsday Argument is to accept the "Self-Indication Assumption" (SIA) — that we should take our own existence as evidence that the number of observers in our reference class is more likely to be large than small. The effect of SIA is to cancel the effect of SSA in the Doomsday Argument, leaving our beliefs about human extinction unchanged from whatever they were originally. I refer to this combination as SSA+SIA, and to SSA with a denial of SIA as SSA−SIA. Bostrom (2002) argues that SIA cannot be correct because of the Presumptuous Philosopher problem. Consider two cosmological theories, A and B, of equal plausibility in light of ordinary evidence. Suppose theory A predicts that there are about ten trillion intelligent species in the universe, whereas theory B predicts that there are only about ten intelligent species. A presumptuous philosopher who accepts SIA would decide that theory A was a trillion times more likely than theory B, and would continue to believe theory A despite virtually any experimental evidence against it, since the chance that the experiments apparently refuting A were fraudulently or incompetently performed, or produced misleading results just by chance, is surely much greater than one in a trillion.

Denying SIA also seems as if it might lead to problems, however. The Sleeping Beauty problem (Elga 2000) sets up a situation in which the flip of a coin determines whether an observer experiences a situation once, if the coin lands Heads, or twice (the second time with no memory of the first), if the coin lands Tails. Logic analogous to accepting SSA+SIA leads one to conclude that upon experiencing this situation, the observer should believe with probability 1/3 that the coin landed Heads, whereas SSA−SIA leads one to conclude that the observer should assess the probability of Heads as being 1/2. Although some have argued that 1/2 is the correct answer (Lewis 2001, Bostrom 2006), the arguments that 1/3 is the correct answer appear to me to be conclusive. These include an argument based on betting considerations, and another argument I detail below. One might therefore be reluctant to abandon SIA.

To summarize, accepting SSA+SIA produces answers regarding Freak Observers, Sleeping Beauty, and the Doomsday Argument that I consider reasonable, but seems to produce unreasonable results for the Presumptuous Philosopher problem. SSA−SIA also resolves the problem of Freak Observers, and produces what might seem like reasonable results for the Presumptuous Philosopher problem, but produces results I consider wrong regarding Sleeping Beauty and the Doomsday Argument.

1.2 The idea of full non-indexical conditioning

In this paper, I will show that this dilemma can be resolved by abandoning both SSA and SIA. Both are *ad hoc* devices with no convincing rationale, and both require a "reference class" of observers, the selection of which is quite arbitrary. Instead, I advocate consistently applying the general principle that one should judge theories by their probabilities conditional on *all* the evidence available, including all the details of one's memory, but without considering "indexical" information regarding one's place in the universe (as opposed to what the universe contains). I call this approach "Full Non-indexical Conditioning" (FNC), and present it in more detail later in Section 2.3. Here I will briefly introduce it and contrast it with one "anthropic" approach.

It is important to be clear on the meaning of "conditioning" for FNC. It means *paying attention to the data*. We use our full set of non-indexical data, N, to evaluate theories A and B by computing their conditional probabilities $P(A|N)$ and $P(B|N)$, judging A to be more plausible than B if the odds in its favour, $P(A|N)/P(B|N)$, are greater than one. We obtain these "posterior" odds for A over B by multiplying the "prior" odds, $P(A)/P(B)$, by the "likelihood", $P(N|A)/P(N|B)$, in accordance with the usual prescription for Bayesian updating of beliefs:

$$\frac{P(A|N)}{P(B|N)} = \frac{P(A)}{P(B)}\,\frac{P(N|A)}{P(N|B)} \tag{1}$$

This procedure contrasts with that followed in some anthropic arguments, also sometimes referred to as "conditioning", which involves *ignoring part of the data*. For example, suppose L denotes the fact that life exists somewhere in the universe, which is of course implied by our total non-indexical knowledge, N. One simple interpretation of the Anthropic Principle (not necessarily shared by all its advocates) is that we should evaluate theories A and B by means of the following odds for A over B:

$$\frac{P(A)}{P(B)}\,\frac{P(N|A\,\mathrm{and}\,L)}{P(N|B\,\mathrm{and}\,L)} \tag{2}$$

(provided that $P(A\,\mathrm{and}\,L)$ and $P(B\,\mathrm{and}\,L)$ are both non-zero, so that the conditional probabilities above are well-defined). The argument is that if there were no life, nobody would be around to observe anything, so it's no surprise that we observe that life exists, and we therefore shouldn't count its existence as evidence for either A or B (provided they both give non-zero probability to life existing). The difference from FNC is apparent if we write the posterior odds in equation (1) as follows:

$$\frac{P(A|N)}{P(B|N)} \;=\; \frac{P(A)}{P(B)}\,\frac{P(N|A\,\mathrm{and}\,L)}{P(N|B\,\mathrm{and}\,L)}\,\frac{P(L|A)}{P(L|B)} \tag{3}$$

The anthropic argument above ignores the last factor, $P(L|A)/P(L|B)$, which can be interpreted as the evidence for A over B obtained from the fact that life exists.

1.3 Testing FNC on the puzzle problems

I will discuss in Section 2.3 how the results obtained using FNC are the same as those found using SSA+SIA, when it is clear how to apply the latter method. As the problems I consider will illustrate, however, FNC is a more general and more natural method of inference, and has a clearer justification.

To test whether the conclusions found by using FNC or by using alternative principles are correct, I introduce the device of "companion" observers. For the Sleeping Beauty problem, this device provides further evidence that the correct answer is obtained by FNC (and by SSA+SIA), whereas the answer produced by applying SSA−SIA in the manner that has been previously done is incorrect. Consideration of companion observers also shows that SSA−SIA produces unacceptable results when used with certain reference classes, including the narrow reference classes that have previously been used for the Sleeping Beauty problem.

When considering the Freak Observers and Presumptuous Philosopher problems, I advocate restricting consideration to cosmological theories in which the universe may be very large, but not so large that it is likely to contain multiple observers with exactly the same memories. The problem of Freak Observers can then be resolved using FNC, without any need for SSA. I argue that as a general methodological principle, one must be cautious of pushing thought experiments to extremes, as this has produced spurious paradoxical results in other contexts. I do consider the possibility of infinite universes later, in connection with inflationary cosmology.

I argue that there are actually two versions of the Presumptuous Philosopher problem, with possibly different answers. When comparing theories differing in the density of observers, but not in the size of the universe, consideration of companion observers provides good reason to doubt the results found using SSA−SIA, whereas the results of applying SSA+SIA or FNC appear correct. I argue that no clear conclusions can be drawn from the Presumptuous Philosopher problem when the theories compared differ in the size of the universe. The Presumptuous philosopher problem therefore fails to provide a reason to reject SSA+SIA or FNC.

1.4 Applications of FNC

After showing that FNC provides reasonable answers for each of the four problems described above, I use FNC to estimate how densely we should expect intelligent observers to occur in the galaxy. This discussion is not entirely *a priori*, but is based also on the observed lack of extraterrestrials in our vicinity, both now, and as far as we can tell, in the past. The results I obtain shed some light on the "Fermi Paradox" — there are reasons to think extraterrestrials should be common in the universe, but if so, where are they? My conclusions imply some pessimism regarding our future prospects, but this is of a milder degree than that produced by the Doomsday Argument, and follows from empirical evidence, not anthropic reasoning.

I then discuss the implications of FNC for anthropic arguments relating to inflationary cosmology, which favours a universe or universes of infinite extent, and to cosmologies based on string theory, in which a multiplicity of universes populate a "landscape" of differing physical laws. I conclude that although it is possible that major features of our universe (some perhaps essential to life) are "accidental", and not present in most other parts of the "multiverse", this explanation should be a last resort. If a plausible alternative explanation can be found that successfully predicts these aspects of our universe, it should be preferred to a theory in which these aspects are accidents, regardless of any connection of these aspects to the existence of life.

2 Methodology

Before discussing the four problems of anthropic reasoning mentioned above, a general examination of the methodology to be employed seems desirable.

2.1 The nature of probabilities

First, since all these problems involve probabilistic answers, one may ask what these probabilities mean. I interpret probabilities as justified subjective degrees of belief — subjective in that they depend on the information (including prior information) available to the subject, and justified in that they follow from correct principles of reasoning, rather than being capricious.

Probabilistic beliefs about scientific hypotheses (eg, whether or not earth-like planets are common in the universe) are based partly on our prior assessments of plausibility. Often, such hypotheses are guesses about the implications of some more fundamental theory, whose true implications cannot be computed exactly, but for which approximations and mathematical intuition provide some guide. We modify these prior beliefs according to how successfully these hypotheses account for observations (eg, of whether nearby stars have planets).

The probabilistic nature of most predictions may be due to at least four sources:

1) Inherent randomness in physical phenomena.

2) Ignorance about the initial conditions of physical phenomena.

3) Ignorance about our place in the universe.

4) Inability to fully deduce the consequences of a theory.

These possible sources of uncertainty are not mutually exclusive. At least (1), (2), and (4) are common sources of uncertainty in ordinary scientific reasoning. One's interpretation of quantum mechanics determines whether "random" quantum phenomena are seen as examples of (1), in the Copenhagen interpretation, or of (3), in the Many Worlds interpretation. Leaving aside the technicalities of the interpretation of this particular theory, one might generally take the ontological position that any apparently random choice is actually made in all possible ways, in parallel universes, all of which are real (though perhaps with different "weights", corresponding to the probabilities of the choices), thereby converting physical randomness to ignorance about which parallel universe we are in.

In trying to resolve the puzzles of anthropic reasoning addressed in the paper, it seems best to not also attempt to resolve issues regarding the nature of probability in physical theories. I will look for a solution based on fairly common sense notions, presuming that these will in essence survive any final resolution of issues such as the interpretation of quantum mechanics. In thought experiments, I will follow convention by usually talking about choices that are determined by a coin flip, whose randomness likely derives from source (2). The reader may, however, replace this with uncertainty of another type, such as whether the 1,341,735'th digit of π is even or odd, assuming that this digit is not already known to the people involved.

2.2 Indexical information and reference classes

A central feature of anthropic reasoning is the use of "indexical" information that certain observations were not just made, but were made *by you*. Another expression of this concept is that you should consider not just "possible worlds", but "possible *centred* worlds", in which your location in the universe is specified (Lewis 1979).

Both SSA and SIA involve the indexical information that *you* are members of a certain reference class. The conclusions that follow from these principles individually are sensitive to the choice of this reference class. Interestingly, however, when *both* SSA and SIA are assumed, this dependence disappears, as long as the reference class is broad enough to encompass all observers who could possibly have observed what you have observed.

Let C and C' be two references classes of observers. Let D be the set of observers who have observed the same data as you have. I will assume here that $D \subseteq C$ and $D \subseteq C'$ — ie, the data you observed indicates that you yourself are a member of both of these reference classes. I will also use the symbol D to denote the event that you are in the set D. Let A and B be two mutually-exclusive hypotheses about the universe, each of which specifies the numbers of observers in C, C', and D. Suppose that based on prior information of the usual sort, $P(A) = P(B) = 1/2$. If A is true, the number of observers in class C is $|C|_A$ and the number in class C' is $|C'|_A$; if B is true, these numbers are $|C|_B$ and $|C'|_B$. If A is true, the number of observers in D is $|D|_A$; if B is true, this number is $|D|_B$.

If we assume SSA with reference class C, but not SIA, the probability of hypothesis A given the observed data is

$$P(A \mid D) = \frac{P(A)\, P(D \mid A)}{P(A)\, P(D \mid A) \;+\; P(B)\, P(D \mid B)} \tag{4}$$

$$= \frac{(1/2)\,(|D|_A/|C|_A)}{(1/2)\,(|D|_A/|C|_A) \;+\; (1/2)\,(|D|_B/|C|_B)} \tag{5}$$

If we instead use reference class C', $P(A \mid D)$ will be given by this formula with $|C'|_A$ and $|C'|_B$

replacing $|C|_A$ and $|C|_B$. The result will in general be different.

However, if we assume SSA+SIA, the prior probabilities for A and B are modified in proportion to the number of observers they imply are in the reference class. This gives the following formula for $P(A \mid D)$ when the reference class is C:

$$P(A \mid D) \;=\; \frac{(|C|_A/2)\,(|D|_A/|C|_A)}{(|C|_A/2)\,(|D|_A/|C|_A) \;+\; (|C|_B/2)\,(|D|_B/|C|_B)} \;=\; \frac{(1/2)\,|D|_A}{(1/2)\,|D|_A \;+\; (1/2)\,|D|_B} \tag{6}$$

Since $|C|_A$ and $|C|_B$ cancel, the identical result is obtained if C' is used as the reference class.

This lack of dependence on the reference class suggests that even if the right result is obtained by assuming both SSA and SIA, the joint affirmation of these two principles may not be the most illuminating way of describing the logic leading to this result.

2.3 Full Non-indexical Conditioning (FNC)

I advocate probabilistic reasoning by the standard method of fully conditioning on all information that you possess. Of course, in most ordinary circumstances, you can ignore much information that you know is not relevant to the problem — eg, when predicting tomorrow's weather, you should condition on the current barometric pressure (if you know it), but there is no need to also condition on the name of your kindergarten teacher (even if you still remember it). When in doubt, however, it is always correct to conditional on additional information, since if this information is in fact irrelevant, conditioning on it will not change the result.

When dealing with puzzling instances of anthropic reasoning, what is relevant and irrelevant is unclear, so I maintain that you should condition on *everything* you know — your entire set of memories — to be sure of getting the right answer. You might also condition on the indexical information that these are *your* memories. However, I will here consider what happens if you ignore such indexical information, conditioning only on the fact that *someone* in the universe with your memories exists. I refer to this procedure as "Full Non-indexical Conditioning" (FNC).

Some ordinary situations might appear to require use of indexical information, but a closer examination shows that FNC produces the correct answer in these cases. For instance, suppose that you and some number of other people are recruited as subjects for an experiment. You do not know the number of subjects for this experiment, but based on your knowledge of the budget limitations in the field of experimental philosophy, you have a prior distribution for this number, N, that is uniform over the integers from 1 to 20. You and the other subjects are taken to separate rooms, without seeing each other, where you are instructed to flip a fair coin three times and record the sequence of Heads and Tails obtained. You record the sequence HTT. On the basis of this new data, what should be your posterior distribution for N?

An invalid way of reasoning here is to condition on the fact that the sequence HTT was recorded by a subject of the experiment, and on that basis conclude that your posterior distribution should be

$$P(N=n \mid \text{HTT recorded}) \;=\; \frac{P(N=n)\;P(\text{HTT recorded} \mid N=n)}{\sum_{n'=1}^{\infty} P(N=n')\;P(\text{HTT recorded} \mid N=n')} \tag{7}$$

$$=\; \frac{P(N=n)\;(1\;-\;P(\text{HTT not recorded} \mid N=n))}{\sum_{n'=1}^{\infty} P(N=n')\;(1\;-\;P(\text{HTT not recorded} \mid N=n'))} \tag{8}$$

$$= \quad \frac{(1/20)\ (1\ -\ (1-2^{-3})^n)}{\sum_{n'=1}^{20} (1/20)\ (1\ -\ (1-2^{-3})^{n'})} \tag{9}$$

These probabilities vary from 0.0093 for $n = 1$ to 0.0690 for $n = 20$. Intuitively, these probabilities seem wrong, for two reasons. First, since you had to record *some* sequence of flips, it seems that knowledge of the particular sequence you recorded shouldn't change your beliefs about N. On the other hand, it seems that the fact that *you* were recruited for the experiment should increase the probability that there are many subjects (by more than happens above).

The problem is fixed if you take account of the indexical information that it was *you* who recorded the sequence HTT. The probability of this sequence being obtained by you is 2^{-3} regardless of N. On the other hand, if the pool of possible experimental subjects is of size M (assumed to be greater than 20), the probability that you will be recruited as a subject if there are n subjects is n/M. The posterior distribution for N that results is

$$P(N = n \,|\, \text{You were recruited and recorded HTT}) \quad = \quad \frac{(1/20)\ (n/M)\ 2^{-3}}{\sum_{n'=1}^{20} (1/20)\ (n'/M)\ 2^{-3}} \tag{10}$$

$$= \quad n \ / \ \textstyle\sum_{n'=1}^{20} n' \quad = \quad n \ / \ 210 \tag{11}$$

These probabilities vary from 0.0048 for $n = 1$ to 0.0952 for $n = 20$.

This answer is also obtained if we condition on *all* non-indexical information. We know not just that the sequence HTT was recorded, but also that it was recorded by a subject of your age, with your hair colour, who went to a school just like yours, who has your taste in music, who has the same opinion of rice pudding as you do, etc. The probability that the i'th subject recruited for the experiment will have all these characteristics is some very small number, ϵ. The probability that the i'th subject has these characteristics and also records coin flips of HTT is $\epsilon\, 2^{-3}$. Since this probability is extremely small, the probability that *any* of n subjects will have these characteristics and record those flips is very well approximated by $n\,\epsilon\, 2^{-3}$. Conditioning on all non-indexical information therefore produces the following posterior distribution for N:

$$P(N = n \,|\, \text{all non-indexical information}) \quad = \quad \frac{(1/20)\ n\,\epsilon\, 2^{-3}}{\sum_{n'=1}^{20} (1/20)\ n\,\epsilon\, 2^{-3}} \tag{12}$$

$$= \quad n \ / \ \textstyle\sum_{n'=1}^{20} n' \quad = \quad n \ / \ 210 \tag{13}$$

This is the same result as found above using indexical information.

Use of indexical information therefore seems unnecessary in ordinary situations, since the non-indexical information regarding your memories is normally sufficient to uniquely identify you. SSA can perhaps be seen as arising from what might be called "Full Indexical Conditioning", in which we assume that in addition to their memories, everyone also has some unique "essence", and everyone in some sense knows what their own essence is. One could then argue that you should condition not only on your memories, but also on having your own essence, which by assumption is shared with no one else. Conditioning on more than FNC rather than less seems the only way of reconciling SSA−SIA with the fundamental principle that probabilistic inferences should be based on all known information. I will illustrate this idea when discussing Sleeping Beauty in Section 3.2. It seems preferable to me to not introduce such mystical "essences" unless ignoring them can be shown to produce implausible results. Moreover, if one does think in terms of such essences, it seems hard not to proceed to acceptance of SIA as well as SSA, which effectively renders thoughts of essences pointless, as I will now explain.

It turns out that if the universe is not excessively huge, using SSA+SIA produces the same results as using FNC. Consider the situation with two hypotheses, A and B, discussed above in Section 2.2. Assume now that you condition on all information you remember, and that these memories are extensive enough that there is only a small probability that an observer with your memories would exist, under either hypothesis. Let $|C|_A$ and $|C|_B$ be the numbers of observers in some suitable reference class (whose members "might have had" your memories) if hypotheses A and B are true, respectively. Let ϵ_A and ϵ_B be the (extremely small) probabilities that a particular observer in this reference class will have your memories under hypotheses A and B. Suppose that you assess the prior probability of A and B as $P(A) = P(B) = 1/2$, where this prior is based on your scientific knowledge, but not on the multitude of details of your life that make you unique. Applying SIA will shift these priors to $P(A) = (|C|_A/2) \,/\, (|C|_A/2 + |C|_B/2)$ and $P(B) = (|C|_B/2) \,/\, (|C|_A/2 + |C|_B/2)$. Applying SSA, the probability that you will have your memories is ϵ_A if hypothesis A is true, and ϵ_B if hypothesis B is true. The result of applying both SIA and SSA is therefore

$$P(A \,|\, \text{all your memories})$$

$$= \frac{\epsilon_A \; (|C|_A/2) \,/\, (|C|_A/2 + |C|_B/2)}{\epsilon_A \; (|C|_A/2) \,/\, (|C|_A/2 + |C|_B/2) \; + \; \epsilon_B \; (|C|_B/2) \,/\, (|C|_A/2 + |C|_B/2)} \tag{14}$$

$$= \frac{\epsilon_A \, |C|_A}{\epsilon_A \, |C|_A \; + \; \epsilon_B \, |C|_B} \tag{15}$$

Provided that $\epsilon_A \, |C|_A$ and $\epsilon_B \, |C|_B$ are both close to zero (as they will be if the universe is not excessively huge), the same result will be obtained by applying FNC. This comes about because $\epsilon_A \, |C|_A$ and $\epsilon_B \, |C|_B$ are then very close to the probabilities of *any* observer with your memories existing under hypotheses A and B, respectively, which given the equal prior probabilities of A and B produces the same result as found above using SSA and SIA.

FNC is a more general principle of inference than SSA and SIA, however, since it does not require any notion of a reference class. FNC requires only that there be some way of computing the probability that an observer with your memories will exist. As was done above, it is convenient to separate your scientific memories (which may be shared with many others) from the rest of your memories, which make you a unique observer. Conditioning on your scientific memories converts whatever primitive prior distribution you had regarding scientific theories to what would ordinarily be regarded as your prior. We can then consider how this prior is altered by conditioning on subsequent scientific observations and on the memories that make you unique.

Note that the probabilities involved in FNC need not derive from some random physical process, but may simply reflect ignorance or an inability to fully deduce the consequences of known facts. This will be discussed further in Section 6.2.

2.4 Assessing arguments by considering companion observers

If your opinions differ from those of an intelligent friend who possesses the same information as you, you should question the validity of the reasoning that led you to these opinions. Ultimately, after exchanging information and fully discussing the matter with your friend, you should expect to come to the same conclusions regarding factual matters. Persistent disagreements might seem possible due to differing prior beliefs, but as discussed by Hanson (2006), this is possible for fully rational observers only if they disagree about the processes by which they came to hold these prior beliefs. Agreement with hypothetical friends has been used as a test of reasoning in the past — in particular, Nozick (1969) uses it in his discussion of Newcomb's Problem, as described in the next section.

I propose here to test the validity of anthropic arguments by comparing the conclusions of such arguments with those that imaginary "companion" observers would reach, using the same principles of reasoning (eg, acceptance of SSA but not SIA). Of course, it is possible that several incompatible sets of principles might each lead to consistency with the conclusions of companions reasoning by these same principles, so this test may sometimes fail to fully resolve the issues.

By considering possible companions, a general constraint on the use of SSA$-$SIA can be derived. Suppose there exist two types of observers, X and Y. These observers are considering two theories, A and B, according to which the numbers of observers of these types are $|X|_A$ and $|Y|_A$, for theory A, and $|X|_B$ and $|Y|_B$, for theory B. There is a pairing of observers of type X with companion observers of type Y, in which each observer is paired with at most one companion observer. If $|X| = |Y|$, all observers have companions; otherwise, some observers of the more numerous type are unpaired.

Suppose that all observers consider theories A and B to be equally likely based on the usual sorts of evidence (ie, without applying SSA or SIA). Now consider what those observers with companions will conclude by applying SSA$-$SIA using as their reference class only observers of their own type, and taking account of their knowledge that they were paired with a companion observer of the other type. Observers of type X will reason that their chance of having a companion observer is $\min(1, |Y|_A/|X|_A)$ if theory A is true, and $\min(1, |Y|_B/|X|_B)$ if theory B is true. The odds an observer of type X assigns to theory A over theory B will therefore be

$$\frac{\min(1, |Y|_A/|X|_A)}{\min(1, |Y|_B/|X|_B)} = \begin{cases} 1 & \text{if } |Y|_A \geq |X|_A \text{ and } |Y|_B \geq |X|_B \\ |Y|_A \;/\; |X|_A & \text{if } |Y|_A \leq |X|_A \text{ and } |Y|_B \geq |X|_B \\ |X|_B \;/\; |Y|_B & \text{if } |Y|_A \geq |X|_A \text{ and } |Y|_B \leq |X|_B \\ |X|_B|Y|_A \;/\; |X|_A|Y|_B & \text{if } |Y|_A \leq |X|_A \text{ and } |Y|_B \leq |X|_B \end{cases} \tag{16}$$

whereas for an observer of type Y, the odds in favour of theory A would be

$$\frac{\min(1, |X|_A/|Y|_A)}{\min(1, |X|_B/|Y|_B)} = \begin{cases} |X|_A|Y|_B \;/\; |X|_B|Y|_A & \text{if } |Y|_A \geq |X|_A \text{ and } |Y|_B \geq |X|_B \\ |Y|_B \;/\; |X|_B & \text{if } |Y|_A \leq |X|_A \text{ and } |Y|_B \geq |X|_B \\ |X|_A \;/\; |Y|_A & \text{if } |Y|_A \geq |X|_A \text{ and } |Y|_B \leq |X|_B \\ 1 & \text{if } |Y|_A \leq |X|_A \text{ and } |Y|_B \leq |X|_B \end{cases} \tag{17}$$

Since these are generally not equal, we see that companions will disagree in this scenario if they each reason with SSA$-$SIA using as their reference class only observers of their own type.

However, these companion observers will agree if they apply SSA$-$SIA using as their reference class all observers of both types, because of the effects of a Doomsday-like argument, of a sort discussed further in Section 4.3. Observers of type X will reason that their chances, applying SSA, of being of type X are $|X|_A/(|X|_A + |Y|_A)$ if theory A is true, and $|X|_B/(|X|_B + |Y|_B)$

if theory B is true. The odds in favour of theory A are therefore multiplied by $(|X|_A/|X|_B) \times (|X|_B+|Y|_B)\,/\,(|X|_A+|Y|_A)$. Multiplying equation (16) by this factor, we get that an observer of type X having a companion will consider the odds in favour of theory A to be

$$\frac{|X|_B+|Y|_B}{|X|_A+|Y|_A} \times \left\{ \begin{array}{ll} |X|_A \;/\; |X|_B & \text{if } |Y|_A \geq |X|_A \text{ and } |Y|_B \geq |X|_B \\ |Y|_A \;/\; |X|_B & \text{if } |Y|_A \leq |X|_A \text{ and } |Y|_B \geq |X|_B \\ |X|_A \;/\; |Y|_B & \text{if } |Y|_A \geq |X|_A \text{ and } |Y|_B \leq |X|_B \\ |Y|_A \;/\; |Y|_B & \text{if } |Y|_A \leq |X|_A \text{ and } |Y|_B \leq |X|_B \end{array} \right\} \tag{18}$$

Similarly, multiplying equation (17) by $(|Y|_A/|Y|_B) \times (|X|_B+|Y|_B)\,/\,(|X|_A+|Y|_A)$ gives the odds in favour of theory A for an observer of type Y with a companion, which turn out to be identical to the odds in equation (18) above.

This computation shows that requiring consistency with conclusions of a companion imposes a constraint on the reference class used with SSA−SIA — the companions must use the same reference class, which must therefore include both of them. This constraint might be seen as making anthropic arguments based on SSA−SIA less arbitrary, and hence more attractive. However, this constraint also makes it harder to apply such arguments, since to chose a suitable reference class, you must know the full set of observers with whom you would expect to agree.

In contrast, SSA+SIA produces consistent results even when observers use reference classes that include only their own type of observer, excluding their companion. This may be confirmed by multiplying equation (16) by $|X|_A/|X|_B$ and equation (17) by $|Y|_A/|Y|_B$, the factors by which SIA modifies the prior odds. Companion observers applying FNC will obviously produce consistent conclusions, since FNC does not involve indexical information, and companions are assumed to share all non-indexical information.

2.5 The dangers of fantastic assumptions

Several of the puzzles treated here employ thought experiments, and make other arguments, that are based on hypothetical and perhaps fantastic assumptions. This can sometimes produce spurious conclusions. We may accept a fantastic assumption, on the basis that although it isn't true in reality, it "might be true", and then proceed to reason utilizing other premises that are based on the reality that we have implicitly rejected in making the fantastic assumption.

Searle's (1980) Chinese Room Argument provides one example. He argues that a computer cannot possibly understand Chinese. Any program that enabled a computer to understand Chinese could in principle be executed by a person in a room who takes inputs from a window, follows certain simple rules for shuffling tokens about, and shoves results out another window. The person executing this program need have no understanding of Chinese to begin with, and is unlikely to acquire any understanding of Chinese by performing the tasks needed to execute this program. So, the argument goes, a computer running such a program will also not really understand Chinese, regardless of whether it might superficially appear to.

A common (and in my view, correct) response is that although the person executing the program does not understand Chinese, the system of person plus room is a physical embodiment of another entity that *does* understand Chinese. To this, a defender of the Chinese Room Argument may reply that, in principle, the room is unnecessary — a person with a sufficiently good memory could execute the program entirely in their head, without the need of any physical tokens. To the subsequent objection that this just means that the new entity is physically contained in the same body as the original person, Harnad (2001) has mockingly replied:

> This was tantamount to conjecturing that, as a result of memorizing and manipulating very many meaningless symbols, Chinese-understanding would be induced either consciously in Searle, or, multiple-personality-style, in another, conscious Chinese-understanding entity inside his head of which Searle was unaware.
>
> I will not dwell on any of these heroics; suffice it to say that even Creationism could be saved by ad hoc speculations of this order.

In a seminar I attended in the 1990's, Harnad explained in more detail that the psychiatric literature on multiple personality disorder contains no recorded case of such a second being, with totally different language and other capabilities, existing within someone's head.

This is an extreme case of making a fantastic assumption and then reasoning with premises that contradict it. Any program capable of appearing to understand Chinese will very likely require a computer at least as powerful as those available today to execute in real time. Compared to manual execution by a person, today's computers are at least a billion times faster, and have at least a billion times as much readily-available memory.[1] The characteristics of a hypothetical person whose computational abilities are a billion times greater than those of ordinary people are certainly not going to be obvious to us, or deducible from the current psychiatric literature. To assume the existence of such a person and then claim incredulity at a consequence of their existence abuses the hospitality of one's interlocutor in conceding that "in principle" a computer program can be executed manually — when in reality, this is true only of programs no more than a few pages long, that operate for no more than a few hundred steps.

A more subtle example of the dangers of fantastic thought experiments is provided by Newcomb's Problem, first discussed in print by Nozick (1969). We imagine that a wealthy "Predictor", who is very good at predicting human behaviour, conducts a "game" that operates as follows. A person is randomly selected to participate, and is then shown two boxes. They are told that the first box contains $1000, and the other box contains either $1,000,000 or $0. The participant may either take both boxes, or take just the second box, and receives all the money in the box or boxes they take. The Predictor puts $1,000,000 in the second box if and only if he predicts that the participant will take only this box. Suppose that you have seen the game played many times, and are convinced that the Predictor's predictions are almost certain to be correct. If you are selected to be a participant in this game, should you take both boxes, or only the second box?

The argument for taking only the second box is that you are then almost certain to receive $1,000,000, whereas if you take both boxes, you almost certainly will receive only $1000. (Conceivably, you might receive $1,001,000 if you take both boxes, but only if the Predictor is wrong, which you know is very unlikely.) The argument for taking both boxes is that you will then receive $1000 more than you would if you took only the second box, regardless of whether the Predictor was right or wrong in his prediction, which he has *already* made. Nozick (1969) favours taking both boxes, strengthening this argument by pointing out that if a friend of yours could see into both boxes, they would certainly advise you to take both of them. Actually, your friend

[1] I refer here to the speed and memory available when a person consciously carries out the simple tasks needed to execute the steps of a computer program. The computational power that underlies unconscious functions of our brains likely exceeds that of today's computers.

cannot see into the boxes, or if they can, they aren't allowed to advise you, but you know what advice your friend would give if they could, and you should follow this advice.

I would find the argument for taking two boxes convincing, if it were not for a matter that seems to have been overlooked in the philosophical literature[2] — How does the Predictor make such accurate predictions?

Superficially, assuming the existence of such an accurate Predictor may not seem too extreme. We all predict other people's actions every day, often successfully. However, we also have a strong sense that we have free will, and that our will is integrated with our whole being — for example, that any part of our memories can potentially affect our actions. Hence, while some of our actions are easy to predict, other actions could only be predicted with high accuracy by a being who has knowledge of almost every detail of our memories and inclinations, and who uses this knowledge to simulate how we will act in a given situation. To predict whether a participant will take one box or two (which for at least some people must be a difficult behaviour to predict), the Predictor must have some way of measuring with high accuracy the relevant aspects of the participant's brain (at some time prior to when the game is played) and a very powerful computer that can simulate the participant's mental processes.[3]

Now we can see why Newcomb's Problem involves an extreme fantastic assumption — the only plausible mechanism for accurate prediction involves brain measurements and simulations that are far beyond our current ability, and that may be impossible in principle, if quantum effects are crucial to how the brain works (since non-destructive copying of quantum states is not possible).[4] This fantastic assumption has a crucial consequence — the simulation the Predictor conducts in order to predict your choice will (if you accept a functionalist view of consciousness) create another conscious being, and *you have no way of knowing that you are not this being*. If you are the being in the simulation, your "choice" has a causal effect on whether the Predictor puts $1,000,000 or $0 in the second box. Supposing that the simulated "you" has sympathy for the real "you", or perhaps that "you" intended to donate the money to a worthy charity all along, it is now clear that you should take only the second box, since that may cause the real "you" to obtain $1,000,000, and at worse costs the real "you" only $1000. Note that the argument involving advice from a friend loses its force once the situation is really understood. Your friend may not actually be there (if you are being simulated, but he is not), and if he is (and understands the situation), he will advise you to take only the second box.

Possible errors from not fully comprehending the implications of fantastic assumptions may

[2] I wrote a paper on this idea twenty years ago, which was rejected by *Mind*, though verbal discussions with philosophers over the years have been more positive. At least two other people have thought of this idea independently — Scott Aaronson described the idea in a November 2005 blog posting at `http://www.scottaaronson.com/blog/2005/11/dude-its-like-you-read-my-mind.html`, and someone going by the name of "Count Iblis" wrote about it in a December 2005 blog posting at `http://countiblis.blogspot.com`.

[3] Note that we needn't assume that this simulation is absolutely accurate, if we allow that the Predictor may be wrong with some tiny probability. Quite large final error rates would be compatible with the Newcomb scenario as long as most errors are introduced by the Predictor's careless assistant, after a highly accurate simulation has been run. Such errors would be uncorrelated with the type of participant, and hence you would not be justified in feeling that you in particular might be able to "beat the game". However, errors due to faulty simulation that arise when, for example, a participant thinks of one particular argument would undermine the Newcomb scenario.

[4] One might object that some other mechanism for accurate prediction not involving simulation might be possible. However, Nozick specifically excludes mechanisms, such as time travel, that introduce backward causation. The onus is on someone wishing us to take the problem seriously as a paradox to provide at least a hint of how such accurate predictions might be obtained with neither accurate simulation nor backward causation.

arise with several of the problems discussed below, perhaps most crucially when the universe is assumed to be infinite. We should also be careful to keep the "companion" observers of the previous section from becoming too fantastic, at least with respect to their cognitive and other relevant characteristics (though other fantastic aspects may be innocuous).

3 Sleeping Beauty

The Sleeping Beauty problem is described by Elga (2000). On Sunday, Beauty is put to sleep. On Monday she is woken, then later put to sleep again. While she is awake, she does not have access to any information that would help her infer the day of the week. If a flip of a fair coin lands Tails, Beauty is woken again on Tuesday, but only after she is administered a drug that causes her to forget her Monday awakening (leaving her memories in the same state as they were after falling asleep on Sunday). Again, she obtains no information that would reveal the day of the week. Regardless of how the coin lands, Beauty is woken on Wednesday, and immediately told that the experiment is over. Beauty knows that this is how the experiment is set up. When Beauty wakens before Wednesday, what probability should she assign to the coin landing Heads?

3.1 The $1/2$ and $1/3$ answers

Some (eg, Lewis 2001) argue that on Sunday Beauty should certainly assign probability $1/2$ to the coin landing Heads, that upon wakening she acquires no additional information (since she knew that she would experience such an awakening regardless of how the coin lands), and that she should therefore still consider the probability of Heads to be $1/2$ at this time.

Others (eg, Elga 2000) argue instead that Beauty should assign probability $1/3$ to the coin landing Heads upon wakening before Wednesday. One argument for this is that if the experiment were repeated many times, $1/3$ of the wakenings before Wednesday would occur when the coin lands Heads (since Beauty wakens twice when it lands Tails, and only once when it lands Heads). This view can be reinforced by supposing that on each awakening Beauty is offered a bet in which she wins 2 dollars if the coin lands Tails and loses 3 dollars if it lands Heads. (We suppose that Beauty knows such a bet will always be offered.) Beauty would not accept this bet if she assigns probability $1/2$ to Heads. If she assigns a probability of $1/3$ to Heads, however, her expected gain is $2 \times (2/3) - 3 \times (1/3) = 1/3$, so she will accept, and if the experiment is repeated many times, she will come out ahead. Furthermore, she can work all this out on Sunday, at which time she will wish herself to accept these bets later on. Accepting the argument that she should assign probability $1/2$ to Heads when she is woken later therefore requires that we accept that Beauty should override her previous decision, even though she has no new knowledge that would justify such a change. This seems at least as strange as accepting that Beauty should alter her probability of Heads from $1/2$ to $1/3$ even though nothing unexpected has apparently happened.

A problem with Lewis's argument for the probability of Heads being $1/2$ arises if we change the experiment so that some time after being woken on Monday, Beauty is told that it is Monday. If she assigned probability $1/2$ to Heads just before being told this, standard Bayesian updating of probabilities would lead her to assign probability $2/3$ to Heads after being told it is Monday — the probability of Monday given Heads is 1, whereas the probability of Monday given Tails is $1/2$; this factor of two difference shifts the previous equal probabilities for Heads and Tails so that Heads has twice the probability of Tails. This seems ridiculous, however, given that at this point, Beauty knows nothing of relevance that would distinguish her from any other person who has gotten a good night's sleep, and is then asked to predict the toss of a fair coin. That she knows this coin toss will determine whether her memory is erased *in the future* should be of no relevance. Elga's (2000) argument for the 1/3 view is essentially to work backwards from the assumption that Beauty should assign probability 1/2 to Heads if she is in this situation.[5]

3.2 Relating Sleeping Beauty to SSA, SIA, and FNC

These differing answers to the Sleeping Beauty problem can be viewed as consequences of applying SSA+SIA or SSA−SIA, with the reference class being instances of Beauty upon wakening before Wednesday. With SSA−SIA, Heads and Tails are equally likely *a priori*, and Beauty's observations on wakening before Wednesday are equally likely given Heads or Tails — if Heads, there is only one possible wakening, if Tails there are two, and SSA tells us that they are equally likely, but in any case they do not differ in any identifiable way. Heads and Tails are therefore still equally likely once Beauty has woken. If we accept SSA+SIA, however, Heads have probability 1/3 *a priori* (once we are in the position of Beauty after wakening, and therefore part of the reference class), since Heads leads to only half as many members of the reference class as Tails. The observations on wakening are still equally likely given Heads or Tails, so Beauty's probability of Heads after wakening should remain 1/3.

As expected from the discussion in Section 2.3, the same conclusion as SSA+SIA is reached by applying FNC — simply conditioning on the full data available to Beauty upon wakening. In this regard, note that the even though the experiences of Beauty upon wakening on Monday and upon wakening on Tuesday (if she is woken then) are identical in all "relevant" respects, they will not be subjectively indistinguishable. On Monday, a fly on the wall may crawl upwards; on Tuesday, it may crawl downwards. Beauty's physiological state (heart rate, blood glucose level, etc.) will not be identical, and will affect her thoughts at least slightly. Treating these and other differences as random, the probability of Beauty having *at some time* the exact memories and experiences she has after being woken this time is twice as great if the coin lands Tails than if the coin lands Heads, since with Tails there are two chances for these experiences to occur rather than only one. This computation assumes that the chance on any given day of Beauty experiencing *exactly* what she finds herself experiencing is extremely small, as will be the case in any realistic version of the experiment.

We can see for Sleeping Beauty how introduction of the "essences" discussed in Section 2.3 together with "Full Indexical Conditioning" changes the result from that of FNC to that of SSA−SIA. We suppose that instances of Beauty on different days have different essences. The probability that an instance of Beauty woken before Wednesday will have both her current memories *and* her current unique essence is the same whether she is woken once or twice — a second awakening doesn't provide a second chance because Beauty on the other awakening will have the wrong essence. Denying SIA is equivalent to assuming that the existence of two

[5] Bostrom (2006) argues that Beauty should assign probability 1/2 to Heads both before and after being told on Monday that it is Monday. He justifies this non-reaction to new information on the basis that there is a shift in reference class on being told that it is Monday. This argument involves the use of narrow reference classes which I argue below are untenable. Bostrom also argues that the betting argument can be defused by further consideration of reference classes and indexical information, but his reasoning applies only if repetitions of the experiment are done with Beauty's memory being erased between each repetition. This is unconvincing, since one can equally well suppose that Beauty remembers how many times the experiment was previously done.

awakenings would not increase the probability that an instance of Beauty with her current essence exists. In the context of this problem, these assumptions regarding essences seems rather contrived, but perhaps advocates of SSA−SIA might maintain that essences with these characteristics are more plausible for the other problems discussed in this paper.

3.3 Beauty and the Prince

Since I maintain that the right results are obtained by using FNC (or SSA+SIA), I would like to provide further evidence that 1/3 is indeed the correct probability of Heads. For this purpose, imagine a "companion" of Beauty, the Prince, who is also put to sleep on Sunday, and woken on Monday. However, unlike Beauty, the Prince is woken on Tuesday regardless of how the coin lands, after being administered a drug that causes him to forget his Monday awakening. Like Beauty, he is always woken on Wednesday and told the experiment is over. Beauty and the Prince will be in the same room at all times, and will be free to discuss their situation (if both are awake). All this is known to both Beauty and the Prince.

If the Prince is woken before Wednesday and finds that Beauty has also been woken, what probability should he assign to the coin landing Heads? Quite clearly, he should assign probability 1/3 to Heads, since given Heads, the probability of Beauty being woken with him is 1/2, whereas given Tails this probability is 1. Since the coin is fair, this factor of two larger probability of what is observed given Tails should produce a factor of two larger probability of Tails given the observation that Beauty has been woken too.

The Prince will tell Beauty of his conclusion. Should Beauty disagree, and maintain that the probability of Heads is actually 1/2? Beauty and the Prince have the same information (and even if they didn't, they would after discussing the situation). Beauty will agree that the Prince's reasoning is correct, for him. There seem to be no grounds for her to decide that, for her, the probability should be different. Furthermore, if we wish, we can disallow discussions between Beauty and the Prince — Beauty is intelligent enough to know what the Prince's conclusion will be without him having to tell her. Indeed, we can assume that the Prince is hidden from Beauty by a curtain, as long as she knows he is there. Does it really matter if we go one step further and eliminate the Prince altogether?

This contradiction between the conclusions reached by Beauty and the Prince when they both apply SSA−SIA is not surprising in light of the discussion in Section 2.4, since the reference class used by Beauty does not include instances of the Prince, and vice versa. If instead they both use the reference class of wakenings before Wednesday of either Beauty or the Prince, the result of applying SSA−SIA changes. Beauty will then reason on wakening before Wednesday that if the coin landed Heads, the probability that she will be an instance of Beauty (rather than the Prince) is 1/3, whereas if the coin landed Tails, this probability will be 2/4, and as a result assign probability $(1/3)\,/(1/3+2/4) \;=\; 2/5$ to Heads. The Prince reasons on wakening that the probability of his being an instance of the Prince is 2/3 if the coin landed Heads and 2/4 if it landed Tails, so the probability of Heads is $(2/3)\,/\,(2/3+2/4) \;=\; 4/7$, equivalent to odds of 4/3 in favour of Heads. When he sees that Beauty is also awake, his odds shift by a factor of two in favour of Tails, producing final odds of 2/3 for Heads, corresponding to the probability of Heads being 2/5, which matches the conclusions of Beauty. While these conclusions are consistent, they appear doubtful because of their novelty, and their sensitivity to the number of companions.

If the reference class used by Beauty and the Prince is expanded to include all wakenings by all humans, which seems natural, the conclusions of SSA−SIA change again. If there are a large number, N, of wakenings by other people, and by Beauty or the Prince on other days, the probability that Beauty will assign to Heads upon wakening before Wednesday will be $(1/(N+3))\,/\,(1/(N+3) + 2/(N+4)) \approx 1/3$. The probability the Prince assigns to Heads upon wakening will be $(2/(N+3))\,/\,(2/(N+3) + 2/(N+4)) \approx 1/2$, which will change to 1/3 (a shift of odds by a factor of two) when he sees that Beauty is also awake. These conclusions of Beauty and the Prince are consistent, and match the conclusions obtained using FNC or SSA+SIA.

We therefore see that to obtain the answer 1/2, or any answer other than 1/3, SSA−SIA must be applied with a narrow reference class. Furthermore, the most natural narrow reference class — instances of Beauty alone — cannot be used if consistency with the conclusions of a companion is required. The arguments based on SSA−SIA for the answer 1/2 appear to not be viable. Any such arguments in favour of some answer other than 1/2 or 1/3 seem arbitrary, and also unmotivated, to the extent that the original intuition in favour of 1/2 — that Beauty learns nothing when she wakens before Wednesday — is violated by any other answer.

3.4 The Sailor's Child problem

The issue underlying the Sleeping Beauty problem can be further clarified by looking at what I will call the Sailor's Child problem. This problem does not involve memory loss. Without any such fantastic aspect, we can surely hope to obtain a clear answer.

A Sailor sails regularly between two ports, in each of which he stays with a woman, both of whom wish to have a child by him. He is reluctant, but eventually decides that he will have one or two children, with the number decided by a coin toss — one if Heads, two if Tails. Furthermore, he decides that if the coin lands Heads, he will have a child with the woman who lives in the city listed first in *The Sailor's Guide to Ports*. (He considers this fair, since although he owns a copy of this book, he hasn't previously read it, and so has no prior knowledge of which city comes first.) Now, suppose that you are this Sailor's child, and that neither you nor your mother know whether he had a child with the other woman. You also do not have a copy of *The Sailor's Guide to Ports*. You do, however, know that he decided these matters as described above. What should you consider to be the probability that you are his only child (ie, that the coin he tossed landed Heads)?

The answer seems clear. Given your ignorance regarding *The Sailor's Guide to Ports*, you should believe that if the coin landed Heads, your mother would have been selected to have a child with probability 1/2, whereas if the coin landed Tails, this probability would have been 1. This 2-to-1 ratio of probabilities for what is observed (that you were born) given Tails versus Heads leads to the probability of Heads being 1/3. The probability of your having a half-sibling is therefore 2/3. If you have any doubts about this, due to some idea that you should consider that you might have been the other child, ask the opinion of your mother, who plays the role of "companion" in this tale. She should have no doubts about this reasoning.

Suppose that you later obtain a copy of *The Sailor's Guide to Ports*, and find that the city you were born in is listed before the other port city. With this additional information, your birth becomes certain, regardless of the result of the coin flip. You therefore have no information regarding the result of this flip, and should assign probability 1/2 to Tails, and hence also to the possibility that you have a half-sibling. This situation is analogous to Beauty being told that it is Monday sometime after wakening.

Do the Sailor's Child and Sleeping Beauty problems differ in any important way? In the Sleeping Beauty problem, the instances of Beauty awakening on Monday and Tuesday can be visualized as "children" of the Beauty who existed on Sunday. That these "children" are much more closely related than are real children of the same father seems inessential, particularly since the only information transferred from Beauty-on-Sunday to Beauty-awakened-later is "common knowledge" about the setup, such as that the coin is fair. (In this light, we can see that contrary to many treatments in the literature, the Sleeping Beauty problem is not really about updating of beliefs as new information is received — a view of the problem that seems dubious in any case when actual or suspected memory loss is an issue.) With no relevant difference between the Sailor's Child and Sleeping Beauty problems, the answer to both must be 1/3.

3.5 So where did the "halfers" go wrong?

With puzzles of this sort, it is helpful to not only argue that some solution is correct, but also to explain why other, wrong, solutions may nevertheless seem appealing.

I speculate that one appeal of the 1/2 solution comes from a misapplication of the notion of falsifiability. Typically, if an experiment is incapable of falsifying a theory (or at least rendering it less probable), it is also incapable of confirming the theory (or even rendering it more probable than before). When Beauty awakens before Wednesday, her experiences are unsurprising according to both the "Heads theory" and the "Tails theory". Neither has been falsified, or could have been falsified. So, one might think, neither can have become more or less probable than before.

However, although this reasoning is usually sound, there are clearly contexts in which it is invalid. Suppose you have a box of things that look like grenades, but which might either be real grenades or fake stage props. You recklessly take one and pull its pin. After a few seconds, you are still alive. Can you conclude that it is now less likely than before that the box contains real grenades? Without wishing to condone such reckless experimentation, I believe it is clear that you can indeed conclude that the box likely contains fake stage props, even though your experiment could not have falsified this theory — if it had been wrong, you would not have drawn any inferences, since you would be dead. In the Sleeping Beauty problem, the reason that Tails cannot be falsified is less dramatic — Beauty is simply asleep at the crucial time. Note, however, that if the Prince is present, he may very well find that Tails is falsified, if he awakens and finds that Beauty is asleep.

Perhaps confusion concerning Sleeping Beauty is also partly a consequence of an implicit assumption that if Beauty is woken on both Monday and Tuesday her subjective experiences will be identical — that she will in essence be a single sentient entity existing at two moments in time. As mentioned above, this assumption is not justified by the standard description of the experiment. And indeed, it is not explicitly used in any of the arguments that I am aware of, but nevertheless seems to colour thinking about the problem. For example, Lewis (2001, p. 171) in describing the problem says, "...the memory erasure on Monday will make sure that her total evidence at the Tuesday awakening is exactly the same as at the Monday awakening", and Elga (2000, p. 145) says, "We may even suppose that you knew at the start of the experiment exactly what sensory experiences you would have upon being awakened on Monday", which in the context of the problem would require also assuming that these experiences are identical to those on Tuesday (if one is woken then). Assuming that Beauty's subjective experiences on Monday and Tuesday are identical converts the thought experiment from one with an only mildly fantastic element (perfect memory erasure) to one which is arguably impossible in principle. It is perhaps not surprising that mistakes can then ensue. In the Sailor's Child problem, however, no one would assume that if the Sailor has two children their lives will be indistinguishable; indeed, it is obvious that their lives will differ substantially (different mothers, different cities, etc.). That we can imagine the Sleeping Beauty experiment happening with the experiences of Beauty on Monday and on Tuesday differing only in much less dramatic ways does not change the correct answer; it only makes it harder to see.

4 The Doomsday Argument

Some versions of the Doomsday Argument, such as that of Gott (1993), depend in essence on an unsupported intuition — if humanity will expand into the galaxy, with hundreds of trillions of humans being born, isn't it rather surprising that you are among the first hundred billion humans? I will deal only with the version due to Leslie (1996), which can be put in formal terms if SSA is assumed, as discussed by Bostrom (2002).

4.1 Formalizing the Doomsday Argument

Suppose you know that you are the r'th human to be born (knowing r approximately is good enough, but would complicate the notation). Let N be the (unknown) total number of humans who will ever be born. If you assume SSA with the reference class being all humans, the probability of your observation that your birth rank, R, is r, given that the total number of humans is n, can be written as

$$P(R = r \,|\, N = n) \quad = \quad \begin{cases} 1/n & \text{if } n \geq r \\ 0 & \text{if } n < r \end{cases} \tag{19}$$

This is a consequence of SSA, since you might equally have been any of the n humans to ever exist. Suppose that $P(N = n)$ gives your prior belief that a total of n humans will ever be born, based on information such as your judgement of the probability that a large asteroid will collide with earth, and of the probability that a species that has evolved by natural selection to be competitive will destroy itself once its members acquire the technological means to do so. Applying Bayes' Rule, you can obtain the posterior distribution for N, which on these assumptions reflects what your beliefs about N should be after accounting for both your prior beliefs and your observation of r:

$$P(N = n \,|\, R = r) \quad = \quad \frac{P(N = n)\, P(R = r \,|\, N = n)}{\sum_{n'=1}^{\infty} P(N = n')\, P(R = r \,|\, N = n')} \tag{20}$$

$$= \quad \begin{cases} \dfrac{P(N = n)/n}{\sum_{n'=r}^{\infty} P(N = n')/n'} & \text{if } n \geq r \\ 0 & \text{if } n < r \end{cases} \tag{21}$$

Compare this with the posterior distribution given the information that N is at least r — which is implied by your observation that *you* are the r'th human, but does not contain any "indexical" information regarding yourself:

$$P(N = n \,|\, N \geq r) \;\; = \;\; \begin{cases} \dfrac{P(N = n)}{\sum_{n'=r}^{\infty} P(N = n')} & \text{if } n \geq r \\ 0 & \text{if } n < r \end{cases} \tag{22}$$

The difference between the posterior distributions for N given by (21) and (22) can be substantial. Suppose, for instance, that you believe that we will either destroy ourselves soon, or if we avoid this fate, we (or our descendants) will go on to colonize the galaxy. This belief would lead to a prior for N that (when idealized a bit) can be expressed as something like the following:

$$P(N = n) \;\; = \;\; \begin{cases} 1/2 & \text{if } n = 10^{11} \\ 1/2 & \text{if } n = 10^{14} \\ 0 & \text{otherwise} \end{cases} \tag{23}$$

If you observe that your birth rank is $r = 6 \times 10^{10}$, conditioning on $N \geq r$ as in (22) produces a posterior distribution that is the same as the prior. In contrast, conditioning on $R = r$ as in (21) produces a posterior distribution in which the probability that humanity will colonize the galaxy is reduced from 1/2 in the prior to $(1/2)/10^{14} \;/\; ((1/2)/10^{11} + (1/2)/10^{14}) \;\; = \;\; 0.000999001$ in the posterior (or put another way, the odds in favour of colonizing the galaxy change from 1 to 1/1000). Much greater shifts in odds are possible if galactic colonization is assumed to be more extensive (eg, of 10^{10} stars, each with population 10^{10}). A large "Doomsday effect" occurs even if the non-doom scenario involves only full utilization of our solar system.

4.2 Why the Doomsday Argument must be wrong

Although Leslie (1996) considers this shift in probabilities towards doom to be correct, and Bostrom (2002) does not consider the argument for it to be definitely refuted, there are several reasons for rejecting the Doomsday Argument that I regard as convincing, even without a detailed understanding of why it is wrong.

The biggest problem with the Doomsday Argument is that its conclusion depends critically on the choice of reference class. Is it all members of the species *Homo sapiens*? If so, exactly how is this species defined? Or should earlier extinct species of the genus *Homo* be included? Do the other Great Apes (gorillas, chimpanzees, and orangutans) count? Would they count if future experiments were to show that their cognitive abilities are greater than is at present believed — so that predictions regarding our prospects of colonizing the galaxy depend not just on the latest research into possible mechanisms of interstellar travel, but also on the latest research into whether apes can learn language?

Such changes in the reference class could easily change the probabilities resulting from the Doomsday Argument by a factor of ten. The probabilities also change if your belief regarding your birth rank changes. Suppose we discover that the population of China from 15000 to 5000 years ago was much larger than previously supposed, so that we estimate an extra 10^{11} people lived there in the past. If you previously estimated your birth rank as 6×10^{10}, you would now estimate it as 1.6×10^{11}. If your previous prior on N was $P(N = 10^{11}) = P(N = 10^{14}) = 1/2$, this would likely now change to $P(N = 2 \times 10^{11}) = P(N = 10^{14}) = 1/2$. The result would be a factor of two improvement in the odds in favour of colonizing the galaxy (from 1/1000 to 1/500). But is it reasonable that the latest results from Chinese archeology should affect your beliefs in this way?

Looking into the future, how much can our descendants differ from ourselves and still count as belonging to the reference class? Depending on the answer, the Doomsday Argument argument might not reduce the chances of our descendants colonizing the galaxy after all, if we think they would do so only after they start implanting computers in their brains, which might disqualify them from membership in the chosen reference class. It seems ridiculous that such an ethical judgement of what counts as "human" would affect our beliefs concerning the factual matter of whether or not our descendants will colonize the galaxy.

The Doomsday Argument falls apart completely if one sees no reason why SSA should be applied to individual intelligent observers (or to briefer "observer moments"). Considering that the Doomsday Argument has been discussed quite extensively, isn't the relevant unit not an individual, but rather an intellectual community? Due to modern communications technology, there is currently only one intellectual community in the world, but in the past there were many. There will again be many communities if civilization collapses (without humans going extinct). A civilization capable of colonizing the galaxy would probably maintain communications, however. The logic behind the Doomsday Argument then leads to the conclusion that we are more likely to colonize the galaxy than one might have otherwise supposed. Clearly, an advocate of the Doomsday Argument needs to exclude this reference class, but it's not apparent how this could be justified.

Another reason to doubt the validity of the Doomsday Argument is that the same reasoning in slightly different contexts leads to conclusions that also seem counterintuitive. Consider the reverse Doomsday Argument, in which you know your death rank, but are uncertain about your birth rank. For instance, you may have detected an asteroid on collision course with earth, one sufficiently large that it will certainly kill all humans. You then know that you will be among the last 7×10^9 humans to die. If you accept the logic of the Doomsday Argument, this will affect your beliefs about how many humans have ever lived. The effect will be even greater if you know that the point of impact will be on the opposite side of the earth from South Georgia Island, and you happen at present to be the only person on that remote island. You will then have good reason to believe that you will be the very last human to die, as the shock wave will reach you last. According to the Doomsday logic, you should then begin to seriously entertain various strange notions, such as that the statistics you'd previously believed regarding world population were actually faked, and that accepted historical and archeological accounts of the past are incorrect.

Moreover, there is no reason to consider only temporal ranks. Suppose you live in a small village of about 100 people high in the Himalayas. You meet occasional visitors from elsewhere, from whom you gather that some people live at lower altitudes. They also inform you that your village is the highest permanent habitation in the world. Due to language difficulties, however, you have obtained no clear idea of the total world population, and think on the basis of these reports that it might equally well be a few million or a few billion. If you accept the logic of the Doomsday argument, you should then downgrade the odds of the world population being a few billion by a factor of a thousand, compared to the possibility that the population is a few million, on the basis that a world population of a few billion would produce a probability (based on SSA) of your "altitude rank" being around 100 (as it is) that is a thousand times smaller than that produced if the world population is a few million.

4.3 More general Doomsday-like arguments

The only real role of birth or other rank in the Doomsday Argument is to provide a definition of a set S of observers in the reference class whose size is known (at least approximately), and which you know you are a member of. If you know that your birth rank is r, then you know that you are a member of the set of of all observers with birth rank no larger than r, a set whose size you know to be r. When you condition on your membership in a set S whose size you known to be r, and apply SSA, your beliefs about the number, N, of observers in the reference class are modified from your prior, given by $P(N = n)$. Specifically, since by SSA, $P(\text{you are in } S \,|\, N = n) \;=\; r/n$, you should conclude that

$$P(N = n \,|\, \text{you are in } S) \;=\; \frac{P(N = n)\, P(\text{you are in } S \,|\, N = n)}{\sum_{n'=1}^{\infty} P(N = n')\, P(\text{ you are in } S \,|\, N = n')} \tag{24}$$

$$= \begin{cases} \dfrac{P(N = n)/n}{\sum_{n'=r}^{\infty} P(N = n')/n'} & \text{if } n \geq r \\ 0 & \text{if } n < r \end{cases} \tag{25}$$

This parallels the Doomsday Argument of equation (21).

This generalization threatens to produce further counter-intuitive results. Perhaps advocates of the Doomsday Argument could find some rationale for disallowing sets S that are defined with too close a reference to you (though doing so without also excluding the set of people with birth rank no greater than yours might be a challenge). If so, you could not conclude on this basis that humanity will soon go extinct (and may never been very numerous) because your native language, of which you are the last living speaker, is, has been, and will be the native language of only a small number of people. Many Doomsday-like conclusions using sets that lack such an obvious connection to the person making the inference still seem possible, however. Suppose, for instance, that I have little idea of my birth rank (lacking any knowledge of archeology), but that I do know that I am among the roughly 10^9 humans born between the invention of nuclear weapons and the first visit by humans to the moon. I can apply Doomsday-like logic (with reference class of all humans) to draw a pessimistic conclusion regarding the total number, N, of humans who ever exist. The argument doesn't tell me whether the humans who do exist were born before or after I was, but this just increases pessimism with regard to the future.

As another example, suppose that you were convinced that only our solar system contains planets and that some sort of catastrophe is bound to wipe out humanity fairly soon. In particular, you think there will be no more than 10^{12} humans. However, you consider it plausible that intelligent beings may exist on Jupiter. Moreover, you believe that if such beings do exist, they are very numerous compared to humans — Jupiter is much larger than earth, supporting a very large population at any given time, and reducing the chances that a catastrophe could wipe out the whole population. Suppose you think that 10^{16} Jupiter beings will exist if any such beings exist. If you now apply SSA with the reference class of all intelligent observers, and consider the set S of human observers, you will multiply your prior odds in favour of the existence of Jupiter-beings by the factor $10^{12}/10^{16} = 1/10000$, since if Jupiter-beings exist, the probability that you would be human rather a Jupiter-being is only 1/10000. Many of the reasons for disbelieving the ordinary Doomsday Argument apply to arguments of this sort as well. For example, how intelligent do the Jupiter-beings have to be to count as members of the reference class?

To me, these arguments seem just as "presumptuous" as the Presumptuous Philosopher's argument discussed below in Section 6. Moreover, being based on SSA−SIA, these Doomsday-like arguments are sensitive to choice of reference class, unlike arguments based on FNC or SSA+SIA (as discussed in Sections 2.2 and 2.3). However, arguments of this type are essential if SSA−SIA is to avoid conflict with conclusions by companions, as discussed generally in Section 2.4, and in connection with the Presumptuous Philosopher problem in Section 6.1.

4.4 The Doomsday Argument with non-human intelligent species

Inclusion of intelligent species other than humans in the reference class changes the focus of the the Doomsday argument from specifically human hazards to hazards affecting intelligent species in general. This is discussed, for example, by Knobe, Olum, and Vilenkin (2006). For the moment, I assume that intelligent species do not interact.

Suppose you are sure that many intelligent species exist, have existed, or will exist. Direct application of the Doomsday Argument with this reference class is then not possible, assuming you have little idea of your birth rank among all intelligent observers. If you know the distribution of the total number of individuals in a species who ever exist, there will be no Doomsday effect — application of SSA should lead you to consider it more likely *a priori* that your species is one of the more numerous ones, which cancels the Doomsday effect from knowing that your birth rank within your species is low. However, a Doomsday effect remains if you are uncertain about the typical lifetime of intelligent species. For instance, you might be uncertain whether species that develop advanced technology are likely to use it to destroy themselves (either by internal conflict, or by destruction of their environment), in which case most intelligent species will be short lived, or whether instead such advanced technology will typically enhance a species' prospects, in which case most intelligent species will be long lived, with numerous individuals. Application of SSA together with knowledge that your birth rank within your species is low then produces a shift of probability toward the hypothesis that most intelligent species are short lived (most likely including yours, absent any evidence that it is an exception).

4.5 Defusing the Doomsday Argument with SIA or FNC

Assuming SIA as well as SSA defuses the Doomsday Argument. Your original prior for N, given by probabilities $P(N = n)$, is adjusted by SIA so that the prior probability that $N = n$ becomes $n\,P(N = n) \;/\; \sum_{n'=1}^{\infty} n'\,P(N = n')$. Substituting this expression for occurrences of the form $P(N = n)$ in equation (21) gives the "no doom" probabilities of equation (22).

As one would expect from the discussion in Section 2.3, the same result is obtained if one uses FNC, with the argument being even more direct. You update your prior for N, with probabilities $P(N = n)$, by conditioning on the existence of a person with your full set of memories, which includes knowledge of your birth rank, r. (Your scientific knowledge regarding what N might be will have been incorporated into the prior, however, and needn't be conditioned on at this point.) However, the (presumably very small) probability that a person exists with birth rank r and with all your other memories is independent of N, apart from the requirement that N be at least r. The posterior distribution of N is therefore just the prior for N renormalized to sum to one over the range from r up — ie, the same as in equation (22).

Similar arguments refute the form of the Doomsday Argument where there are many intelligent species. Assuming SIA makes it more likely that intelligent species are usually long-lived, cancelling the doomsday effect. If you apply FNC, the probability that someone exists with all your memories, including your knowledge that your birth rank within your species is r, depends only on how many intelligent species have at least r individuals, not on how long-lived these species are beyond that.

The apparent simplicity of these refutations of the Doomsday Argument is deceptive, however. These refutations will have no force if assuming FNC (or SIA, if you prefer) leads to insurmountable problems in other contexts. This issue is explored in the next two sections.

5 Freak Observers

Bostrom (2002) argues for SSA on the grounds that without it drawing conclusions from empirical evidence is impossible, due to the existence of "freak observers". The problem is that in a large universe, *someone* will have made every possible observation, regardless of what the true state of the universe is. So knowing that a particular observation has been made provides no evidence at all concerning reality. However, if you accept SSA, and know that *you* made a particular observation, you can draw useful conclusions, as long as *most* observations made by observers in your reference class correspond (at least approximately) to reality. For this to work, your reference class needn't be very large — it makes no difference whether you use all human-like beings or all intelligent observers, for instance — but it must be at least a bit larger than the set of observers with exactly your memories, since that narrow reference class might consist only of observers who have made the same misleading observation.

In arguing for the existence of freak observers, Bostrom mentions possibilities such as brains in all possible states being emitted from black holes as Hawking radiation, or condensing by chance from clouds of gas. However, it is perhaps too easy to say that in an infinite universe such events must happen. The size of the universe that is needed to make such events likely is quite unimaginably huge, even in comparison with the vastness of the observable universe that we have by now become accustomed to. It is much easier to imagine misleading observations arising by more normal mechanisms. Equipment failures, unusual amounts of noise, incompetence, and fraud are all possible reasons why an apparently definitive scientific observation might actually be wrong. The probability of an observation being wrong will almost always be at least one in a billion. Since there are quite likely more than a billion planets in the observable universe that are inhabited by intelligent beings (this is much less than one per galaxy), it is likely that numerous highly misleading observations have been made.

I will argue that you can draw conclusions from observation despite the existence of such misleading observations without needing SSA — use of FNC being sufficient — as long as the universe is not so large that you would expect there to be other observers with exactly the same memories as you. According to FNC, you should condition not just on what you know to be the result of a scientific observation, but also on all your other memories. The probability that an observer exists with all your memories, including your memory of the observation, will be much greater if the observation is correct than if it is incorrect, unless the universe is so large that it contains many observers whose memories match yours in all respects other than the result of this observation. You will therefore be justified in concluding that your observation likely corresponds to reality.

How big would the universe have to be for the assumption that there are no other observers whose memories match yours to be false? Though I have not performed any detailed calculations, it seems to me that the most likely way for another observer with your memories to arise is by ordinary biological processes on a planet somewhere — not by bizarre mechanisms such as Hawking radiation.[6] To get a lower limit on the required size of the universe, let us suppose that life-bearing planets are common, and that biology on them is always much like it is on earth. Producing a duplicate of you would then require that a species evolve that is nearly identical to *Homo sapiens*, and that an individual in this species then acquire the same memories as you. The human genome contains about 3×10^9 base pairs, for each of which there are four possible nucleotides. Even supposing that only 1% of these base pairs might differ in a similar species (others being functionally constrained), and that only 1% of these differences would have a noticeable effect, we are left with $4^{3\times10^5} \approx 10^{180000}$ possible and distinguishable human-like individuals. Humans have approximately 10^{11} neurons. Even supposing that each neuron and its connections (which typically number in the thousands) encodes only one bit of useful information, there will be $2^{10^{11}} \approx 10^{30000000000}$ possible sets of memories. This number dominates the number of possible genomes. For comparison, there are roughly 10^{11} galaxies in the observable universe, each containing roughly 10^{11} stars. Even if all these stars have life-bearing planets, the number of such planets in the observable universe is only 10^{22}. If each contained 10^{10} observers, replaced over 10^{10} generations, the total number of observers would be 10^{42}. The universe would therefore need to be a factor of around $10^{30000000000}/10^{42} = 10^{29999999958}$ times larger than the portion of it that we can observe in order for there to be a good chance that another observer exists with the same memories as you.

Large as it is, $10^{29999999958}$ is of course as nothing compared to infinity, which some may believe describes the actual extent of the universe (eg, Knobe, Olum, and Vilenkin 2006). However, before insisting that the possibility of a universe this large or infinite should constrain our reasoning processes, we should ask what else would change if we took this possibility seriously. Common notions of decisions and ethics would seem to be in serious trouble — if everything is bound to happen someplace, why strive for a good outcome here? As I argued in Section 2.5, making fantastic assumptions of this sort carries the danger that subsequent reasoning may utilize premises that are in fact incompatible with the assumption.

Accordingly, it seems safer to at least initially consider problems of anthropic reasoning on

[6]This seems clear for the present epoch of the universe — if we were to explore the galaxy, we could certainly expect to come across a planet with life that arose by normal evolutionary processes before coming across one that popped for no reason out of a black hole. Dyson, Kleban, and Susskind (2002) argue that, under certain conditions, the universe will visit all possible states, and consequently conscious beings will arise more often from "random" fluctuations than from normal evolution, since for only a small proportion of the microstates corresponding to a conscious being would backwards dynamics lead to a low-entropy state from which ordinary evolution could proceed. Regardless of how plausible this is as a correct description of the universe, I think it is an excellent example of a "fantastic" possibility that we are better off ignoring, at least until we are truly prepared to reason through *all* its counter-intuitive implications. For example, one question we would need to resolve is whether identification of a physical system as a conscious entity is dependent only on its macrostate, or whether a meaningful correspondence of memory with history, and of actions with future state, is also a requirement.

the assumption of a finite (and not ridiculously large) universe. However, I do not dismiss the possibility that the universe is truly infinite in spatial extent, or that an infinity of parallel universes exist, due perhaps to the Many Worlds interpretation of quantum mechanics being correct. But if so, and if the consequences are as they might superficially seem, then the arguments concerning the puzzles of anthropic reasoning that I address here need to go beyond what has appeared in the literature so far. Great care would need to be taken to ensure that assumptions based on ideas such as uniqueness of individuals do not enter in subtle ways. I will consider infinite universes in Section 8, but for the moment, I confine myself to arguments that are compatible with a more common sense view of the universe.

6 Presumptuous Philosophers

The Presumptuous Philosopher problem has been interpreted (eg, by Bostrom (2002)) as showing that SIA should not be accepted, because it leads to an unreasonable preference for cosmological theories that imply that the number of observers in the universe is large. If theory A implies that the number of observers (in the chosen reference class) is a trillion times larger than that implied by theory B, SIA says that you should shift your relative prior beliefs in theories A and B by a factor of a trillion. If you judge the two theories equally likely on other grounds (and there are no other plausible theories), application of SIA should leave you virtually certain that theory A is true — so certain that you would rationally ignore almost any future evidence to the contrary. Such dogmatism seems intuitively unacceptable.

FNC also seems vulnerable to the Presumptuous Philosopher problem. The probability of an observer with exactly your memories existing somewhere in the universe will be greater if the number of observers who "might have" your memories is larger. If your memories are detailed enough to make the probability of their occurring small even in the largest universe considered, the probability that an observer with your memories exists will be directly proportional to the number of observers, producing the same shift as for SIA.

As an extreme, a theory that says the universe is infinite would appear to be infinitely favoured by SIA. FNC would also favour such a theory over one in which the universe is only a few billion light years in extent, though with FNC the preference for an infinite universe would only be very large, not infinite (since once the universe is large enough that it is nearly certain that at least one observer with your memories will exist somewhere, sometime, further increases in the size of the universe are neither favoured or disfavoured). Here, however, I will discuss the Presumptuous Philosopher problem under the assumption that the universe is finite, and though it may be very large, it is not so large that exact duplicates of observers are likely to occur. I consider first the consequences of SSA−SIA versus those of SSA+SIA for theories that differ in the density of observers, but not in the size of the universe. I then consider what FNC says in this situation. Finally, I discuss the more difficult problem of assessing theories that predict universes of different sizes.

6.1 Theories differing in the density of observers — SSA−SIA vs. SSA+SIA

Implicit in the simple statement of the Presumptuous Philosopher problem is the assumption that the details of why theory A predicts many more observers than theory B do not matter. In particular, Bostrom and Ćirković (2003) present two versions of the Presumptuous Philosopher problem, one in which theories A and B differ with respect to the size of the universe, the other in which they differ with respect to the density of observers, and consider (without discussing the matter) that the same conclusion (that SIA gives wrong results) should be reached in both situations. On the contrary, I will argue here that if theories A and B agree on the size of the universe (which both also predict is homogeneous), but differ in that theory A predicts a higher density of observers, then the preference given by SIA to theory A may be well justified.

Throughout this section and the next, I will assume that intelligent observers in different star systems cannot affect each other — not through travel, communication, or detection, nor though any non-deliberate means — since any contact with observers in other star systems would provide direct evidence of the density of observers, invalidating the discussion. It is important to keep in mind that this assumption is false. Section 7 discusses what we may conclude about the density of observers given what we actually know. The discussion below is meant to clarify the philosophical issues involved in a simple empirical context, which does not correspond to our actual state of knowledge.

Leslie (1996) and Olum (2002) discuss a historical instance of theories differing with regard to the density of observers, in which Olum argues in favour of the predictions of SIA, whereas Leslie, and also Bostrom and Ćirković (2003), argue against SIA. Marochnik (1983) advanced a theory that earth-like planets can form only around stars whose distance from the galactic centre leads them to revolve around the galactic centre at a speed that nearly maintains their position relative to the density waves defining the galaxy's spiral arms. This theory limits the possible locations of earth-like planets to a small region, occupying a fraction f of the galaxy, with f perhaps being in the range 0.01 to 0.1. Given various other assumptions (eg, that life formed in this region does not colonize the rest of the galaxy), Marochnik's theory would imply that there are a fraction f fewer intelligent observers in the universe than would be expected under an alternative "planets everywhere" theory, in which there is no such restriction on where an earth-like planet can form.

As Olum notes, Marochnik's theory is therefore disfavoured by SIA — ie, if you accept SIA, you should reduce the probability you assign to this theory below the probability you would have assigned to it based on ordinary considerations. In particular, if you thought the two theories equally likely excluding consideration of SIA, and no other theories are plausible, you would consider Marochnik's theory to have probability $f/(1+f)$ after applying SIA (equivalently, the odds in favour of Marochnik's theory shift from 1 to f). In contrast, to someone who accepts SSA but not SIA, and who does not know the distance of any earth-like planet from the galactic centre, Marochnik's theory is neither favoured nor disfavoured compared to the "planets everywhere" theory, provided that the regions where life is possible according to Marochnik's theory are large enough that intelligent observers are nearly certain to have arisen in some such region at least once in the history of the universe. (f would need to be very small, less than about 10^{-20}, for this condition to be false.)

Suppose now that we are able to measure the distance of the sun from the galactic centre, and we find that this distance is such that it leads to the sun nearly maintaining its position with respect to the galaxy's spiral arms, as predicted by Marochnik's theory. In fact, according to Marochnik's (1983) paper (though perhaps not more recent measurements), our sun does appear to be at the required distance. We could easily imagine this was not known until later, however. Should such an observation be taken as a confirmation of Marochnik's theory?

According to all views of the matter, this observation does indeed increase the probability that Marochnik's theory is correct. In particular, the odds in favour of Marochnik's theory are multiplied by the ratio of the probabilities of this observation under Marochnik's theory and the "planets everywhere" theory, which is $1/f$ (since the probability of observing this is 1 for Marochnik's theory and f for the "planets everywhere" theory). However, if SIA is accepted, this increase in the probability of Marochnik's theory merely cancels the previous lowering of the theory's probability due to its prediction that there are relatively few intelligent observers. (Equivalently, the odds in favour of Marochnik's theory shift from f to $f \times (1/f) = 1$.) The result is that Marochnik's theory, after such a observation is made, has the same probability as it would have had without any such observation, and without adjusting its prior probability by applying SIA. In contrast, someone who accepts SSA but not SIA, and who on the basis of prior information regards Marochnik's theory and the" planets everywhere" theory as equally likely, would take the observation that our sun is in the small region of the galaxy where Marochnik's theory predicts stars with earth-like planets are possible as reason to increase the probability of Marochnik's theory to $1/(1+f)$ (ie, the odds in favour of Marochnik's theory would be $1/f$). This preference comes about because under SSA (with a reference class of all intelligent observers) it is unlikely that we would be in this special place in the galaxy if intelligent observers are found throughout the galaxy, but it is certain that we will be in this special place if it is the only place where intelligent observers can exist.

The device of imagining "companion" observers can be used to shed light on which of these views is correct. Suppose that in addition to any intelligent observers who may originate on planets, intelligent observers taking the form of complex patterns of plasma and magnetic fields exist in the atmospheres of all stars. Initially, let us assume that each star harbours only around a dozen such star-beings (and we know this). Such star-beings therefore make up a negligible fraction of the reference class of all intelligent observers, even if a planet holding billions of intelligent beings is found around only one star in a million. The star-beings living in our sun's atmosphere are quite willing to engage in astrophysical discussions, once we realize they are there. After these discussions they have the same observational data as we do. Will their conclusions about Marochnik's theory agree with ours? The answer depends on the principles by which inference is done, as discussed below, and summarized in the tables on the next page.

Consider first what conclusions will be drawn if humans (or other planet-beings) use as their reference class for SSA or SIA only other planet-beings (not star beings), and similarly star-beings use as their reference reference class only other star-beings. Since the two theories under consideration make the same predictions regarding star-beings, SSA and SIA will then have no effect on inferences by star-beings, but may have an effect on inferences by planet-beings. (These conclusions are shown on the left side of the top table.)

Suppose first that neither we nor the star-beings in our sun's atmosphere know the position of the sun in the galaxy. The star-beings will then take our existence on earth as evidence against Marochnik's theory, since according to that theory, earth-like planets occur only in a special region of the galaxy, and (like us) the star-beings have no reason to think that the sun is in this special region. If they thought Marochnik's theory and the "planets everywhere" theory were equally likely before knowing that humans exist, they will think Marochnik's theory has probability $f/(1+f)$ after (ie, the odds in favour of Marochnik's theory will be f).

Suppose now that the distance of the sun from the galactic centre is measured, and found to be

STAR-BEINGS MUCH LESS NUMEROUS	Reference class only star-beings or only planet-beings				Reference class both star-beings and planet-beings			
	SSA−SIA		SSA+SIA		SSA−SIA		SSA+SIA	
	planet beings	star beings	planet beings	star beings	planet beings	star beings	planet beings	star beings
Prior based on ordinary information	1	1	1	1	1	1	1	1
Prior after adjustment using SIA			f	1			f	f
Prior after adjustment using SSA	1	1	f	1	1	$1/f$	f	1
Posterior after existence of companions known	1	f	f	f	1	1	f	f
Posterior after location of sun in galaxy known	$1/f$	1	1	1	$1/f$	$1/f$	1	1

STAR-BEINGS MUCH MORE NUMEROUS	Reference class only star-beings or only planet-beings				Reference class both star-beings and planet-beings			
	SSA−SIA		SSA+SIA		SSA−SIA		SSA+SIA	
	planet beings	star beings	planet beings	star beings	planet beings	star beings	planet beings	star beings
Prior based on ordinary information	1	1	1	1	1	1	1	1
Prior after adjustment using SIA			f	1			1	1
Prior after adjustment using SSA	1	1	f	1	f	1	f	1
Posterior after existence of companions known	1	f	f	f	f	f	f	f
Posterior after location of sun in galaxy known	$1/f$	1	1	1	1	1	1	1

Inferences by planet-beings and star-beings under various assumptions. The upper table is for the scenario in which star-beings are much less numerous than planet-beings, the lower table when star-beings are much more numerous than planet-beings. Entries in the tables are the odds, utilizing the information listed on the left for that row and the rows above, in favour of Marocknik's theory versus the "planets everywhere" theory, with f being the fraction of stars in the location where Marochnik's theory says earth-like planets are possible.

such that the sun nearly maintains its position with respect to the spiral arms. The star-beings will now no longer take our existence on earth as evidence against Marochnik's theory, since given that the sun is in this special place, it is not surprising that it has an earth-like planet. However, Marochnik's theory is not made any more probable than the "planets everywhere" theory by this observation. As discussed above, after finding that humans exist, the star-beings' odds for Marochnik's theory being true would be f. The probabilities for the subsequent observation that the sun is in the special position required by Marochnik's theory are 1 if Marochnik's theory is true, and f if the "planets everywhere" theory is true. The odds for Marochnik's theory shift by the ratio of these probabilities, leaving the odds at $f \times (1/f) = 1$.

To see why it is reasonable that the star-beings would not favour Marochnik's theory in this situation, consider for comparison how you would evaluate a theory that a certain fish occurs only in acidic lakes, versus the contrary theory that it occurs in all lakes. The observation that this fish is present in a nearby acidic lake tells you nothing about which of these theories is true — you need to look in a non-acidic lake to obtain any relevant data.[7]

The conclusions of the star-beings regarding Marochnik's theory are the same as we would reach by applying SIA. I will call these the "non-anthropic" conclusions, since they are also what one would obtain by ignoring both SSA and SIA, as some observer outside the universe would do (just as with the fish example above).

Before considering this reasoning by companion star-beings as supporting the non-anthropic conclusions, however, we should consider that the star-beings might apply SSA and/or SIA with the reference class of all intelligent observers, including both us and them. (The resulting conclusions are shown on the right of the top table.) If the star-beings accept SIA, they will adjust their prior to disfavour Marochnik's theory, since it predicts many fewer intelligent observers, thereby reducing the odds in favour of Marochnik's theory to approximately f. (Recall that the star-beings are assumed to form a negligible fraction of all intelligent observers.) However, if they now apply SSA in conjunction with their observation that they are star-beings, this effect is undone, since the more planet-based intelligent observers there are, the smaller the odds that one is a star-being. (Recall that the number of star-beings is the same for both theories). The odds in favour of Marochnik's theory therefore shift by the factor $1/f$, to $f \times (1/f) = 1$. Subsequent reasoning proceeds to the non-anthropic conclusions just as above — the observation of humans on earth decreases the probability of Marochnik's theory (the odds in favour decline to f), and the subsequent measurement showing that the sun is in the special place where earth-like planets are possible restores this probability to its original value, but no higher (ie, at this point, Marochnik's theory is neither favoured nor disfavoured).

On the other hand, if the star-beings accept SSA but not SIA, and use the reference class

[7] There may be a curious order dependence of intuitions here. If you first find that this lake is acidic, and then find that it contains this fish, you will certainly reason as above. But if you first discover that the lake contains this fish, and only later find that the lake is acidic, you might be tempted to take this observation as confirmation that the fish is found only in acidic lakes, particularly if acidic lakes are rare. The difference appears to derive from a heuristic for avoiding self-deception — predicting that the lake is acidic after finding the fish in it is psychologically risky, in that you might be wrong. So if you actually make such a prediction, your *prior* probability that the fish is found only in acidic lakes must really be high. In contrast, no such stark confrontation with reality occurs when you know the lake is acidic before looking for the fish (which is therefore likely to be found regardless of which theory is correct). It might then be easier to deceive yourself regarding your true prior beliefs. So, taking into account your own capacity for self-deception, your conclusion may depend on the order of observations. Here, however, I assume that we are not prone to self-deception of this sort.

of all intelligent beings, their conclusions will match those of humans who also accept SSA but not SIA (with the same reference class). A doomsday-style effect occurs, of the sort discussed in Section 4.3, in which the star-beings initially adjust the probability of Marochnik's theory upwards, since this theory makes it more likely that one is a star-being, like them, rather than a planet-being. Observation of humans on earth causes the probability of Marochnik's theory to go down again (since it says that earth-like planets are rare). Finding that the sun is in the special place where Marochnik's theory says earth-like planets are possible then raises the probability of Marochnik's theory back up again, to the point where it is favoured by the factor $1/f$ over the "planets everywhere" theory.

This consideration of companion star-beings therefore does not definitively refute the methodology of accepting SSA but not SIA — provided humans and star-beings both use SSA−SIA with the reference class of all intelligent beings, their conclusions are the same. This is expected from the (only slightly different) general discussion in Section 4.3.

However, this consideration of companions does undermine the claim that the Presumptuous Philosopher problem makes SIA implausible (at least on the basis of this scenario). To review, the claim is that although SIA defuses the counter-intuitive Doomsday Argument, it does so at the cost of producing an equally counter-intuitive Presumptuous Philosopher effect. Here, however, we see that the conclusion of the Presumptuous Philosopher in this scenario is implausible only if you accept arguments of the Doomsday type — such as would lead the star-beings to favour Marochnik's theory prior to any observations solely on the basis that it makes it more probable that an observer will be a star-being like themselves. An advocate of SIA who rejects Doomsday-type arguments will therefore be untroubled by this instance of the Presumptuous Philosopher problem.

We might alternatively suppose that, rather than each star having only a dozen star-beings, each star instead has trillions of them, so they are vastly more numerous than planet-based beings, under any theory. (Conclusions on this assumption are shown in the bottom table.) In this situation, anthropic reasoning has no effect on the conclusions of the star-beings, who will reach the non-anthropic conclusions regardless of whether they accept SSA and/or SIA, using any plausible reference class. SIA also has no effect for human observers in this situation, provided that they use the reference class of all intelligent observers (not all humans, or all planet-based observers). However, SSA has the effect, for humans, of decreasing the probability of Marochnik's theory, since under this theory, one is less likely to be a planet-based being than one is under the "planets everywhere" theory. This decrease is undone once the sun is found to be in the special place where planets are possible under Marochnik's theory. The results match the non-anthropic conclusions of the star-beings, once they know of the existence of humans, so this scenario does not resolve any issues. However, if the humans used the reference class of all planet-based intelligent observers (excluding star-beings), their conclusions using SSA−SIA will not match those reached by the star-beings.

Here again, SSA−SIA can produce conclusions consistent with those of companion observers provided a reference class including both is used. Notice, however, that the conclusions found using SSA−SIA in this scenario with numerous companions are different from those found when the companions were less numerous. Applying anthropic reasoning based on SSA−SIA leads to conclusions regarding planet-based observers that depend on how many non-planet-based observers exist, even though this information would appear to be irrelevant.

In another scenario, we might have two theories, one of which says that intelligent observers are common, whereas the other says that they are randomly distributed at a low density (but high enough that it is likely that at least one intelligent species does exist). In contrast with Marochnik's theory, in this scenario there is no possibility of discovering that the sun is in a special life-bearing region. Using SSA−SIA, the prior probabilities for the two theories depend only on normal considerations of plausibility, and our observation that we exist does not change these probabilities. Using SSA+SIA, the prior probabilities are adjusted in favour of the theory that intelligent observers are common, and these probabilities are again unchanged by the observation that we exist. Consideration of star-beings as possible companion observers produces results analogous to those discussed above for Marochnik's theory — consistency requires that the reference class include all intelligent observers, and the conclusions using SSA−SIA, but not SSA+SIA, depend on the number of companion observers.

In summary, consideration of companion observers provides strong evidence that in scenarios where the density of observers varies, the conclusions found using SSA+SIA are correct, whereas those found using SSA−SIA are not. Certainly, the conclusions of SSA+SIA regarding Marochnik's theory seem quite acceptable. Lingering unease may remain, however, when the shift in prior odds produced by SIA is not the factor of 10 to 100 that occurs with Marochnik's theory, but rather a factor of a trillion or more, which one can imagine could occur with some other theory. I will consider such cases of extreme "presumption" below, when discussing FNC, which I see as the more principled, even if largely equivalent, alternative to SSA+SIA.

6.2 Theories differing in the density of observers — result of applying FNC

To apply FNC, you multiply your prior odds for one theory over another, based on ordinary scientific evidence, by the ratio of the probabilities that these theories give for someone to exist with your exact memories (excluding your scientific knowledge that contributed to the original prior odds, but including any additional scientific observations). As discussed in Section 2.3, the results of applying FNC are much the same as those of applying SSA+SIA. Thinking in terms of FNC avoids the need to specify any reference class of observers, however, and clarifies the issues that are involved in this type of reasoning.

Here is a superficial analysis of how FNC applies to Marochnik's theory versus the "planets everywhere" theory, which was discussed in Section 6.1 using SSA−SIA and SSA+SIA. If a total of C earth-like planets exist according to the "planets everywhere" theory, and each has some very small probability, ϵ, of producing someone with your exact memories, then the probability of your existing according to the "planets everywhere" theory is ϵC (assuming, as I am, that this is much less than one). According to Marochnik's theory, the number of earth-like planets will be smaller by the factor f, and hence the probability that you exist will be only $\epsilon f C$. Assuming equal prior probabilities for the two theories, your odds in favour of Marochnik's theory should be f, if this is all you know. Suppose you then make a reliable observation that the sun is in the special region where, according to Marochnik's theory, earth-like planets can form. Your odds in favour of Marochnik's theory should then change to 1 (ie, the two theories should become equally likely), since the chance that someone exists with your memories — including your memory of observing that the sun is in this region — is the same for both theories. The extra earth-like planets that exist according to the "planets everywhere" theory do not increase the probability that you will exist, since a being on a planet outside the special region is very unlikely to remember having observed that they are in the special region, and also have your other memories. (See Section 5 for consideration of the possibility of false observations.) These conclusions are the same as those found in Section 6.1 using SSA+SIA.

Although I believe that this superficial analysis produces the correct result, it conceals a number of subtleties. One is that, contrary to what is implicitly assumed in the argument above, earth-like planets in other galaxies could not really produce someone having your memories, assuming that you have seen the numerous photos of distant galaxies that most people have seen. From a planet in a different galaxy, these galaxies would be viewed from a different angle, be much larger or smaller, or be obscured. (As discussed earlier, I assume for the moment that the universe is not so large that one would expect to find another galaxy whose views of other galaxies are just by chance virtually identical to ours.) Because of this, it is actually essential to the argument that Marochnik's theory applies not just to most galaxies, but to our galaxy in particular. If our galaxy were a rare exception in which earth-like planets were possible everywhere even according to Marochnik's theory (and you knew this), applying FNC would not change the probabilities of the two theories, since the probability that you would exist in our galaxy (where you clearly are) would be the same for both theories. Careful application of SSA+SIA would also lead to this conclusion, but only because the shift in odds away from Marochnik's theory that is produced by SIA is cancelled by applying SSA, taking account of the greater probability of being in an exceptional galaxy if the other galaxies are less populated. This seems to me to be a rather perverse way of reasoning to the correct conclusion, however.

Furthermore, it is questionable whether a planet in a distant part of our galaxy — likely differing from earth in elemental abundances (as determined by local supernovae), in the local density of stars, in cosmic ray intensities, and in the view of the Milky Way in the night sky — would have even a tiny chance of producing life that evolves in just the way it has on earth, and of then producing an individual with your memories. As an analogy, suppose you are given detailed photographs of a house, which you are told is either in India or in Canada, and are asked to guess in which of these countries the house is located. If you are knowledgeable about architectural styles and construction practices in the two countries, it is quite likely that you would be able to tell which country the house is located in. Of course, someone with less knowledge might not be able to tell where the house is located. Similarly, someone with sufficient knowledge of our galaxy would likely be able to tell where in our galaxy earth is located, without the need for any explicit measurement of location. However, if you lack sufficient knowledge, you will not know where in the galaxy earth is located without an explicit measurement, and so, *as far as you know*, any earth-like planet in the galaxy might have produced someone with your memories, and the more such earth-like planets there are, the greater the chance that you will exist. Put another way, the narrow region where earth-like planets are possible according to Marochnik's theory leads to a restricted range of possible characteristics of these planets and their inhabitants. Since you do not know what this range is, you do not know whether or not the characteristics of earth and humanity are included. The possibility that they are not reduces the chance of your existing if Marochnik's theory is true. As this example makes clear, the probabilities used in FNC may reflect your ignorance, rather than the operation of some random physical process.

When applying FNC, it is clear that some "presumptuous" conclusions that may appear to follow from SIA are not actually problematic. Consider, for example, the theory that all bacteria are intelligent beings. You may regard this theory as unlikely, and assign it a low prior probability. However, there are approximately 10^{21} times as many bacteria as humans on earth (Whitman, Coleman, and Wiebe 1998). Similar ratios for analogous organisms presumably hold on other earth-like planets. According to SIA, we should therefore increase the prior odds that bacteria are intelligent by a factor of 10^{21}, which may well make the theory highly probable despite its prior implausibility. However, if you apply FNC rather than SSA+SIA, the probability of this theory will not be increased — whether bacteria are intelligent or not has no effect on the probability that you will exist with all your memories, since you are not a bacterium. One does in fact reach this same conclusion in the end using SSA+SIA, since the huge increase in the theory's probability from applying SIA is cancelled by an equally huge decrease from the low probability of an intelligent observer being human if the theory is true. As was the case above, however, such reasoning based on SSA+SIA seems rather contorted, even if the right answer is obtained, compared to the straightforward application of FNC. Note also that according to SSA−SIA, you should decrease your (presumably already low) odds in favour of bacteria being intelligent by a factor of 10^{21}, on the grounds that if they were intelligent, you would likely be a bacterium. In this scenario it is SSA−SIA, not SSA+SIA or FNC, that could be accused of presumption.

Scenarios more troubling for an advocate of FNC can be imagined, however. Suppose you have calculated that the number of earth-like planets in the galaxy is about one thousand, on the basis of what you believe to be the correct mechanism of planet formation, and assuming that Newton's theory of gravity is an adequate approximation. It occurs to you that perhaps Einstein's theory of gravity would give different results. You think the chances of this are only about 9% (odds of about 1/10), since Newton's theory is usually a good approximation, but you decide nevertheless to redo the calculation using Einstein's more accurate theory. This new calculation says that the number of earth-like planets in the galaxy is about one billion — a million times more than found with the Newtonian calculation. You judge that mistakes in such calculations happen about 10% of the time (at least without further checking, which you haven't done yet), so the probability of getting a divergent result such as you obtained if Newton's theory is actually an adequate approximation is 10% (since a mistake would need to be made), whereas the probability of a divergent result if Newton's theory is not adequate is about one (since a correct result would differ, and an error would also be fairly likely to produce a different result). Using ordinary reasoning, the result of this calculation should therefore lead you to multiply by 10 the original odds in favour of the Newtonian calculation being wrong, which produces odds of about 1. So at this point, you would consider that the number of earth-like planets in the galaxy is equally likely to be one thousand or one billion.

However, if you now apply FNC (or SIA), you will increase the odds in favour of the Newtonian calculation being wrong by a factor of a million, since the calculation using Einstein's theory leads to a factor of a million more earth-like planets, with a corresponding increase in the probability of someone with your memories existing. This extreme certainty seems presumptuous, particularly when you haven't even checked your calculation yet.

A hint at resolving this problem comes from considering a scenario that is similar except that the calculations are not of the number of earth-like planets, but rather of a numerical quantity that has been precisely measured by experiment. If your calculation using Einstein's theory produces a very good fit to the experimental data, you might indeed be highly confident that it is correct, even before checking it. When calculating the number of earth-like planets, however, no precise target number is matched — FNC and SIA just say that bigger is better, up to whatever limit is imposed by other observations.

Accordingly, even if you accept that the number of earth-like planets with human-like observers must be large, there is no necessity that this number be large *for this particular reason.* There may be many ways that the probability of your existing could be increased other than by increasing the number of earth-like planets — for instance, by a higher chance of life developing on each planet, or a higher chance that once life develops it produces an intelligent species. If there were no upper limit, FNC or SIA would just favour all of these, but if there is a limit on the density of intelligent observers, only a limited number of these factors can strongly favour more human-like observers, reducing the probability that any one of them in particular does.

At this point, recall the assumption stated at the beginning of Section 6.1 — that intelligent observers in different star systems have no effect on each other. If this is true, we can have no bound from observation on the density of intelligent observers, and the considerations just discussed will not reduce the excessive certainty of the conclusions from FNC and SIA. However, if there is a limit on the density of observers, FNC (and SIA) need not produce unreasonably certain belief in particular theories, such as that the hypothetical Newtonian calculation above is wrong. We in fact know that intelligent species may possibly interact. The implications of this are discussed in detail in Section 7, and show that the actual effects of FNC are not what what one would think from a simplistic consideration of the Presumptuous Philosopher problem.

6.3 Theories differing in the size of the universe

I will now consider the effect that FNC has on the probabilities of theories that differ in the size of universe that they predict. The effects of applying SSA+SIA are similar, but I will omit the details of this here. As above, I will assume that all theories predict a universe of a finite size, which moreover is not so large that you would expect another observer with exactly your memories to exist. I will also assume that all theories predict a homogeneous universe, in which intelligent observers arise with some density. In practice, different theories might well predict both different sizes of the universe and different densities of observers, but for simplicity, I will assume here that all theories predict the same density, so that the total number of observers is simply proportional to the size of the universe.

With these assumptions, a Presumptuous Philosopher effect can easily arise. Suppose theory A says that the universe contains 10^{24} galaxies, whereas theory B says that it contains only 10^{12} galaxies. If these theories appear equally likely on ordinary grounds, application of FNC will lead you to consider theory A to be a trillion times more likely than theory B, since it is a trillion times more likely that someone with your memories will exist somewhere if theory A is true.[8] Note that this implication of FNC holds regardless of any details of where and how often human-like or other intelligent observers might or might not arise — as long as these details are the same for both theories, the theory producing a bigger universe will also produce a greater probability that a being with your memories exists, in direct proportion.[9]

[8]Here "somewhere" could be anywhere in the universe. In Section 6.2, where the large-scale features of the universe could be considered fixed (since the theories did not differ in this regard), I pointed out that someone with your memories could exist only in our galaxy. This is not true in this context, where a galactic neighborhood matching what we see is more likely to exist if the universe is large than if it is small.

[9]Theories in which the universe changes more slowly, and so stays longer in something resembling the state you currently observe, might also be favoured. I will not elaborate on this possibility, however, but merely assume that the universe evolves at the same rate in all theories.

This factor of a trillion preference for theory A seems unreasonable to most people. FNC will produce even greater degrees of certainty in favour of theories predicting even bigger universes, up to odds of $10^{30000000000}$ or more, before the assumption of no duplicate observers breaks down (see Section 5). Unlike the situation with theories differing in the density of observers, there seems to be no plausible story involving companion observers that would provide any support for this result of FNC — if the star-being companions of Section 6.1 employ FNC in this situation, they will come to the same extreme conclusion, but will also be subject to the same intuition that this is unreasonable.

Olum (2002) offers a way of avoiding the extreme preference for larger universes produced by FNC (or in his case, SIA) — reduce the prior probability of theories in proportion to the size of universe they predict. In the example above, if we assign theory A a prior probability a trillion times less than that assigned to theory B, then after the multiplication by a factor of a trillion that comes from applying FNC, the final odds in favour of theory A will be 1 (ie, A and B will be considered equally likely). This seems rather contrived, but it does raise a crucial question — how should prior probabilities for cosmological theories be assigned?

For many theories, we can assign well-justified prior probabilities based on a wealth of background knowledge. Consider, for example, theories regarding where eels spawn. We can assess their prior plausibility using our knowledge of the behaviour of other fish, as well as our knowledge of related matters, such as ocean currents. In other situations, our prior beliefs will have a less detailed basis, but will at least incorporate various common-sense constraints. The background knowledge we use to set priors will itself be based partly on deeper prior beliefs. If we could trace the origins of our beliefs back far enough, we would presumably find some genetically-determined prior biases, that result from natural selection. When assessing theories of biology, geology, macroscopic physics, or other earth-bound phenomena, knowing that our prior beliefs have this ultimate origin is reassuring — it gives us some reason to think these prior biases are well founded.

It is difficult to see, however, why natural selection should have provided us with genetically-determined biases suitable for assigning prior probabilities to cosmological theories. Suppose, for example, that the crucial difference between theories A and B above is that A says space is flat, with the topology of a torus, whereas B says space is positively curved, with the topology of a sphere. (Assume that for some theoretical reason not in dispute, the torus must have a trillion times the volume of the sphere.) Canceling the effect of FNC by deciding that the spherical universe should have prior probability a trillion times greater than the toroidal universe seems quite arbitrary, but deciding that they should have equal prior probabilities is really just as arbitrary. We simply have no basis for any prior beliefs regarding the topology of the universe.

A further difficulty is that we have no firm basis for excluding "extraneous" multiple universes. Suppose the advocates of theory B above modify it to produce theory B^*, which is just like B, except that rather than postulating the existence of only the single universe we observe, it claims that there are a trillion similar universes, which differ only in the actual results of random physical processes.[10] The probability of someone with your memories existing in any of these universes is now the same as for theory A. This maneuver may appear unaesthetic, at least if

[10] Of course, this will not work if theory B is deterministic, but there will likely be "pseudo-random" aspects of any theory, sensitive to slight changes in parameters or initial conditions, that would again allow for a multiplicity of similar, but not identical, universes.

these trillion universes have no possibility of interacting, but compared to the previous situation with odds of a trillion against theory B, lack of elegance is a minor problem.

Is rationally assigning prior probabilities to cosmological theories simply impossible? Perhaps not entirely. Sometimes, the theories being compared all assume the same fundamental physical laws, but represent different calculations of the consequences of these laws. Two theories of galaxy formation, for example, are likely to assume the same laws for gravitation and other forces, and may also assume the same initial conditions from the big bang. If so, the theories can be seen as making different approximations to a single mathematical result, whose exact computation is infeasible. We have some experience with mathematical approximations, and so have some basis for assigning prior probabilities to which (if any) of these theories is correct.

Because of the lack of clarity surrounding these issues, I see no clear grounds for rejecting FNC or SIA on the basis of their supposedly counterintuitive consequences regarding theories with differently-sized universes. Greater clarity might be obtained by considering examples of actual cosmological theories that predict universes of different (finite) sizes, but I am not aware of any such examples. Most current cosmological theories favour a universe, or universes, of infinite size, as I discuss below in Section 8.1.

7 How densely do intelligent species occur?

As a first application of FNC to a real problem, I will consider what it has to say about how densely we should expect intelligent species to occur. This can be seen as a continuation of the discussion regarding the density of observers in Sections 6.1 and 6.2, except that I will now apply FNC in conjunction with our actual empirical knowledge, which does not correspond to the earlier assumption that there is no possibility of intelligent species interacting.

Our knowledge of astronomy and technology leads us to believe that if intelligent extraterrestrials exist, it would probably not be tremendously difficult for them, or at least their robotic probes, to visit earth. (We ourselves are likely to have this capability within at most a few hundred years, unless our technological civilization collapses.) Interstellar travel is likely to be costly, of course, and will certainly require patience, due to the speed of light limit. Many extraterrestrials may decide not to undertake such exploration. But if a large number of extraterrestrial species exist, it seems certain that at least a fair number will explore neighboring stars. Sometimes exploration will be followed by colonization, producing a sphere of habitation that expands at perhaps 1% of the speed of light. In this manner, a single species could reach most of the galaxy in around 10 million years, which is a small fraction of the galaxy's age.

Radio communication with extraterrestrial civilizations is much easier than travel, and is well within our current capabilities (at least if transmissions are directed at a particular star).

Despite this, we do not currently observe any extraterrestrials, nor do we see any evidence that they have been in our vicinity in the past.[11] This conflict with expectations has been called "Fermi's Paradox", and has prompted many attempts at explanation, summarized in a review by Brin (1983). The paradox seems even more severe if you consider FNC (or SIA) to be a correct principle of inference, since it seems there would then be a further bias in favour of a

[11] Readers who believe they have observed extraterrestrials may of course apply FNC themselves, and reach different conclusions than I do here.

high density of intelligent extraterrestrial species (of the sort who "might have" produced an observer with your memories).

The application of FNC to this problem is actually more subtle, however. For someone with your memories to exist, it is necessary not only for a suitable planet to exist, but also for the subsequent evolution of an intelligent species on that planet to proceed without disturbance by other intelligent species. Once someone like you is produced, they must remain unaware of contact with any other intelligent species. There is therefore a tradeoff. If earth-like planets are common, if life arises easily on each planet, if intelligence species are likely to evolve, and to develop a technological civilization, the existence of someone with your memories will be more likely, *provided* there is no interference by some other intelligent species. But these same factors increase the probability that such an interfering species will exist.

A realistic analysis of this situation would be complex, as can be seen from earlier related work on interstellar colonization, such as that of Hanson (1998). I will consider only a fairly simple and abstract model intended to show the general nature of the tradeoff described above. This model has three components.

First, suppose that the mechanisms of galaxy formation are known, and that the pattern of stars in our galaxy is beyond the influence of intelligent life. Someone with your memories, which include your memory of the night sky, can then only have arisen on a planet of our sun, at the current time. Suppose, however, that we have various theories regarding planet formation, the origin of life, the evolution of intelligence, and the development of technological civilization. Any particular combination of theories will produce some (tiny) probability, p, that an individual with your memories will arise, *assuming* that this development is not interfered with by a species from elsewhere. Note that you don't know p, since you don't know which theories are true, though you have prior probabilities for them based on ordinary scientific knowledge. Your priors regarding these theories give rise to a prior distribution for p.

Second, suppose the probability that an intelligent species with our level of science and technology will arise in a region of size dw around spacetime point w is $p\,M(w)\,dw$, where $M(w)$ is a known function giving the relative densities of intelligent species originating at different times and places. $M(w)$ will be zero outside of galaxies, and at times too early for life to have developed. Making the probability of such an intelligent species arising elsewhere be proportional to p incorporates the assumption that the unknown factors that influence the probability of your existence are the same as those that influence the probability of other intelligent species arising.

Third, suppose there is a known function, $A(w)$, and an unknown factor, f, such that $fA(w)dw$ is the probability that a species arising in a region of size dw around spacetime location w will destroy the possibility of someone with your memories existing — either by colonizing earth and thereby preventing the development of humans, or by simply making its existence known to you before the present time, contrary to your actual memories. Assuming influences are limited by the speed of light, $A(w)$ will be zero if w is outside your past light-cone. The factor f will depend on how stable technological civilizations are, how easy interstellar travel is, and how often intelligent species are motivated to communicate, explore, and colonize. Assume you have prior distributions for these factors, and hence also for f.

We can now write the expected number of other species that interfere with your existence as follows:

$$\int f A(w)\, p\, M(w)\, dw \;=\; fp \int A(w) M(w)\, dw \;=\; fpV \tag{26}$$

where $V = \int A(w)M(w)\,dw$. Suppose that either fpV is small (of order 1 or less), or any interference from distant spacetime points is largely independent, so that the distribution of the number of interfering species will be approximately Poisson. The probability that no species interferes will then be $\exp(-fpV)$, and hence the probability that someone with your memories exists will be

$$P(\text{someone like you exists}) \;=\; p \exp(-fpV) \tag{27}$$

This is maximized when $p = 1\,/\,fV$, corresponding to $fpV = 1$. Thus we see that although FNC favours as large a value of p as possible when there are no interactions between species, this is not true when interactions such as those modeled here exist, thereby justifying the comments at the end of Section 6.2.

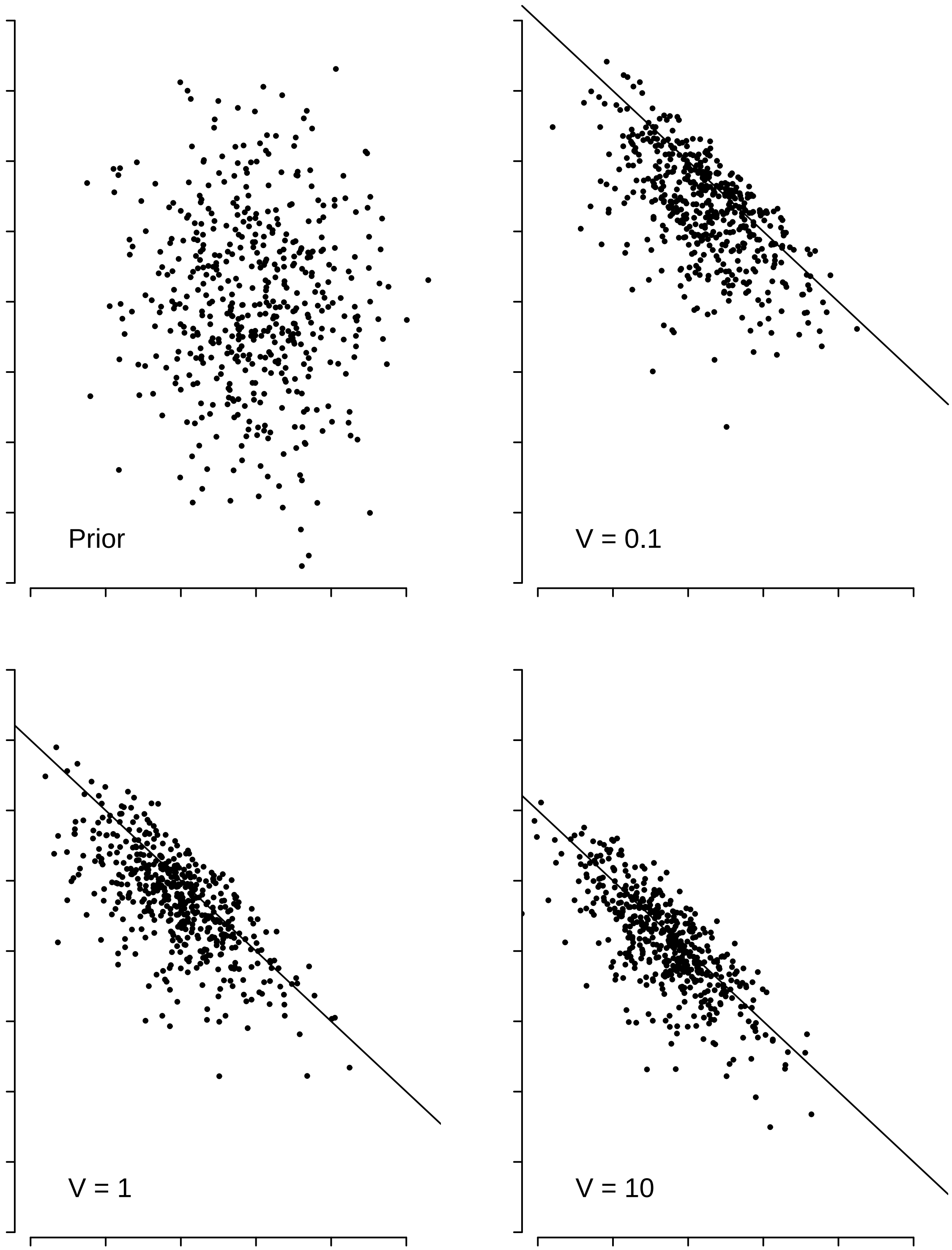
The Fermi Paradox now seems unsurprising. If the expected number of other intelligent species to influence earth, which is equal to fpV, is around one, we should not be especially surprised that we have not seen evidence of any other species. We still have no specific explanation of what factors are responsible for this, however. In the other direction, discovery of another intelligent species would also not be surprising, especially if we looked somewhat more widely than the region where a species would have influenced us without effort on our part.

Further analysis requires some assumptions about your uncertainty regarding p and f. If many unknown factors affect p and f, in a multiplicative fashion, it may be reasonable (due to the Central Limit Theorem) to suppose that $\log(p)$ and $\log(f)$ have Gaussian prior distributions. It is also plausible that p and f are independent, *a priori*.

Multiplying this prior density for $\log(p)$ and $\log(f)$ by the probability that you exist for given values of p and f, from equation (27), and renormalizing, gives the posterior joint probability density for $\log(p)$ and $\log(f)$. This density is not analytically tractable, but is easily displayed graphically by means of a sample of points, as shown in the accompanying figure. Note that the numerical magnitude of p depends on exactly how detailed your memories are, and hence is probably not of much interest. The scale of f is arbitrary, since it can be compensated for by a change in the scale of $A(w)$, and hence of V. It is convenient to set the scale of f so that the mean of $\log(p) + \log(f)$ is zero. The parameters of interest are then the value of V and the standard deviations of $\log(p)$ and $\log(f)$. The top-left plot shows a sample of 500 points from the prior with standard deviation for $\log_{10}(p)$ of 1.25, giving a 95% central interval for p that spans a range of 10^5, and standard deviation for $\log_{10}(f)$ of 0.75, giving a 95% central interval for f that spans a range of 10^3.

The remaining plots in the figure show samples of points from the posterior for $\log(p)$ and $\log(f)$ when V is 0.1, 1, and 10. The lines shown are where $\log_{10}(p) + \log_{10}(f) = -\log_{10}(V)$, indicating for each f the value of p that maximizes the probability that someone with your memories exists.[12] Larger values of V correspond to a greater potential for another species to develop and then interfere with your existence, a potential that is modulated by the same factor, p, that controls the likelihood of your development. Accordingly, larger values of V shift the

[12]Some computational details: The effect of the factor p in equation (27) is to shift the mean of $\log_{10}(p)$ by $1.25^2 \log(10)$, with the distribution remaining Gaussian with the same standard deviation. The remaining factor of $\exp(-fpV)$ is never greater than one, so rejection sampling can be used to obtain the posterior sample.



Plots of prior and posterior distributions for $\log_{10}(f)$ (horizontal axis) and $\log_{10}(p)$ (vertical axis). The top-left plot shows 500 points drawn from the prior described in the text. The top-right plot shows 500 points from the posterior distribution given that someone with your memories exists, assuming $V = 0.1$. The bottom plots show the posterior distributions assuming $V = 1$ and $V = 10$. Tick marks are spaced one unit apart, representing change in f or p by a factor of 10. The diagonal lines indicate where $\log_{10}(f) + \log_{10}(p) = -\log_{10}(V)$.

posterior distribution towards smaller values of p. The posterior distribution of f is also shifted towards smaller values (more so for large V), since smaller values of f reduce the probability that another species will interfere.

We can now determine the effect of FNC on your uncertainty concerning one factor that enters into p. Let us write $p = p_0 p_1$, where p_1 is a single relevant factor, such as the probability that multi-cellular life will evolve from single-celled life, and p_0 is the product of all other factors. Suppose that p_0 and p_1 are independent, and that your prior distribution for $\log_{10}(p_1)$ is Gaussian with mean $\log_{10}(0.1)$ and standard deviation 0.2, giving a 95% central interval for p_1 of 0.041 to 0.247, and a mean for p_1 of 0.111. (Your prior for $\log_{10}(p_0)$ will therefore be Gaussian with standard deviation $\sqrt{1.25^2 - 0.2^2} = 1.234$.) The conditional distribution for $\log_{10}(p_1)$ given $\log_{10}(p)$ is Gaussian with mean given by

$$
\begin{aligned}
&E[\log_{10}(p_1) \mid \log_{10}(p)] \\
&\quad = E[\log_{10}(p_1)] + (\log_{10}(p) - E[\log_{10}(p)]) \operatorname{Var}[\log_{10}(p_1)] / \operatorname{Var}[\log_{10}(p)] && (28) \\
&\quad = \log_{10}(0.1) + (\log_{10}(p) - E[\log_{10}(p)])\, 0.2^2/1.25^2 && (29) \\
&\quad = \log_{10}(0.1) + 0.0256\, (\log_{10}(p) - E[\log_{10}(p)]) && (30)
\end{aligned}
$$

and variance given by

$$
\begin{aligned}
\operatorname{Var}[\log_{10}(p_1) \mid \log_{10}(p)] &= \operatorname{Var}[\log_{10}(p_1)]\, (1 - \operatorname{Var}[\log_{10}(p_1)] / \operatorname{Var}[\log_{10}(p)]) && (31) \\
&= 0.2^2\, (1 - 0.2^2/1.25^2) = 0.0390 && (32)
\end{aligned}
$$

To find the posterior mean of $\log_{10}(p_1)$ given that someone with your memories exists, we take the mean of (30) with respect to the posterior distribution of $\log_{10}(p)$. The posterior variance of $\log_{10}(p_1)$ is the sum of (32) and the variance of (30) with respect to the posterior distribution of $\log_{10}(p)$.

If $V = 0$, so other intelligent species have no effect on earth, the result of this computation is that the posterior mean and standard deviation of $\log_{10}(p_1)$ are $\log_{10}(0.1236)$ and 0.2, which give a 95% central interval of 0.050 to 0.305, and a posterior mean for p_1 of 0.137. When $V = 0$, the posterior distribution of $\log_{10}(p_1)$ is Gaussian, and is the same as would be obtained if p_1 were the only uncertain factor. There is a significant "Presumptuous Philosopher" effect from applying FNC, although it is not as large in magnitude as some previous examples.

In contrast, the effect of FNC on the distribution of p_1 is much less when V is of significant size, even though, as can be seen in the plots, the posterior distribution of p itself is quite different from the prior. The posterior mean and standard deviation of $\log_{10}(p_1)$ are $\log_{10}(0.1080)$ and 0.1985 when $V = 0.1$, $\log_{10}(0.1042)$ and 0.1984 when $V = 1$, and $\log_{10}(0.1003)$ and 0.1984 when $V = 10$. The posterior means of p_1 for these values of V are 0.120, 0.116, and 0.111. The last is nearly identical to the prior mean of p_1, so there is almost no "Presumptuous Philosopher" effect on inference regarding this single factor of p when $V = 10$. With larger values of V, it is possible for the posterior mean of p_1 to be less than the prior mean.

When $V = 0$, the posterior distribution of f is the same as the prior, but with larger V, the posterior favours smaller values for f, as can be seen in the plots. We can look at a single factor entering into f, just as we did for p. If we write $f = f_0 f_1$, we can proceed much as above. Suppose the prior for $\log_{10}(f_1)$ is Gaussian with mean $\log_{10}(0.1)$ and standard deviation 0.2, giving a prior mean for f_1 of 0.111. The posterior mean of f_1 is 0.111, 0.097, 0.093, and 0.089 for $V = 0$, $V = 0.1$, $V = 1$, and $V = 10$. A substantial change occurs when you condition on someone with your memories existing, with the effect increasing as V increases.

This is disturbing, since many of the factors contributing to f — such as the probability of a technological civilization avoiding self-destruction, and the probability that interstellar travel is feasible — are also relevant to human prospects, with larger values being more favourable. (However, some other factors going into f, such as the probability that an intelligent species will decide to destroy the potential habitat of another intelligent species, are ones that many of us would not wish to be large.) There is thus a "doomsday" aspect to this analysis, since use of FNC has revealed that we should increase the probability we assign to some negative scenarios, above the probability we would assign based on ordinary considerations. The source of this pessimism is quite different from that of the Doomsday Argument of Section 4, however. It is based on the empirical observation that we are not aware of any other intelligent species. One possible explanation of this observation is that most intelligent species are destroyed in some fashion, or at least fail to develop in a way that would make their presence known to us. This is a reason to increase our assessment of the probability of this happening to us.

The magnitude of pessimism that this argument warrants depends on our beliefs regarding a wide range of topics in physics, astronomy, biology, and sociology. In contrast, the Doomsday Argument depends only on the size of the future human population in different scenarios, and can produce very large probabilities of "doom" if the alternative is a future involving interstellar colonization, or even just intensive settlement of the solar system. Arguments based on FNC are unlikely to produce such extreme pessimism.

8 Anthropic arguments in cosmology

I will conclude by discussing how FNC relates to cosmology, where anthropic arguments have recently become prominent, particularly in connection with "multiverse" theories and the "landscape" of physical laws arising from string theory.

As in other discussions of anthropic reasoning, papers discussing cosomology often fail to clearly state the basis for the reasoning employed. One suspects that often the reasoning would be recognized as invalid if its basis were clearly stated. For example, in explaining his "top down" approach to cosmology, Hawking (2003) says, concerning the dimensionality of space-time:

> ...most physicists are very reluctant to appeal to the anthropic principle. They would rather believe that there is some mechanism that causes all but four of the dimensions to compactify spontaneously... I'm sorry to disappoint these hopes... We live in a universe that appears four dimensional, so we are interested only in amplitudes for surfaces with three large dimensions. This may sound like the anthropic principle argument that the reason we observe the universe to be four dimensional, is that life is possible only in four dimensions. But the argument here is different, because it doesn't depend on whether four dimensions, is the only arena for life. Rather it is that the probability distribution over dimensions is irrelevant, because we have already measured that we are in four dimensions.

The principle necessary to justify this reasoning appears to be the exact opposite of FNC — that one should base inferences on probabilities that are conditional on *none* of the observed information. This is, of course, ridiculous. No one would say, for instance, that "we have already measured the melting point of copper", so a a theory that tries to predict the melting point of copper is pointless, being no better than a theory that says melting points of metals are random.

One of the problems with anthropic reasoning is that clarifying its exact meaning seems very difficult. Nevertheless, I will assume in this section that anthropic reasoning is something like SSA−SIA, with a reference class of something like "all intelligent observers", even though this class is unavoidably vague.

8.1 Inflation and infinite universes

Cosmological theories in which an early period of "inflation" greatly expands the universe imply that the universe we are in is infinite in size.[13] Furthermore, in most such cosmologies, our universe is only one of many within a larger "multiverse". Finally, these theories do not produce any tight linkage between distant parts of the universe, which might constrain them either to be similar in detail, or different. It follows that in an inflationary universe we should expect all possible observers to exist, each an infinite number of times. In particular, there should be an infinite number of distant observers with exactly your current memories.

This is a problem for FNC. If you accept inflationary cosmology as correct, someone with your memories exists with probability one, regardless of what else might be true. Conditioning on the existence of someone with your memories will then have no effect on the probabilities of any other theories. In particular, FNC no longer provides a solution to the Freak Observers problem (Section 5).

However, an infinite universe leads to many other problems as well. For example, Knobe, Olum, and Vilenkin (2006) discuss the ethical implications of an infinite universe. These and other issues with infinities do not seem at all clear to me. As an interim solution, I advocate simply *ignoring* the problem of infinity, which is certainly what everyone does in everyday life.

Though some readers may see this as a cowardly "head in the sand" approach, I see it as a simple acknowledgement of the limitations of current understanding. This approach has numerous successful historical parallels, such as the long-term (and continuing) fruitful application of Maxwell's equations of electrodynamics, despite the fact that they completely fail to explain how the hydrogen atom can possibly exist. It is typical that although such incomplete theories are ultimately replaced by more general theories, the conclusions obtained using an incomplete theory for problems within its domain remain correct.

One justification for seeing the problems FNC has with infinity as ignorable (for the moment) is that an extraordinarily large univese is necessary to cause problems for FNC. As discussed in Section 5, for duplicate observers to exist, the universe must be a huge number of orders of magnitude greater than the portion of the universe we presently observe. Can the difference between an unimaginably vast universe and one that is truly infinite actually be crucial to our inferences regarding local matters, which concern only the small region within a few tens of billions of light years of us?

Conceivably, the answer is yes. But it seems more likely to me that either the infinity will

[13] At least according to Knobe, Olum, and Vilenkin (2006), though Olum (2004) says models of finite inflationary universes can be contrived.

disappear once the theory is better understood, or it will turn out that its implications, at least for the questions dealt with here, are not great. The situation is analogous to thought experiments with extreme assumptions, where (as discussed in Section 2.5) there is a danger that our reasoning will implicitly use premises that are not true given these extreme assumptions. The difference, of course, is that the extreme assumption in this case concerns reality, and may ultimately prove unavoidable. But it seems best to try to avoid it at least initially.

Some technical matters also support the strategy of ignoring infinity. First, even if the universe we are in is infinite, our knowledge of it is certainly not infinite, since distant parts of the universe are outside our past light-cone, due to the universe's finite age. This is fortunate, since if we were subjected to non-negligible influences from every part of an infinite universe, our experience would be a incomprehensible jumble. (This is just a more general form of Olbers' Paradox — that if the universe is infinite, the night sky should be white.) Should the infinite regions with which we have had no contact really count as part of "our" universe? One might argue that they should, on the grounds the we might be in contact with them in the future. Whether this is so depends on details of the universe's expansion, but let's suppose that any two regions of the universe, even very distant ones, will eventually come into contact. Who will receive information from such distant regions? You will likely be dead, but suppose instead that you have achieved immortality. If you are actually attending to news from increasingly distant regions, you must be expanding your memory. But any increase in your memory results in a huge increase in the size of universe needed for a duplicate observer with your exact memories to exist. So it is difficult to imagine any scenario in which the existence of duplicate observers has observational consequences.

It is therefore not surprising that the puzzle presented by Olum (2004) as arising from inflationary cosmology is not really dependent on the universe being infinite.[14] Olum considers the probability that an intelligent species will colonizing its galaxy (or even many galaxies), and thereby achieve an enormous population (eg, 10^{19} individuals), and concludes that the probability of a species doing this, while perhaps substantially less than one, is not minuscule. Accordingly, one would expect most intelligent observers to belong to such a galactic civilization. Yet we don't. Olum sees this as a conflict between observation and "anthropic reasoning", by which he apparently means SSA−SIA.[15] If you consider yourself to be a randomly selected observer, as advocated by SSA, you should very likely be either a member of some other species that has colonized their galaxy, or be a human from later in our history, when we have done so.

Although Olum doesn't present it as such, this is essentially the Doomsday Argument (applied in the context of many species, as in Section 4.4), except that Olum is sufficiently confident that doom is not nearly universal that he regards the result of the argument as a paradox rather than a prediction. Trying to resolve the paradox, he considers the possibility that "anthropic reasoning" (SSA−SIA) is invalid, along with other possibilities (eg, galactic colonization is actually exceedingly difficult). He comes to no definite conclusion, but considers that several of these possibilities might together be sufficient to explain the conflict.

[14] A universe of the size we observe probably suffices. A bigger universe could be necessary if for some reason life is extraordinary rare, but if so, the larger size will not cause problems for FNC, since the probability of duplicate observers will also be lower if life is rare. It is possible that Olum sees an infinite universe as necessary to justify use of SSA, thinking it would then be the only way to avoid the Freak Observers problem.

[15] Previously (Olum 2002), he had advocated SSA+SIA, but he apparently had doubts about SIA at the time of this paper, and more recently (Knobe, Olum, and Vilenkin 2006).

My conclusion is that "anthropic reasoning" — meaning SSA−SIA — is indeed invalid. In contrast, application of FNC produces no paradox. Suppose we know that intelligent species are very rare, and hence seldom interact, so that we can ignore the complexities discussed in Section 7. The probability of an observer such as you existing, as a member of a species that has not colonized the galaxy, is determined by factors influencing the evolution of species up to our stage of development. It is irrelevant what happens to these species later; hence it is irrelevant whether, for example, galactic colonization is easy or hard.[16]

Anthropic reasoning has also been applied to theories in which multiple inflating universes can have different values of fundamental physical parameters, in particular the "cosmological constant", which influences how rapidly the universe expands. The observed value of the cosmological constant is close to, but not exactly, zero. The most well-accepted theories of the cosmological constant provide no apparent reason for it to be as small as it is — it might equally well have any value over a range that is 10^{120} larger than its actual value. However, Weinberg (1987) calculated that only a much narrower range of values around zero will lead to the formation of galaxies, which he considered a prerequisite for life to exist. Since subsequent measurements found a non-zero value in this range, this calculation has been taken to be a successful prediction using the Anthropic Principle. I will critique such reasoning below in connection with anthropic arguments relating to string theory.

8.2 The landscape of string theory

String theory is an attempt to unify Einstein's theory of gravity with the "Standard Model", which describes electromagnetism and the weak and strong nuclear forces. String theorists originally hoped that the requirement of mathematical consistency would produce a unique theory, which would predict the previously unexplained parameters of the Standard Model, such as the masses of elementary particles. Though this possibility has not been definitely ruled out, many string theorists now think it more likely that hundreds of parameters of the theory can be varied while retaining consistency. This results in a huge "landscape" of possible physical laws, with perhaps 10^{500} or more possibilities, each of which produces different values for the parameters of the Standard Model, and for the cosmological constant. The universe sits in a "valley" in this landscape, to which it "descended" during its inflationary period. If a huge number of inflating universes formed, or if, following the Many Worlds interpretation of quantum mechanics, a single universe has a huge number of superposed versions, almost all valleys of the landscape will be populated by one or more universes. The landscape will then describe not just a set of mathematical possibilities, but an actual multitude of real universes.

This view of string theory and cosmology has been advocated by Susskind (2003, 2006), who then uses it as a basis for anthropic reasoning. In his view, the particular values of the physical parameters we observe, and indeed, even the set of particles we see, cannot be explained by the requirements of any fundamental theory, but they can be explained (at least partially) by the requirement that the universe contain intelligent observers such as ourselves, since otherwise there would be no one to look for an explanation. In other words, we measure the values of

[16] Two explanations considered by Olum are not irrelevant: We are part of a galactic civilization without being aware of it, or (perhaps a special case of this) we don't actually live on earth, but rather exist in a computer simulation. Both possibilities could increase the probability of someone with your memories existing, and hence might be favoured by FNC.

the physical constants that we do because only these values (or similar values) allow for the existence of someone to measure them.

Unfortunately, Susskind is not too clear on the exact purpose of this reasoning, or its justification. Before attempting to critique his views, I will try to clarify the issues by discussing what one might conclude by applying FNC.

As discussed in Section 8.1, infinite universes pose a problem for FNC. Accordingly, I will suppose that the landscape is populated by only around 10^{600} universes (more than enough to guarantee at least one in each of 10^{500} valleys) and that each universe has at most 10^{350} galaxies (much more than the 10^{11} we can observe in our universe). If each galaxy has 10^{10} inhabited planets, each of which has a generous 10^{20} inhabitants, who are replaced by equal numbers for 10^{20} generations, the total number of intelligent observers in all universes who ever exist will be at most 10^{1000}. As discussed in Section 5, this is far too few for there to be any non-negligible chance of another observer with your exact memories existing.

In this scenario, we can apply FNC without difficulty. Conceivably, the answers we obtain might not be correct if in reality there are an infinite number of universes of truly infinite extent. However, in none of the anthropic arguments concerning the landscape that I am aware of does such a distinction between unimaginably vast and truly infinite universes play any apparent role. If infinity is actually crucial, those advancing these anthropic arguments need to make the reason for this more explicit.

Consider two cosmological theories, in both of which there are 10^{600} universes formed by inflation. In theory L, these universes populate a huge number of valleys in a landscape of possible physical laws, as described above. In theory S, there is either no landscape, perhaps because the requirement of mathematical consistency uniquely determines physical laws, or the landscape has only a single valley, which has much the same effect once inflation is over. If string theory is accepted as the correct foundation of physics, and its basic principles are not in dispute, whether L or S is the correct theory may be a mathematical question, whose answer we are ignorant of only because of the difficulty of performing the necessary calculations. Alternatively, L and S may have different foundations, even though they both lead to similar collections of inflating universes. In either case, suppose that, on mathematical and physical grounds, you judge the two theories to be equally plausible. What should you judge the probabilities of these theories to be after applying FNC, conditioning on all your memories, both of everyday life, and of the results of whatever scientific measurements have been performed (but excluding those experiences that are the basis for your judgement that L and S have equal "prior" probabilities)?

We can distinguish two situations. First, suppose that the unique parameters underlying theory S are known, and that at least some of the implications of these fundamental parameters for the parameters of the Standard Model and for the value of the cosmological constant have been worked out. I'll refer to this version of theory S as theory S_1. If the implications of theory S_1 contradict experimental measurements, we can clearly rule out S_1, and conclude that theory L is true (assuming that these are the only alternatives). Note that "measurement" includes general observations, such as the existence of galaxies, which may rule out certain values for parameters of the Standard Model or for the cosmological constant. Alternatively, the fundamental parameters of theory S_1 may produced parameters for the Standard Model and cosmological constant that lie within the region, Y, that so far as you know is compatible with observation. The probability that someone with your memories will exist according to theory

S_1 will then be equal to 10^{600} times the probability that a universe with parameters in Y will produce an observer with your memories.[17] On the other hand, the probability that someone exists with your memories under theory L will be equal to 10^{600} times the fraction of valleys in the landscape that produce parameters in region Y times the probability that a universe with parameters in Y will produce an observer with your memories. The odds in favour of theory L will therefore be equal to the fraction of valleys in the landscape that produce parameters in Y.[18] The landscape of string theory is typically seen as containing valleys with a great diversity of physical laws, so the odds in favour of L in this scenario would be tiny — ie, theory S_1 would be very strongly favoured.

In the second situation, the fundamental parameters for theory S are unknown. Perhaps, for example, it has been proved that the structure of theory S (but not theory L) must lead to a unique set of parameters, but their actual values are not known, though mathematical intuition allows one to give them some broad prior distribution. Or theory S might just baldly state that the universes that exist have only a single set of parameter values, but these values are arbitrary, with some broad prior distribution. I'll use S_* to refer to a theory S of this type. In this situation, the probability that someone with your memories exists under S_* is equal to 10^{600} times the prior probability of region Y times the probability that someone with your memories will exist in a universe whose parameters are in Y. The odds in favour of theory L will be equal to the fraction of valleys that produce parameters in Y according to L divided by the prior probability of Y according to S. If the distribution of parameters of valleys in L is similar in breadth to the prior for parameters in S_*, these odds will be roughly one — ie, neither theory will be favoured, since neither gives any very specific predictions.

In these arguments, a crucial role is played by the region Y, which encompasses values of the parameters of the Standard Model and of the cosmological constant that are not ruled out by your memories (including your memories of scientific measurements). In contrast, it is irrelevant what region of parameters is compatible with life, or with intelligent life, or with intelligent life that has developed a scientific culture. These regions would likely be much bigger than Y, since there is no apparent reason why, for instance, life couldn't develop in a universe with only half as many galaxies as we see.

These applications of FNC accord with usual scientific reasoning. If theory S makes specific predictions, and these are compatible with what is observed, it is favoured over theory L, since L makes no specific predictions. If theory S also makes no specific predictions, either because it has not been sufficiently worked out, or because it has arbitrary parameters, then neither S nor L are favoured.

How is this different from "anthropic" reasoning? The crucial point seems to be that theory S_1, whose parameters are known, and match observations, implies that 10^{600} universes much like ours exist. In contrast, theory L implies that far fewer universes like ours, or even compatible with life, will exist. (Though it is assumed that theory L implies the existence of at least one universe with intelligent life.) If one applied SSA+SIA, the prior probability of theory S_1 would be greatly boosted compared to that of theory L, and the result would be the same as applying

[17] This probability is (at least roughly) the same for all universes with parameters in Y, since Y is defined to be the region of parameters that can't be ruled out based on your memories.

[18] It's possible that theory L defines some non-uniform measure over valleys, in which case the odds would be the total measure for valleys in region Y divided by the total measure for all valleys. This elaboration does not affect the basic argument.

FNC. But if one instead applies SSA−SIA, there is no boost for theory S_1. The crux of the "anthropic" argument seems to be that one should not penalize theory L for predicting that only a few habitable universes exist, as long as it predicts at least one, since we will naturally find ourselves in a habitable universe, even if they are rare. As a result, the degree to which theory S_1 is favoured over theory L is much reduced.

A numerical example may clarify the situation. Suppose that the landscape of theory L has 10^{500} valleys, whereas theory S_1 has only one valley, whose properties are known. The single valley of theory S_1 is compatible with intelligent life, and furthermore, with your specific memories. Of the 10^{500} valleys of theory L, 10^{10} are compatible with intelligent life, and 10^6 of these are compatible with your specific memories. For simplicity, let's assume that all universes with intelligent life have the same population. Application of FNC then gives odds of $10^6/10^{500} = 10^{-494}$ for theory L, but the anthropic reasoning described above, based on SSA−SIA, gives odds of $10^6/10^{10} = 10^{-4}$ for L. So whereas L is essentially disproved if FNC is used, it retains a non-negligible probability under SSA−SIA. This result may seem reasonable if you take an anthropic view, but note the disturbing sensitivity of the odds for L to the definition of "intelligent life", and the need to determine whether such life exists in every one of 10^{500} universes with different physical laws before a conclusion can be reached.

This situation resembles that discussed in Sections 6.1 and 6.2, where Marochnik's theory and other theories in which the density of observers vary were considered. I argued there that the results of FNC and SSA+SIA are correct using the device of companion observers. In the context of inflationary cosmology, the "companions" would need to exist in every universe, regardless of whether it is hospitable to us, even though the physical laws differ radically from universe to universe. Suppose there are a great many such observers in every universe (albeit unobserved by us, so far), and that they know that observers like them exist in every universe. They will take the existence of humans in this universe as evidence that many universes have physical laws that allow beings like humans to exist. Why should we think differently? One might well wonder whether this scenario is stretching the concept of companion observers too far, but I see no specific reason for thinking that these conclusions are inappropriate.

Susskind does not discuss anthropic reasoning in terms of probabilistic principles such as SSA−SIA, nor in reference to any explicit comparison of theories. Instead, his focus seems to be on finding an *explanation* for our universe's physical laws. In his book, *The Cosmic Landscape*, he describes how he came to accept use of the Anthropic Principle, beginning with an account of the many "coincidences" that seem necessary for life to exist:

> There are multiple ways that things could go wrong with the nuclear cooking [of heavy elements]. ... But again, it would do no good for the nuclear physics to be "just right" if the universe had no stars. ... How then did the universe get to have such a large preponderance of matter over antimatter? ... Another essential requirement for life is that gravity be extremely weak. ...
>
> Just how seriously should we take this collection of lucky coincidences? Do they really make a strong case for some kind of Anthropic Principle? My own feeling is that they are very impressive, but no so impressive that they would have pushed me past the tipping point to embrace an anthropic explanation. ... accidents, after all, do happen.
>
> However, the smallness of the cosmological constant is another matter. To make

> the first 119 decimal places of the vacuum energy zero is most certainly no accident. But it was not just that the cosmological constant was very small. Had it been even smaller than it is, had it continued to be zero to the current level of accuracy, one could have gone on believing that some unknown mathematical principle would make it exactly zero. ...
>
> But even the cosmological constant would not have been enough to tip the balance for me. For me the tipping point came with the discovery of the huge Landscape that String Theory appears to be forcing on us. (Susskind 2006, pp. 182-185)

I will discuss the cosmological constant in more detail below, but for now let us count it as just one more "lucky coincidence". The last point above seems crucial. He expands on it later:

> ... in my own mind, the "straw that broke the camel's back" was the realization that String Theory was moving in what seemed to be a perverse direction. Instead of zeroing in on a single, unique system of physical laws, it was yielding an ever-expanding collection of Rube Goldberg concoctions. I felt that the goal of a single unique string world was an ever-receding mirage and that the theorists looking for such a unique world were on a doomed mission. (Susskind 2006, p. 199)

In terms of theories of type S and L discussed above, it appears that Susskind initially saw string theory as a theory S_*, for which it was believed (though not proven) that the fundamental parameters of the theory were unique, even though they were unknown. If he had thought to compare it to another plausible theory L (obviously based on some different structure), and had applied FNC, he would have concluded that the two theories were about equally likely, since at that point neither could make specific predictions. Of course, he would have hoped to find the unknown unique parameters of S, and he would have hoped that the predictions of theory S with these parameters matched observations. If both hopes had been fulfilled, application of FNC would have produced the conclusion that this theory (now of type S_1) was vastly more probable than theory L. Perhaps these applications of FNC approximate the logic Susskind employed at that time.

After abandoning the quest for a unique set of physical laws, accepting instead a landscape of possible laws, populated by multiple universes, Susskind appears to have been concerned with only one competing theory — that the particular laws we see were chosen by an Intelligent Designer, with the purpose of creating a universe containing life. It is this alternative that his anthropic arguments appear aimed at refuting, or at least rendering unnecessary. In his book, which is subtitled "The Illusion of Intelligent Design", he writes:

> To Victor's [a friend's] question, "Was it not God's infinite kindness and love that permitted our existence?" I would have to answer with Laplace's reply to Napoléon: "I have no need of this hypothesis." *The Cosmic Landscape* is my answer... (Susskind 2006, p. 15)

Obtaining this answer doesn't require anthropic reasoning, however. Intelligent Design can be seen as a theory S_* in which all universes operate by a single set of physical laws that are fixed to arbitrarily values by the Designer. Supposing we have some broad prior distribution for the parameters the Designer chose for these physical laws, we find that the theory makes no specific predictions. Application of FNC leads to the conclusion that this theory and theory L are about equally likely. There is "no need" for the hypothesis of an Intelligent Designer.

An advocate of Intelligent Design might, of course, maintain that a broad prior is not appropriate — that the prior should be confined to physical laws that will produce a universe containing intelligent life. I'll call this theory S_D. If you consider S_D and L equally likely *a priori*, FNC will lead you to conclude that theory S_D is much more probable than theory L — extending the numerical example above, theory S_D will predict that the universe has one of the 10^{10} sets of laws that are compatible with intelligent life, of which 10^6 are compatible with your observations, so the odds in favour of L will be $(10^6/10^{500})\,/\,(10^6/10^{10}) \;=\; 10^{-490}$. But why should one think the Designer wished intelligent life to exist, as one must to regard S_D as plausible? Some may think this, but an argument that has as a premise God's infinite kindness and love for humanity is not a scientific argument, and requires no scientific refutation.

Nevertheless, if one wishes a counter-argument, anthropic reasoning may appear to provide one. Applying SSA−SIA will make the theories of the landscape (L) and of an Intelligent Designer who likes intelligent life (S_D) equally likely. Of the 10^{500} valleys in theory L, only the 10^{10} with intelligent life "count" when applying SSA−SIA, so the probability of a universe compatible with what you observe is $10^6/10^{10}$, the same as for theory S_D.

I have argued in this paper that SSA−SIA is not a valid principle of reasoning. If so, one would expect Susskind's approach to produce strange results in other contexts. Consider a comparison of Susskind's theory L, in which there is a landscape of 10^{500} possible physical laws, with a theory S_* that other string theorists may still be working on, in which it is thought that only one of these 10^{500} apparent possibilities is mathematically consistent, though it is not known which of the 10^{500} it is. As discussed above, applying FNC leads to the conclusion that S_* and L are equally likely (if they are equally plausible on other grounds). What is the result of applying SSA−SIA?

SSA−SIA will strongly favour theory L. In the numerical example above, theory L would predict a universe compatible with what you see with probability $10^6/10^{10} \;=\; 10^{-4}$, since of the 10^{10} valleys in the landscape that allow intelligent life, 10^6 are compatible with your observations. The corresponding probability under theory S_* is only $10^6/10^{500} \;=\; 10^{-494}$, so it is very strongly disfavoured, with the odds in favour of L being $10^{-4}/10^{-494} \;=\; 10^{490}$. Another way of looking at this problem is to split theory S_* into theories S^1, S^2, $\ldots$, $S^{10^{500}}$, one for each possible set of physical laws, and split the prior probability of $1/2$ for S_* into prior probabilities of 0.5×10^{-500} for each of these theories. All but 10^6 of these theories are incompatible with your observations. The total posterior probability of all the sub-theories of S_* that are compatible with what you see works out to $10^6\times 0.5\times 10^{-500} \;/\; (10^6\times 0.5\times 10^{-500} \;+\; 0.5\times 10^{-4}) \;\approx\; 10^{-490}$.

This seems unreasonable. Perhaps there are good reasons to think that the old research programme of looking for unique physical laws within string theory has poor prospects, but until it is actually proved hopeless, its chances of success are surely not as low as 10^{-490}. Susskind does not explicitly draw such a pessimistic conclusion, but it seems to follow from the logic of anthropic reasoning that he uses.

Susskind does draw an even more surprising conclusion from the anthropic viewpoint. Discussing the idea that the laws of physics might be an emergent phenomenon, of the sort that is well-known in condensed-matter physics, he writes:

> The properties of emergent systems are not very flexible. There may be an enormous variety of starting points for the microscopic behavior of atoms, but... they tend to lead to a very small number of large-scale endpoints. ... This insensitivity to

> the microscopic starting point is the thing that condensed-matter physicists like best about emergent systems. But the probability that out of the small number of possible fixed points (endpoints) there should be one with the incredibly fine-tuned properties of our anthropic world is negligible. ... A universe based on conventional condensed-matter emergence seems to me to be a dead-end idea. (Susskind 2006, pp. 359-360)

This comment is remarkable. An inflexible theory leading to only a small number of possible sets of physical laws (preferably just one) is what Susskind had originally hoped string theory would be! Yet now he sees such a theory as being almost certainly false, not (just) because of detailed problems with it, but because of the very inflexibility, leading to near uniqueness, that he previously saw as one of the most attractive features of string theory. Moreover, even application of SSA−SIA does not lead to this theory being greatly disfavoured, if the details have not been worked out that would show what the small number of possibilities actually predict. Rather than 10^{500} sub-theories as in the example above, there are only, say, 10 sub-theories, each of which has a substantial portion of the prior probability for the theory as a whole. The low probability Susskind assigns to this theory can only come from his assigning a low *prior* probability to the whole theory, based on a prior belief that physical laws do not have any simple explanation, but are instead a "Rube Goldberg concoction".

Such a belief is, of course, contradicted by numerous scientific success stories, such as the use of quantum mechanics to explain the complex features of atomic spectra. However, some other complex phenomena do seem to have no explanation other than accident — the outlines of the continents, for example, have no fundamental geological explanation. Whether a phenomenon has a simple explanation or not cannot be determined *a priori*. Perhaps a multiplicity of universes with differing physical laws exist; perhaps the set of possible physical laws is much more constrained. One can tell which only by creating and testing theories of both sorts.

Anthropic reasoning has also been criticized by Smolin (2006), who has in addition proposed a third possibility — universes with a great diversity of physical laws can indeed exist, but rather than the physical laws of each universe being chosen at random from some simple distribution, they are chosen according to some dynamical process, which leads to a distribution of universes in which the physical laws we actually observe are much more likely. He proposes a particular theory of "cosmic natural selection", based on the idea that new universes are formed inside black holes, with slightly perturbed physical laws. Selection will then tend to favour physical laws that make a universe produce many black holes. Smolin argues that such a universe will resemble ours.

A successful theory of this sort would be greatly favoured by FNC, in comparison with a theory that distributes universes uniformly over valleys of the landscape, since it would (if successful) greatly increase the probability of a universe similar to ours (in the region Y defined earlier), and hence also the probability that someone with your memories will exist. In contrast, such a theory might not be favoured at all by SSA−SIA. Universes without intelligent life "don't count" with SSA−SIA, so if Smolin's theory (for example) leads to many more universes that contain intelligent life, but fails to further concentrate the distribution towards universes more precisely like ours, it will not be considered more probable by SSA−SIA than a theory in which the physical laws for each universe are drawn from a much broader distribution.

As promised above, I will now consider in more detail the issue of the cosmological constant, which is usually denoted by Λ. As seen from the quote above, Susskind considers the observed small, but non-zero, value for Λ to be the strongest of the "coincidences" that led him to consider anthropic explanations. Two separate aspects of the situation seem responsible for this — the large magnitude of the coincidence, and the special role of the value zero.

The range of values for Λ that are compatible with life (taken to be the range for which galaxies form) is much narrower than the range of values that seem plausible on general theoretical grounds, by a factor of roughly 10^{120}. This ratio of prior range to "anthropic" range (for which life can exist) is substantially greater than for the other parameters of the Standard Model that seem to be "fine-tuned" for life. Someone who accepts the basic anthropic argument (based, so far as I can tell, on SSA−SIA) will naturally be impressed by this. As I argue above, however, application of FNC does not lead one to favour a theory based on the landscape for this reason, so the magnitude of the coincidence is irrelevant.

Does the fact that the observed value of Λ is close to zero, but not exactly zero, modify this conclusion? Consider some other parameter, for which the range of conceivable values is $(0, 1)$ and the range of values compatible with life is $(0.3181, 0.3192)$. The best measurement of this parameter gives the 95% confidence interval $(0.3185, 0.3187)$. Suppose you consider an anthropic explanation for the value of this parameter to be attractive. Someone now advances a plausible theory that the true value is exactly $1/\pi = 0.3183\ldots$, which is somewhat at variance with the measurement, but not hopelessly so. After learning of this theory, should your confidence in an anthropic explanation be greater or less than before? Surely you should be less confident, since it's possible that this new theory provides the true explanation. Certainly you shouldn't be *more* confident in an anthropic explanation now that before.

Analogously, the fact that the anthropic range for the cosmological constant includes the special value zero, which one might imagine could result from some theoretical constraint enforcing cancellation of terms, does *not* make an anthropic explanation more likely, but rather the reverse. This is partly because of the possibility that Λ is indeed exactly zero, even though current observations are somewhat contrary to this. More likely, however, is that some theory might explain why Λ is close to, but not exactly, zero.

Even if no good non-anthropic explanation for Λ being near zero can be found, the anthropic explanation may have its own problem — why is the special value zero contained in the rather narrow anthropic range (about 10^2 wide compared with a prior range of 10^{120})? The anthropic range of Λ is a function of the *other* parameters of the physical laws. Why should these other parameters conspire to make this range contain zero? Perhaps there is some plausible cosmological explanation, valid even when the set of particles is much different from what we observe, but I have not seen the issue discussed.

To summarize, at least the following seem possible explanations for the value of Λ:

1) Λ must be exactly zero, for theoretical reasons.

2) Λ has a specific value that is close to but not equal to zero, for theoretical reasons.

3) Λ has a value that is not completely determined theoretically, but which theory says is likely to be close to zero.

4) Λ takes on various values in different valleys of the landscape. A non-negligible fraction of these values are close to zero, with the others being widely distributed.

5) Λ takes on various values in different valleys of the landscape, with no tendency for these values to be close to zero.

Explanation (1) is viable only if current observations are in error. A theory of the sort required for explanation (2) would seem on general grounds to be conceivable — reasons for something to be zero often can be modified to produced reasons for something to be near zero. Explanations (3) and (4) are not entirely distinct. Smolin's cosmic natural selection theory (Smolin 2006) and a recent cyclic model of the universe due to Steinhardt and Turok (2006) provide explanations of this type. Explanation (5) provides a reason to think that a small value of Λ is possible, but explains why we see such a rare value only if you accept anthropic explanations.

Arguments in favour of an anthropic explanation for the cosmological constant seem to generally dismiss explanations (1) to (4), though Weinberg (2000) remarks that an *a priori* distribution for Λ with a peak near zero would obviate anthropic explanations. If only explanation (5) is considered, however, anthropic reasoning does no actual work, but just makes one feel more comfortable. The real question is whether the Anthropic Principle provides good reason to increase the probability of explanation (5) compared to the others. The effect of applying SSA−SIA, as discussed earlier, is to let a theory predict many lifeless universes (eg, with $\Lambda \gg 0$) without penalty, as long as it predicts at least one universe with intelligent life. In contrast, when FNC is applied, explanation (5) is heavily penalized compared to an otherwise plausible theory that provides an explanation of type (1) to (4). (This assumes that all theories produces a similar collection of universes — if not, we get into the difficult problem (discussed in Section 6.3) of comparing theories that differ in the size or multiplicity of universes.)

My conclusion is that when FNC can be clearly applied, it does not support the type of anthropic reasoning that has been used to "explain" the apparent fine-tuning of physical constants to values necessary for life, via a multitude of universes populating a landscape of physical laws. Such anthropic reasoning appears to be based on SSA−SIA, and shares with it a disturbing sensitivity to the reference class chosen. Moreover, SSA−SIA, in both this application and its applications to the problems discussed previously, can produce counterintuitive conclusions. When the universe is truly infinite, and especially when different theories predict universes of different sizes, some more general version of FNC is needed. However, I see no reason at present to think that my conclusions regarding anthropic reasoning would be invalid in these situations.

None of this says that a cosmology with multiple universes populating a landscape of physical laws cannot be correct. FNC does give a preference to theories of this sort in which the distribution of universes is concentrated on valleys in the landscape that produce the physical laws we see, but perhaps no such theory is viable. Many ordinary phenomena, such as the outlines of the continents and the radii of the orbits of the planets, are believed to have no explanation other than accident. On cannot rule out *a priori* the possibility that the cosmological constant and the parameters of the Standard Model have only this explanation, since this might be the truth. Such an explanation is, however, a "last resort", in that any theory that more specifically predicts the observed values, and is otherwise acceptable, should be greatly preferred.

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References

Bostrom, N. (2002) *Anthropic Bias: Observation Selection Effects in Science and Philosophy*, New York: Routledge.

Bostrom, N. (2006) "Sleeping Beauty and self-location: A hybrid model", preprint available from `http://www.nickbostrom.com`, to appear in *Synthese*.

Bostrom, N. and Ćirković, M. M. (2003) "The doomsday argument and the self-indication assumption: reply to Olum", *The Philosophical Quarterly*, vol. 53, pp. 83-91.

Brin, D. (1983) "The 'Great Silence': The controversy concerning extraterrestrial life", *Quarterly Journal of the Royal Astronomical Society*, vol. 24, pp. 283-309.

Carter, B. (1974) "Large number coincidences and the Anthropic Principle in cosmology", in M. S. Longair (editor), *Confrontation of Cosmological Theories with Data*, Dordrecht: Reidel, pp. 291-298.

Carter, B. (2004) "Anthropic principle in cosmology", available from the e-print archive at `http://arxiv.org/abs/gr-qc/0606117`.

Dyson, L., Kleban, M., and Susskind, L. (2002) "Disturbing implications of a cosmological constant", `http://arxiv.org/abs/hep-th/0208013v3`.

Elga, A. (2000) "Self-locating belief and the Sleeping Beauty problem", *Analysis*, vol. 60, pp. 143-147.

Gott, J. R. (1993) "Implications of the Copernican Principle for our future prospects", *Nature*, vol. 363, pp. 315-319.

Hanson, R. (1998) "Burning the cosmic commons: Evolutionary strategies of interstellar colonization", available from `http://hanson.gmu.edu`.

Hanson, R. (2006) "Uncommon priors require origin disputes", to appear in *Theory and Decision*, available from `http://hanson.gmu.edu`.

Harnad, S. (2001) "What's wrong and right about Searle's Chinese Room Argument?" in: M. Bishop and J. Preston (editors) *Essays on Searle's Chinese Room Argument*, Oxford University Press. Also available at `http://cogprints.org/4023/01/searlbook.htm`.

Hawking, S. (2003) "Cosmology from the top down", `http://arxiv.org/abs/astro-ph/0305562`.

Knobe, J., Olum, K. D., and Vilenkin, A. (2006) "Philosophical implications of inflationary cosmology", *British Journal for the Philosophy of Science*, vol. 57, pp. 47-67.

Lewis, D. (1979) "Attitudes *de dicto* and *de se*", *The Philosophical Review*, Vol. 88, pp. 513-543.

Lewis, D. (2001) "Sleeping Beauty: reply to Elga", *Analysis*, vol. 61, pp. 171-176.

Leslie, J. (1996) *The End of the World: The Science and Ethics of Human Extinction*, London: Routledge.

Marochnik, L. S. (1983) "On the origin of the solar system and the exceptional position of the sun in the galaxy", *Astrophysics and Space Science*, vol. 89, pp. 71-75.

Nozick (1969) "Newcomb's problem and two principles of choice", in N. Rescher (editor) *Essays in Honor of Carl G. Hempel*, Boston: Reidel, pp. 115-146.

Olum, K. D. (2002) "The doomsday argument and the number of possible observers", *The Philosophical Quarterly*, vol. 52, pp. 164-184.

Olum, K. D. (2004) "Conflict between anthropic reasoning and observation", *Analysis*, vol. 64, pp. 1-8.

Smolin, L. (2006) "Scientific alternatives to the anthropic principle" (version 3, May 2006), available from the e-print archive at `http://arxiv.org/abs/hep-th/0407213` (first version posted July 2004).

Steinhardt, P. J. and Turok, N. (2006) "Why the cosmological constant is small and positive", *Science*, vol. 312, pp. 1180-1183.

Susskind, L. (2003) "The anthropic landscape of string theory", available from the e-print archive at `http://arxiv.org/abs/hep-th/0302219`.

Susskind, L. (2006) *The Cosmic Landscape: String Theory and the Illusion of Intelligent Design*, New York: Little, Brown, and Company.

Weinberg, S. (1987) "Anthropic bound on the cosmological constant", *Physical Review Letters*, vol. 59, pp. 2607-2610.

Weinberg, S. (2000) "*A priori* probability distribution of the cosmological constant", *Physical Review D*, vol. 61, 103505 (4 pages).

Whitman, W. B., Coleman, D. C., and Wiebe, W. J. (1998) "Prokaryotes: The unseen majority", *Proceedings of the National Academy of Sciences (USA)*, vol. 95, pp. 6578-6583.