Too Soon for Doom Gloom? *

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Abstract

The observation that we are among the first $10^{11}$ or so humans reduces the prior probability that we find ourselves in a species whose total lifetime number of individuals is much higher, according to arguments of Carter, Leslie, Nielsen, and Gott. However, if we instead start with a prior probability that a history has a total lifetime number which is very large, without assuming that we are in such a history, this more basic probability is not reduced by the observation of how early in history we exist.

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John Leslie [1-16], expanding upon largely unpublished lectures by Brandon Carter [17], has argued that our observed position in history increases, perhaps greatly, the probability that the human race will soon end. Variants of this argument have also been discovered independently by Holgar Nielsen [18] and by J. Richard Gott III [19].

The idea is that if humans were to continue at present or growing populations for more than a few hundred additional years, it would be unlikely for us to have found ourselves in the relatively small fraction alive by now. On the other hand, if the human race were to end today (e.g., at the end of the Mayan 13th b’ak’tun when this paper is being revised), we would not be so unusual, since about 5-10% of all humans are alive today [20-22,19]. This possibility, or any doom within the next few hundred years, does not make it nearly so unlikely for us to find ourselves alive now.

Of course, what we are more interested in is the actual conditional probability (often called a posterior probability) that the human race will end soon, given that we are here, rather than the reverse conditional probability (often called a likelihood) that we are here, given that the human race will end soon. To calculate the former from the latter, we need the prior probabilities that the human race will end at various times in the future (or after various total numbers \(N\) of people may have lived), and then we can apply Bayes’ rule. However, we do not have universally accepted prior probabilities, so we cannot actually calculate universally accepted posterior probabilities.

Without agreeing on the prior probabilities for the various possibilities for the total number \(N\) of humans in an entire human history, one can only use the observation of one’s position \(N_0\) within human history to say how the prior probabilities would need to be adjusted to give the posterior probabilities. For example, suppose the prior probability for an observer to be somewhere in a human race containing a total of \(N\) people throughout its history were \(P(N)\). For simplicity, we shall consider only probabilities conditional upon the existence of a human race, so \(N \geq 1\) and \(P(N)\) is normalized to unity when summed from \(N = 1\) to \(\infty\).

The naïve result of incorporating the observation of the position \(N_0\) of the observer would be the probability of \(N\), given that \(N\) is at least \(N_0\),

\[
P(N|N \geq N_0) = \frac{\theta(N - N_0)P(N)}{\sum_{n=N_0}^{\infty} P(n)}, \tag{1}
\]

where \(\theta(N - N_0)\) is 1 if \(N \geq N_0\) and is 0 otherwise. \(P(N|N \geq N_0)\) is simply the prior probability \(P(N)\) truncated for all impossible situations \(N < N_0\) and renormalized.

However, the point of the doomsday argument is to use the fact that, within the range of the necessary condition \(N \geq N_0\), the larger \(N\) is, the smaller is the likelihood or conditional probability that the observer is the \(N_0\)th person within such a history. Here one adopts the following simplifying hypothesis:
Assumption 1

In a given history of length $N$, the probability is equal for an observer to be in any of the $N$ possible positions (his or her possible birth order in the history, the value of $N_0$). That is, the normalized conditional probability for the observer to have position $N_0$, given the length $N$, is

$$P(N_0 | N) = \frac{\theta(N - N_0)}{N}.$$  

(2)

This is the assumption that the observer’s birth order is purely random in the history. It would follow from the assumption that the observer is a purely random human in the total history of $N$ people, but it is weaker in that it does not require that any of the other characteristics of the observer be random. It is admittedly unrealistic if the observer has special characteristics that are correlated with his or her position. For example, if the observer refers to a person reading this paper (e.g., you), he or she probably has a knowledge of the English language that would make it less likely for him or her to be the first human than to be a much later human. Nevertheless, Leslie’s argument against this type of objection, (IId) in [4], essentially the argument that Carter is right to select an observer by characteristics that are not correlated with birth order, seems plausible, and is perhaps even necessary in order to be able to use anthropic reasoning at all, so we shall hereafter simply accept Assumption 1, except when otherwise stated.

From Assumption 1 it follows that the joint probability that the total history has $N$ total people and that the observer is the $N_0$th one is

$$P(N, N_0) = P(N)P(N_0 | N) = \frac{\theta(N - N_0)P(N)}{N}.$$  

(3)

From this joint probability one can readily compute the marginal probability distribution for $N_0$ alone as

$$P(N_0) = \sum_N P(N, N_0) = \sum_{N=N_0}^{\infty} \frac{P(N)}{N}. $$  

(4)

Then the posterior or conditional probability for $N$, given an observed value of $N_0$, is, by Bayes’ rule,

$$P(N | N_0) = \frac{P(N,N_0)}{P(N_0)} = \frac{\theta(N - N_0)N^{-1}P(N)}{\sum_{n=N_0}^{\infty} n^{-1}P(n)}. $$  

(5)

A comparison with Eq. (1) shows that the true posterior probability $P(N | N_0)$ has the same form as the naïve probability $P(N | N \geq N_0)$, except with $P(N)$ replaced by $N^{-1}P(N)$, or by a normalized

$$\tilde{P}(N) = N^{-1}P(N)\theta(N - 1)/\sum_{n=1}^{\infty} n^{-1}P(n),$$  

(6)
which is weighted toward smaller values of \( N \) than \( P(N) \) is. For example, the naïve expectation value of \( N \), simply given that \( N \geq N_0 \), is

\[
E(N|N \geq N_0) \equiv \sum_N NP(N|N \geq N_0) = \left( \sum_{N=N_0}^{\infty} NP(N) \right) / \left( \sum_{N=N_0}^{\infty} P(N) \right),
\]

(7)

whereas the true posterior expectation value of \( N \), given that one is the \( N_0 \)th person, is

\[
E(N|N_0) \equiv \sum_N NP(N|N_0) = \left( \sum_{N=N_0}^{\infty} P(N) \right) / \left( \sum_{N=N_0}^{\infty} \frac{P(N)}{N} \right).
\]

(8)

Assuming that both of these expectation values are defined and that \( P(N) \) is nonzero for more than one value of \( N \geq N_0 \), one can readily show from the Cauchy-Schwarz inequality that

\[
E(N|N_0) < E(N|N \geq N_0).
\]

(9)

Thus the true posterior expectation value of the total number of humans is lower than the naïve expectation value from the prior probability distribution \( P(N) \) for histories containing the observer.

To illustrate these various quantities, suppose that \( P(N) \) has a power-law dependence on \( N \) for \( N \) between 1 and some integer \( L \), which we shall take to be much larger than \( N_0 \), which we shall also take to be large, as the historical record indicates. (One way to get a power-law probability distribution is to assume that the population grows exponentially with time at one rate until it is suddenly destroyed by a disaster that occur randomly in time at some other expected rate. However, we are simply using a power law for illustrative purposes, without implying that we believe the true distribution has this form.) Then

\[
P(N) = \theta(N - 1)\theta(L - N)N^{-s} / \sum_{n=1}^{L} n^{-s},
\]

(10)

\[
P(N|N \geq N_0) = \theta(N - N_0)\theta(L - N)N^{-s} / \sum_{N=N_0}^{L} N^{-s}
\approx (s - 1)\theta(N - N_0)\theta(L - N)N^{-s}/(N_0^{1-s} - L^{1-s}),
\]

(11)

\[
P(N, N_0) = \theta(N - N_0)\theta(L - N)N^{-s-1} / \sum_{n=1}^{L} n^{-s},
\]

(12)

\[
P(N|N_0) = \theta(N - N_0)\theta(L - N)N^{-s-1} / \sum_{n=N_0}^{L} n^{-s-1}
\approx s\theta(N - N_0)\theta(L - N)N^{-s-1}/(N_0^{-s} - L^{-s}),
\]

(13)
\[
E(N|N \geq N_0) = \left( \sum_{N=N_0}^{L} N^{1-s} \right) / \left( \sum_{N=N_0}^{L} N^{-s} \right) \approx \frac{(s-1)}{s-2} \frac{N_0^{2-s} - L^{2-s}}{N_0^{1-s} - L^{1-s}}, \tag{14}
\]

\[
E(N|N_0) = \left( \sum_{N=N_0}^{L} N^{-s} \right) / \left( \sum_{N=N_0}^{L} N^{-s-1} \right) \approx \frac{s}{s-1} \frac{N_0^{1-s} - L^{1-s}}{N_0^{-s} - L^{-s}}. \tag{15}
\]

For example, if \( s > 2 \), the case in which both of these expectation values are defined even in the limit \( L \to \infty \), they are both of order \( N_0 \) (unless \( s - 2 \) is very small), with the ratio

\[
\frac{E(N|N_0)}{E(N \geq N_0)} \approx 1 - \frac{1}{(s-1)^2}. \tag{16}
\]

This would be the case in which one would expect doom within the next few hundred years, whether one used the naive probability \( P(N \geq N_0) \) or the better posterior probability \( P(N|N_0) \). The latter would only shorten the time to the expected doom by a factor of order unity (again, unless \( s - 2 \) is very small).

If \( 1 < s < 2 \), \( E(N|N_0) \) remains about \( sN_0/(s-1) \), but \( E(N|N \leq N_0) \) is about \( (s-1)N_0^sL^{s-1}/(2-s) \) and hence is much larger for \( L \gg N_0 \). If \( 0 < s < 1 \), \( E(N|N_0) \) is about \( sN_0^sL^{1-s}/(1-s) \), but \( E(N|N \leq N_0) \) is roughly \( (1-s)L/(2-s) \), again much larger. However, if \( s < 0 \), both \( E(N|N_0) \) and \( E(N|N \leq N_0) \) are of order \( L \), with their ratio again being given by Eq. (16). Therefore, for a power-law prior probability distribution \( P(N) \) up to \( L \gg N_0 \), with exponent \(-s\), only for \( 0 \leq s \leq 2 \) is the actual posterior expectation value for \( N \) significantly lower than the naive expectation value. Only for \( s \gtrsim 1 \) is \( E(N|N \leq N_0) \) of order \( N_0 \), but for most of this possible range of \( s \), i.e., for \( s \gtrsim 2 \), the naive estimate \( E(N|N \leq N_0) \) is also of order \( N_0 \). That is, if \( P(N) \) has the power-law form (10) with \( L \gg N_0 \), only for \( 1 \lesssim s \lesssim 2 \) is the doomsday argument needed to conclude that doom is expected to loom soon.

Incidentally, Gott’s analysis [19] initially looks quite defective in avoiding mention of \( P(N) \) altogether and in conflating \( P(N|N_0) \) with \( P(N_0|N) \) [23], but Gott later explained [24] that he was adopting a specific “appropriate vague Bayesian prior” analogous to assuming that \( P(N) \) has the power-law distribution (10) with \( s = 1 \) and with the limit \( L \to \infty \). Although in this limit \( P(N) \) is not normalizable except to zero, Eq. (13) does give a normalizable \( P(N|N_0) \), though one with an infinite expectation value for \( N \). For example, for \( L \) finite but much larger than \( N_0 \), \( E(N|N_0) \approx N_0 \ln (L/N_0) \), which grows indefinitely with \( L \), though at a much slower rate than \( E(N|N \geq N_0) \approx L/ \ln (L/N_0) \).

We are not claiming that such an assumption for \( P(N) \) is necessarily unreasonable, and indeed one can advance some reasons for preferring it if all that is known about \( N \) is that it is positive [24, 25] (though even with that unrealistic assumption it would seem more natural to apply it to the probability distribution \( P_0(N) \) to be defined below, rather than to \( P(N) \)). However, it is not obvious to us that this assumption for \( P(N) \) follows from “only the assumption that you are a random intelligent observer” [19], unless one implicitly defines the latter assumption to mean the former.
Thus if one starts with a prior probability \( P(N) \) for the observer to exist within a human history with a total of \( N \) people, the doomsday argument weights the posterior probability distribution \( P(N|N_0) \) toward lower values of \( N \) than the naïve estimate \( P(N|N \leq N_0) \), but for this to have a significant effect, \( P(N) \) must have a rather restricted form.

However, the main point of the present paper is that instead of starting with the probability \( P(N) \) for a history containing \( N \) people that includes the observer in question, it would be more natural to start with a probability \( P_0(N) \) for a history to contain \( N \) people, without requiring the observer’s existence within it. Certainly \( P_0(N) \) would be more basic and easier to calculate if one could ever get a theory giving the probabilities for various human histories.

Again we shall only consider \( N \geq 1 \) and normalize \( P_0(N) \) over such values. That is, \( P_0(N) \) is actually the conditional probability that a human history has \( N \) people, given the condition that a history of at least one person exists. This is obtained by dropping the possibility of no human history (since this possibility is irrelevant to our present arguments), and renormalizing the remaining probabilities we do consider. Thus we actually use what we might write more precisely as \( p_0(N|N \geq 1) \), but we shall simply call this conditional probability \( P_0(N) \) for short. However, the crucial point is that in \( P_0(N) \), we do not require the condition that the observer in question be included in the history.

(Incidentally, the subscript 0 on \( P_0(N) \) here is intended to give the connotation of a more basic probability distribution than \( P(N) \). It is not intended to have the same connotation as the subscript 0 on \( N_0 \), where it denotes the observer in the history. The latter usage has a roughly similar connotation to the subscript 0 on the \( t_0 \) used in cosmology to denote the present age of the universe, if the observer is taken to be a person at the present point in history, for example, you.)

If one does start with \( P_0(N) \) rather than \( P(N) \), the naïve result of incorporating the observation that the observer is the \( N_0 \)th person would be

\[
P_0(N|N \geq N_0) = \theta(N - N_0)P_0(N)/\sum_{n=N_0}^{\infty} P_0(n).
\]

We would now like to compare this naïve result with the result \( P(N|N_0) \) of using Bayes’ rule and the doomsday argument. Since that procedure led to Eq. (5), we can continue to use it once we calculate \( P(N) \) in terms of \( P_0(N) \).

In the same spirit in which we previously adopted Assumption 1, it is now simplest to assume that for two different histories of equal probability (say with \( N_1 \) and \( N_2 \) people respectively), the observer has an equal probability to be any of the \( N_1 + N_2 \) people in both of these histories. Then even though in this case \( P_0(N_1) = P_0(N_2) \), the probability that the history contains the observer would be proportional to the number of people in the history, \( P(N_1)/P(N_2) = N_1/N_2 \). Extending this reasoning to histories with different existence probabilities \( P_0(N) \) leads to the following hypothesis:
Assumption 2

The probability for the observer to exist somewhere in a history of length \( N \) is proportional to the probability for that history and to the number of people in that history. That is, the normalized probability for a history containing the observer is

\[
P(N) = NP_0(N)/\sum_{n=1}^{\infty}nP_0(n) = NP_0(N)/E_0,
\]

where

\[
E_0 = \sum_{n=1}^{\infty}nP_0(n)
\]

is the prior expected length of a human history, assuming that one of some positive length \( n \geq 1 \) does exist.

(Of course, if the observer’s detailed individual characteristics were considered, such as a knowledge of an estimate for \( N_0 \), the probabilities for one to be at different positions in various histories of equal existence probabilities would not be equal, whether for a single history containing \( N \) people, as discussed above, or whether for two histories, containing \( N_1 \) and \( N_2 \) respectively. Then the doomsday argument would lose its simple applicability, but, as we discussed above for Assumption 1, we shall assume that the characteristics defining the observer are uncorrelated with \( N_0 \) and with \( N \).)

Inserting Eq. (19) into Eq. (3), we find that the joint probability for the history to have length \( N \) and for the individual to be the \( N_0 \)th person in the history is

\[
P(N, N_0) = \theta(N - N_0)P_0(N)/\sum_{n=1}^{\infty}nP_0(n) = \theta(N - N_0)P_0(N)E_0^{-1},
\]

where \( E_0^{-1} \) may be considered as the prior probability for one to be the \( N_0 \)th person in a history at least as long as \( N_0 \), a constant under Assumptions 1 and 2.

Once we use Eq. (20) in Eq. (5), we find that it gives exactly the same result as Eq. (17), the naïve consequence of \( P_0(N) \). That is,

\[
P(N|N_0) = P_0(N|N \geq N_0),
\]

as the weighting toward smaller \( N \) that the doomsday argument provides is precisely canceled by the greater probability of finding the observer within the larger of two sets of people whose prior existence is equally probable. In other words, the doomsday argument has no effect at all if, instead of starting with \( P(N) \), we start with the more natural prior probability \( P_0(N) \) for a history containing \( N \) humans. Incidentally, one can readily see that \( P_0(N) \) is the same as \( \tilde{P}(N) \) defined by Eq. (6).

As a simple analogue to illustrate our main point, consider two north-south roads with \( N_1 \) and \( N_2 \) houses along each respectively, say with \( N_1 \ll N_2 \). If we choose randomly between the two roads, \( P_0(N_1) = P_0(N_2) = 1/2 \). However, if we choose randomly between the \( N_1 + N_2 \) houses, each has a probability \( 1/(N_1 + N_2) \), so the
probability of having the first road along a random house is $P(N_1) = N_1/(N_1 + N_2)$ $\ll P(N_2) = N_2/(N_1 + N_2)$.

Now suppose we observe that the house is the $N_0$th from the north end, with $N_0 \leq N_1 \ll N_2$. Starting from the unequal probabilities $P(N_1)$ and $P(N_2)$, we would get the same two unequal numbers for the na"ıve probabilities $P(N_1 | N_1 \geq N_0)$ and $P(N_2 | N_2 \geq N_0)$, but these are obviously not the true probabilities, since the $N_0$th house from the north end is certainly not a house chosen randomly from the $N_1 + N_2$ houses.

For our example, the analogue of the doomsday argument corrects for this error. The likelihood for a random house to be $N_0$th from the north end is $P(N_0 | N_1) = 1/N_1$ if it is on the first road and $P(N_0 | N_2) = 1/N_2$ if it is on the second. Although $P(N_0 | N_1) \gg P(N_0 | N_2)$, that does not imply $P(N_1 | N_0) \gg P(N_2 | N_0)$ as Gott’s analysis [19] implicitly assumes, but it does combine with $P(N_1)$ and $P(N_2)$ to give equal joint probabilities

$$P(N_1, N_2) = P(N_0 | N_1)P(N_1) = P(N_2, N_0) = P(N_0 | N_2)P(N_2) = 1/(N_1 + N_2) \tag{22}$$

and equal posterior probabilities

$$P(N_1 | N_0) = P(N_2 | N_0) = 1/2. \tag{23}$$

However, these equal posterior probabilities are obviously the same as what Eq. (17) would give directly for $P_0(N_1 | N_1 \geq N_0)$ and $P_0(N_2 | N_2 \geq N_0)$ without having to bother with doomsday-like arguments.

In other words, if the two roads, with their $N_1$ and $N_2$ respective houses, have equal prior probability, these probabilities are not affected by the observation that a house chosen at random from all of the houses is at the $N_0$th position (assuming $N_0 \leq N_1$ and $N_0 \leq N_2$). Each road has an equal number of houses at the $N_0$th position (namely, one), so the observation of this position does not affect the probabilities for the two roads.

As a weaker alternative to Assumptions 1 and 2, one could start with the following hypothesis instead:

**Assumption 3**

The length $N$ of a history and the observer’s position $N_0$ in a history are independent random variables, except for the trivial restriction $1 \leq N_0 \leq N$. That is, the joint probability has the essentially product form

$$P(N, N_0) = P_0(N)p_0(N_0)\theta(N - N_0), \tag{24}$$

where $P_0(N)$ may be considered to be the prior existence probability for a history of length $N$, and where $p_0(N_0)$ (using a lower case $p$ for distinction) may be considered to be the prior probability for the observer to be the $N_0$th person in a history at least as long as $N_0$. 8
A comparison of Eqs. (20) and (24) shows that Assumptions 1 and 2 give the special case $p_0(N_0) = E_0^{-1}$, a constant, so Assumption 3 is indeed more general. However, even it is ultimately unrealistic if one includes any special characteristics in the definition of the observer in question. For example, if that observer is a person who knows of the existence of nuclear weapons of mass destruction, one might reasonably expect that not only does that characteristic makes $p_0(N_0)$ larger for $N_0$ near $10^{11}$, say, than for $N_0$ near unity, but also it might reduce the probability $P(N, N_0)$ for $N \gg N_0$ below what the product form (24) would give, due to the greater probability of the ending of the human history by the weapons known to the observer. Nevertheless, in the same spirit in which we considered Assumptions 1 and 2, we shall consider Assumption 3 here for the sake of argument.

From Eq. (24) one can readily calculate that the marginal distributions for $N$ and $N_0$ are

$$P(N) = P_0(N) \sum_{N_0=1}^{N} p_0(N_0),$$

(25)

$$P(N_0) = p_0(N_0) \sum_{n=N_0}^{\infty} P_0(N).$$

(26)

Therefore, instead of Eq. (2), we get

$$P(N_0|N) = P(N, N_0)/P(N) = p_0(N_0)\theta(N - N_0)/\sum_{n_0}^{N} p_0(N_0).$$

(27)

However, we continue to get Eq. (21), $P(N|N_0) = P_0(N|N \geq N_0)$, so even with the weaker Assumption 3, the doomsday argument is not needed if we start with the $P_0(N)$ in Eq. (24) and its na"ive consequence $P_0(N|N \geq N_0)$ defined by Eq. (17).

This says that we cannot obtain any information about the length $N$ of human history from the knowledge of an observer’s position $N_0$ in history (except for the trivial restriction $N \geq N_0$). This is an obvious consequence of Assumption 3, which says that, except for the trivial restriction, the length and the position are independent.

Of course, the advocate of the doomsday argument can still point out that if one instead started with the marginal distribution $P(N)$ given in Eq. (25), and then used Eq. (1) to define the na"ive $P(N|N \geq N_0)$, that would not be the same as $P(N|N_0)$, and so doomsday arguments would be needed to correct this alternate na"ive result. Because of that fact, we cannot claim to have proved that the doomsday argument is absolutely wrong. We only claim that it is unnecessary if one starts with $P_0(N)$ instead of $P(N)$, and that both as a prior probability and as a component of Eq. (25), $P_0(N)$ appears to be more basic than $P(N)$.

After formulating the present objection against the necessity of using doomsday arguments, we found that Leslie [4, 13] had already discussed it, though he was unconvinced by this objection. He gives one form of the objection as (IIIa) in
[4]: “The larger our race is in its temporal entirety, the more opportunities there are of being born into it. This counterbalances the greater unlikelihood of being born early.” Then he responds, “This seems to me false. We are not here dealing with some ordinary lottery where we would have existed in numbers that remained constant whether or not we had got tickets, so that possessing a ticket could itself readily suggest that many were sold or thrown to the crowd; for it seems wrong to treat ourselves as if we were once immaterial souls harbouring hopes of becoming embodied, hopes that would have been greater, the greater the number of bodies to be created. . . .” However, this objection shifts the doomsday argument from its simple setting towards the question of choosing in a sophisticated way $P(N)$ or $P_0(N)—a separate problem which we shall not discuss here, though one of us may discuss it in a future publication.

We do not say that we believe that human history will necessarily continue long into the future. There are many reasons, such as the history of perished species, overpopulation, dwindling resources, pollution, disease, technological capabilities for destruction, the aggressive nature of humans, and religious revelation, to suggest that human history, at least as we know it, could well end rather soon. For example, if $P_0(N) \propto N^\alpha$ with $\alpha = -s - 1 < -2$, then given one’s position $N_0$, the expected total number of humans, $E(N|N_0)$, is of the same order as $N_0$, and if $\alpha < -1$, most of the total probability is for $N \sim N_0$. We are also not saying that the end of human history as we know it is necessarily best described as a gloomy “doom,” a semantic objection that Carter also has [26] with the name Leslie says Frank Tipler gave to the argument [27], but it was irresistible for us to be able to include four double o’s in our title. However, what we have shown is that the Carter-Leslie-Nielsen-Gott doomsday argument, at the level at which we discuss it, is inconclusive in predicting how soon there may be “doom.”

Our consideration of this topic has been especially motivated by long discussions with John Leslie, for which we are grateful. After our first draft was written, we have benefited from lengthy responses from Brandon Carter, Leslie, and J. R. Gott III, who continue to disagree with us but have not convinced us to abandon our objection to the doomsday argument. We have also benefited from discussions with Geoffrey Hayward, Werner Israel, and others at a CIAR conference in Lake Louise and at the University of Alberta, where some of these ideas have been presented in seminars. This work has been supported in part by the Natural Sciences and Engineering Research Council of Canada. We have also been motivated by the Mayans to submit this paper to a journal on this particular auspicious day.
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