Objective and subjective time
in anthropic reasoning.

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Abstract. The original formulation of the (weak) anthropic principle was prompted by a question about objective time at a macroscopic level, namely the age of the universe when “anthropic” observers such as ourselves would be most likely to emerge. Theoretical interpretation of what one observes requires the theory to indicate what is expected, which will commonly depend on where, and particularly when, the observation can be expected to occur. In response to the question of where and when, the original version of the anthropic principle proposed an it a priori probability weighting proportional to the number of “anthropic” observers present. The present discussion takes up the question of the time unit characterising the biological clock controlling our subjective internal time, using a revised alternative to a line of argument due to Press, who postulated that animal size is limited by the brittleness of bone. On the basis of a static support condition depending on the tensile strength of flesh rather than bone, it is reasoned here that our size should be subject to a limit inversely proportional to the surface gravitation field $g$, which is itself found to be proportional (with a factor given by the $5/2$ power of the fine structure constant) to the gravitational coupling constant. This provides an animal size limit that will in all cases be of the order of a thousandth of the maximum mountain height, which will itself be of the order of a thousandth of the planetary radius. The upshot, via the (strong) anthropic principle, is that the need for brains, and therefore planets, that are large in terms of baryon number may be what explains the weakness of gravity relative to electromagnetism.
1 Introduction: fundamental parameters.

In this interdisciplinary forum for the discussion of various kinds of time, one of the first questions that comes to mind is that of the relationship between external time of the kind measured by physicists in the objective world, and the internal psychological time characterising successive instants of conscious perception by a human (or other comparable) mind. As this is something I had previously thought about in the context [1] of anthropic reasoning for astronomical and other purposes (notably in the development [2, 3] of a microanthropic principle such as seems necessary for the interpretation of quantum theory) my objective here will be to offer a brief account of what emerges from that point of view.

Before recapitulating what is meant by the notion of anthropic reasoning, I would start by explaining that this essay will will take for granted the usual paradigm whereby it is assumed that the mind, as perceived from inside, corresponds, in a material physical world, to an organism of the kind known as a brain. More specifically, the motivation for the following discussion derives from the supposition (invoked in previous relevant work by Dyson [4] and Page [5]) that mental processes are describable in terms of instants of perception characterised by a finite duration, $\tilde{t} = \delta t$, of time $t$ – interpretable as a basic biological clock unit – as measured in the physical world wherein the brain is situated. In the human case it would seem that the shortest biological clock timescale on which coherent mental processes occur is of the order of a fraction of a second, which is of course why the latter has been chosen as the standard time measurement unit.

It has for more than a century been possible, and for more that half a century been common usage, to take the fundamental physical measurement units of mass, of length, and (for our present purpose most pertinent) time to be those of what is known as the Planck system, which attributes unit value to three particularly important fundamental parameters. The first of these is the coupling constant $G$ that was crucial for what was historically the earliest satisfactory physical theory namely Newtonian gravitation. The second is the propagation speed $c$ that was crucial for the next great physical theory, namely that of Maxwellian electromagnetism, which was subsequently unified with gravitation by Einstein. The third is the more mysterious parameter designated $\hbar$, of which the importance was first recognised by Planck, but of which the significance was not properly understood until (synthesising contributions by by Schrodinger, Heisenberg, Born and others) the principles of modern quantum theory were finally established by Dirac.

An immediate consequence of this astounding breakthrough was to provide an explanation of the complexity of the chemical behaviour of the elements, as described by Mendleef’s puzzling periodic table, in terms of just a single dimensionless coupling constant, namely the charge of the electron, whose square, the fine structure constant $\alpha_e = e^2$, is given approximately, in these units, by $e^2 \approx 1/137$, while a complete account of low energy physics on a local scale required only one
more dimensionless parameter namely the electron proton mass ratio \( m_e/m_p \approx 1/1830 \) which is important for the properties of liquid helium. These values, and those of the Yukawa coupling constant \( \alpha_Y \approx 2/7 \) and the pion proton mass ratio \( m_\pi/m_p \approx 1/7 \) that play an analogous role in the much less complete theory of strong interactions introduced about the same time, were fundamental in the sense of being obtainable only by empirical observation. Early hopes that they would soon be obtainable by calculation from some deeper theory remain unfulfilled half a century later.

Although there has of course been progress in the derivation of Yukawa’s rudimentary pion coupling model from more sophisticated strong interaction theories involving quarks and gluons, this has been done only by introducing even more adjustable parameters than before, so the outcome is that the value of the effective coupling constant \( \alpha_Y \) still remains something known only by empirical measurement. Therefore to account for the value of this and other such quantities, there is now more interest than ever in what I called the strong anthropic principle [6]. This means an approach whereby the quantities in question are postulated to have values that vary over observationally inaccessible parts of what recently come to be known [7] as a multiverse, within which our own region has been selected by the existence of – and therefore environmental suitability for – observers like ourselves.

As the prototype candidate for such a selection effect, I had drawn attention [8] to the observed Yukawa coupling relation

\[
\alpha_Y \approx 2 m_\pi/m_p ,
\]

(1)

that is well known as the condition for the nuclear coupling to be marginally strong enough for the formation of a deuteron by binding of a proton and a neutron within the distance fixed by the pion mass. As consequently remarked by Dyson [9] and confirmed by subsequent calculations [10], a relatively small respective decrease or increase in this coupling would suffice to provide a chemically sterile universe consisting exclusively of hydrogen, or containing none at all.

Whereas most such fundamental coupling coupling constants were found to have values more or less comparable with unity, Dirac was impressed by the fact that there is an exception. Compared with their electromagnetic attraction, the gravitational attraction between an electron and a proton is weaker by an enormous factor of the order of \( 10^{40} \), a number that is interpretable as roughly the inverse of the product of the mass of these particles, as given in Planck units roughly by \( m_e \approx 10^{-22} \) and \( m_p \approx 10^{-19} \), so that their geometric mean square value is given in very round figures by

\[
m_e m_p \approx \langle m \rangle^2 \approx 10^{-40}.
\]

(2)

The point to which I wish to draw attention here – and for which at the end I shall offer a tentative explanation – is that in terms of such Planck units the fraction of a second time unit characterising our mental (and other biological) processes has
a value of about the same enormous order of magnitude, namely

\[ \bar{\tau} \approx 10^{40}. \] (3)

2 Dirac’s coincidence

Dirac himself drew attention, not to the coincidence I have just mentioned, but to another coincidence involving the same number, which is that it is roughly the square root of the number \( N \approx 10^{80} \) of protons (or equivalently, by charge neutrality, of electrons) in the visible universe, meaning the volume characterised by the cosmological Hubble radius, which was first measured (though not very accurately) about the same time (three quarters of a century ago) that the principles of modern quantum theory were first established. It was Dirac’s mistaken explanation for this highly significant coincidence that prompted me to provide an explicit formulation of what I called the anthropic principle.

Dirac’s idea was based on the supposition that we are observing at a random – so presumably typical – instant in the history of our expanding universe, so if (for whatever reason) the inverse of the gravitational coupling constant is presently equal to the square root of the number of particles in the visible volume determined by the Hubble expansion rate then it should be expected to remain so. Since the visible volume will include progressively more and more particles as the universe expands, it would follow that the gravitational coupling should become correspondingly weaker.

When I first read about this (in Bondi’s classic textbook [11] on cosmology) I realised that there was a weak link in Dirac’s reasoning, namely his implicit adoption of what I would criticise as an ubiquity principle rather than the anthropic principle that seems appropriate. The essential content of what I called the anthropic principle is that, a priori, our location in space or time should not be considered as random with just with respect to the corresponding ordinary physical measure of space or time (as in what I would call an ubiquity principle) but with respect to a measure that is anthropically weighted in the sense of being proportional to the population density of individuals comparable with ourselves.

It has since become observationally clear that the conclusion to which Dirac was drawn by his misguided line of reasoning was indeed wrong, since his predicted (cosmological rapid) weakening of gravitation does not actually occur. Already, even before this was as obvious as it is now, the weak point in Dirac’s line of reasoning had been noticed by Dicke [12] (an advocate of another theory of progressive weakening of gravity, but at a much slower and so less easily measurable rate) who preceded my own contribution [6] in pointing out that observers comparable to ourselves (which is what I meant by the adjective anthropic) could not possibly have
existed when the age of our expanding universe was much less than the lifetime of a typical hydrogen burning star, and could be expected to become relatively rare when the universe is much older than that. The (then recently discovered) reason for the lower cut off is that such hydrogen burning is the only way of fabricating the medium and heavy elements of which we are made. The (more obvious) reason for the upper time limitation on the relevant anthropic weighting measure is the dependence of life systems such as ours on energy input from a neighbouring star, and of the fact that although later generations of such stars will continue to be formed they will become progressively rarer as the matter that was originally present is transformed into unavailable end states such as cold dead neutron stars and black holes.

Although Dirac was wrong in his conclusion of weakening of gravitation with time, it appears that he was right in deducing that there is a direct connection between the strength of gravity and the number of particles in the universe as presently observed. The coincidence he noted is that the value, roughly $10^{80}$ of $N$ is roughly the inverse square of the value, roughly $10^{-40}$, of the gravitational coupling constant that is itself given very roughly as square of the proton mass $m_p$. Dirac’s coincidence is thus roughly expressible in Planck units simply as

$$N \approx m_p^{-4}.$$  \hspace{1cm} (4)

A first step in what now appears to be the correct explanation of this is the recognition that, as has been known since Newton’s time, the dynamical timescale $t$ associated with the free self gravitational acceleration of a body with mass density $\rho$ will (remembering our units here are such that $G = 1$) be given roughly by $\rho \approx 1/t^2$. In the cosmological case (remembering our units are such that $c = 1$) the relevant Hubble radius will be of the same order as the age $t$, so the order magnitude of the mass in the visible volume will be given roughly by $M \approx \rho t^3 \approx t$ which means that the corresponding number $N$ of particles with mass $m_p$ will be given by $N \approx t/m_p$. Dirac’s coincidence is therefore equivalent to the (directly verifiable) observation that the present age, $t_*$, say, of the universe is given very roughly by

$$t_* \approx m_p^{-3},$$  \hspace{1cm} (5)

which in very round figures comes out to be something like $10^{60}$.

### 3 Explanation from stellar physics

To explain Dirac’s coincidence on the basis of the anthropic line of reasoning that was implicitly followed by Dicke, it suffices to work out the typical lifetime $\tau_*$ of a main sequence star, something that was first understood, on the basis of work by Eddington and others, about the same time as Dirac was clarifying the essential principles of quantum theory. Since a star is held together by gravity, it is not
Figure 1: Logarithmic plot of inverse density against mass for the main kinds of stellar and planetary bodies, as accounted for [13] (on the basis of work by pioneers such as Eddington and Chandrasekhar) in terms just of the masses and charge of the proton and the electron.
surprising (see my recent recapitulation [13]) that its properties should be essentially determined by the gravitational coupling strength: the essential conclusions are that typically (give or take one or two factors of ten) the mass $M_\star$ will be given roughly by $M_\star \approx m_p^{-2}$, while its lifetime, which is what we are principally concerned with here, will be given by $\tau_\star \approx \varepsilon_N M_\star / L$ where $L$ is its luminosity, and $\varepsilon_N$ is the nuclear binding energy which, on account of (1), will be expressible simply as $\varepsilon_N \approx (2 m_\pi / m_p)^2$. The luminosity is sensitive to the stellar mass, and is given by a rather complicated formula [8] for small slow burning stars. However for larger brighter stars of the kind that manufactured our heavy elements one can use the simple Eddington luminosity formula $L / M_\star \approx m_p m_e^2 / e^4$ which gives

\[ \tau_\star \approx (2 e^2 m_\pi / m_e)^2 m_p^{-3} . \]  

(6)

Since (in our part of the universe, if not elsewhere) the factor $e^2 m_\pi / m_e$ happens to be of order unity, it is evident that (at the admittedly rather crude level of accuracy involved) the agreement with (5) is perfect: the coincidence is explained, and the essential role of gravity confirmed. However instead of providing evidence for a radically new theory as foreseen by Dirac, the explanation merely confirms what was already the established understanding of the situation. Dirac’s persistent refusal to accept this (from his point of view disappointing) outcome shows that, despite the fact that it ultimately contributes nothing new in such a case, the anthropic principle is not merely a tautology. Indeed, whereas Dirac’s inclination was to spread the a priori probability measure too widely, a more common kind of deviation from the anthropic principle is to spread it too restrictively. Both kinds of deviation tend to be motivated by wishful thinking, typically unwillingness to accept the limitations, particularly concerning future prospects, that are involved in unbiased application of the anthropic principle.

4 Anthropic or autocentric forecast

An extreme, but not unusual, example of a non-anthropic principle of the restrictive kind is that of what I would call the autocentric principle, whose application consists in a (logically admissible, but for predictive purposes sterile) refusal to attribute any a priori probability at all to situations other than that in which one has already found oneself a posteriori. (As a recent proponent [14] puts it “what other hypothetical observers with data different from ours might see, how many of them there are, and what properties they might or might not share with us are irrelevant”)

Recourse to such an autocentric standpoint may be a temptation for advocates [15] of scenarios in which the population of our terrestrial civilisation is maintained indefinitely at a sustainable level (as envisaged by ecologists) or even conceived
to undergo continued growth (as desired by economists). Whereas the autocentric principle is compatible with (neither encouraging nor discouraging) such scenarios, on the other hand, according to the anthropic principle, the integrated future population of our civilisation can not be expected to greatly exceed the number that have lived so far, which leaves us with the choice between a sudden cut off (what has been called [16] the doomsday scenario, due to a catastrophe like a global war or some kind of environmental disaster) or the less apocalyptic alternative of a gentle and controlled decline in population, of the kind that seems already to have begun in some developed countries. It is to be noted that since I first made such a prediction, about a quarter of a century ago [17], there has already been an inflection, whereby, according to official United Nations statistics, see Figure 2, the second time derivative of the global human population has changed sign and become negative. It is also to be noted that this anthropic prediction concurs with what is to be expected anyway on the basis of environmental and other considerations, so much so as to be almost redundant, in the sense that its conclusion can not be easily escaped even by recourse to autocentrism.

5 Understanding our past evolution

Although it is perhaps of less immediate practical importance, a more intellectually interesting application [17] of the anthropic principle is concerned with another remarkable coincidence concerning the stellar lifetime discussed above, and in particular with the more precise value that can be given to it when one is concerned not with the whole category of main sequence stars but with a single specific case,
Figure 3: Probability distribution and expectation value for anthropic arrival time, firstly if number of difficult steps is zero (high curve), secondly if it is one (middle curve) and thirdly if it is two (low curve), using dotted lines for extrapolation beyond the cut-off imposed by the Sun’s lifetime. The expectation value in the first case is far too low to account for the observation that the present age of the earth is about half the calculated cut-off time. However the second case, that of a single difficult step, fits very well, and it is still possible to envisage that there may have been two difficult steps (or even more if – to allow for rising of the solar temperature – the standard cut-off calculation needs downward revision).

namely that of our own Sun. The remarkable coincidence (much more precise than the vague order of magnitude relation that fascinated Dirac) is that the predicted total hydrogen burning lifetime of the Sun is only about twice the present geologically measured age of our planet Earth. What this means is that the stochastic biological evolution process whereby our (at one stage single celled, then worm like, fish like, and finally mammalian) ancestors developed to become our anthropoid selves took fully half the astrophysically available time. If this very complicated and technically (unlike stellar astrophysics) not at all well understood process had been slower by a modest factor of two our civilisation here would never have got to exist at all. It is not at all plausible that the intrinsic stochastic mechanism of such a biological process should have been tuned a priori so as to agree with the externally imposed astrophysical timescale.

What could have been expected a priori is that in the given planetary environment, the stochastically expected time scale, $\tilde{t}$ say, for evolution to our anthropically advanced state would be either very short or else very long compared with the relevant stellar lifetime. In the former case advanced civilisations would be of rather common occurrence and the anthropic weighting factor would favour their emergence when the relevant star was relatively young. Since that is not what we observe in our own case, we are left, as the only plausible alternative, with the conclusion that the available time is short compared with the stochastically ex-
pected timescale, 7, which implies that (whereas primitive life may be be relatively common [18]) advanced civilisations like ours will occur only in rare cases for which there was an exceptional run of luck. More detailed conclusions can be obtained by classifying the intermediate evolutionary steps as easy ones, meaning those with a high chance of going through in the time available, and difficult ones, meaning those with a low chance of going through in the time available. Our observation that the Sun is no longer young implies that at least one of the steps must have been of the difficult kind, but on the other hand the number of difficult steps can not have been very large since if it had the remaining main sequence time would have been expected to be much smaller than, not comparable with, the time elapsed so far.

6 Our planetary environment

The smallest timescales of which we have any actual experimental or observational knowledge are those of nuclear physical processes for which the relevant timescales are of the order of \( m_p^{-1} \) meaning about \( 10^{20} \) in Planck units. The very long cosmological, stellar, and biological evolution timescales whose anthropic relationships have been discussed are of the order of \( m_p^{-3} \) meaning about \( 10^{60} \) in Planck units. Between these very large and very small values, the minimum (fraction of a second) perception timescale \( \tau \) referred to in (3) is given by the geometric mean, namely about \( 10^{40} \) in Planck units. As this happens to be what is recognisably expressible as \( m_p^{-2} \) we again find ourselves confronted with the question of whether this is just an accidental coincidence, or whether, as with Dirac’s coincidence it really is explicable in terms of gravitational coupling.

A significant step toward such an explanation is contained in the pioneering investigation of the physical and astrophysical limitations on human space dimensions provided [19] by Press, whose key point was that the dimensions of the host planet are rather tightly restricted by the requirement that the gravitational field should be strong enough for binding of water and heavier molecules, but not quite strong enough for binding of hydrogen. This means that, compared with the square of the escape velocity, the thermal energy factor given for the atmospheric nitrogen and oxygen by the square of the sound speed has to be rather (but not too) small – by a factor of roughly the order of a thousandth.

For marginal gravitational binding of hydrogen atoms (with thermal velocity not far below the escape velocity) the generic virial equilibrium formula – as explained in my recent recapitulation [13] – for a planetary or non-relativistic stellar type body of mass \( M \) density \( \rho \) and temperature \( \Theta \), takes a form given roughly by \( M \approx 10 m_p^{-3/2} \rho^{-1/2} \Theta^{3/2} \). Since on a solid or liquid planet the typical interparticle separation will be given by the Bohr radius, \( e^{-2} m_e^{-1} \), the ensuing mass density will be a few times that of water, with order of magnitude \( \rho \approx e^6 m_e^3 m_p \), so for hydrogen binding to be marginal the planetary mass must be given roughly
by \( M \approx 10 m_p^{-2}(\Theta/e^2m_e)^{3/2} \). Now in order for water to exist in liquid form, the temperature must be small, but not extremely small, compared with the Rydberg (electronic binding) energy, and therefore given by an expression of the form

\[
\Theta_\oplus \approx \frac{1}{2} \epsilon e^4 m_e ,
\]

where \( \epsilon \) is a numerical factor that was taken by Press to be about \( 3 \times 10^{-3} \). On the basis of these considerations, Press obtained for the radius of an earth-like planet an expression of the form

\[
R_\oplus \approx 2 \epsilon^{1/2} e^{-1} m_e^{-1} m_p^{-1} .
\]

This corresponds to a mass of given by an expression of the form

\[
M_\oplus \approx 8 \epsilon^{3/2} e^3 m_p^{-2} ,
\]

which is smaller than the value \( M_\odot \approx m_p^{-2} \) that characterises a typical main sequence star such as the Sun by a factor of order \( \epsilon^{3/2} e^3 \).

To make the link with local biology what one needs is not the global quantities given by the preceding Press formulae, but the value of the local Galilean acceleration field given (according to the gravitation law discovered by Hooke but subsequently named after Newton) by \( g \approx M_\oplus/R_\oplus^2 \). By a convenient cancellation (that does not seem to have been previously noticed) it turns out that the result depends on the mass only of the electron, not the proton, taking the remarkably simple form

\[
g \approx 2 \epsilon^{1/2} e^5 m_e^2 ,
\]

which is only weakly dependent on the small arithmetical factor \( \epsilon \), but strongly dependent on the electron charge \( e \).

### 7 The weakness of animal flesh.

Having thus discovered what governs the value of our local gravitational field, we are now faced with the less simple question of how the resulting value of \( g \) affects biological organisms of the kind to which we belong. This is an issue that I think deserves detailed biophysical investigation. Deviating at this point from the approach followed by Press [19] – and also from a related approach recently developed by Page [20] – my own suggestion is that one should think in terms of a basic biological – or to be more specific, zoological – characteristic velocity, \( \tilde{v} \), given – as a small fraction of the speed of ordinary sound at the relevant temperature, by a relation of the form

\[
\tilde{m} \tilde{v}^2 \approx \Theta_\oplus ,
\]
in which $\bar{m}$ is a mass scale characterising relevant large biochemical molecules such as proteins. This means that it will be expressible by a relation of the form

$$\bar{m} \approx \bar{\epsilon}^{-1} m_p,$$

(12)

in which (like the Press coefficient $\epsilon$ introduced above) the quantity $\bar{\epsilon}$ is a small arithmetical factor that – for $\bar{m}$ to be the mass of a typical protein molecule – should have order of magnitude $\bar{\epsilon} \approx 0.3 \times 10^{-4}$.

This quantity $\bar{\epsilon}$ has the same status as that of the Press coefficient $\epsilon$, in that the smallness of these quantities is just an arithmetical (in principle calculable) measure of the complexity of the (molecular, not just atomic) systems involved, and – contrary to a notion that was suggested, but justifiably criticised by Peierls, in a related discussion [21] – it has nothing to do with the smallness of the fine structure constant $e^2$ (whose role is significant only when heavy metals are involved) nor of the ratio $m_e/m_p$ (which is too small to matter much except for the lightest elements, namely pure hydrogen and helium, at temperatures far too low for ordinary life).

The foregoing estimate for $\bar{\epsilon}$ is actually interpretable as meaning that the corresponding zoological characteristic velocity,

$$\bar{v} \approx e^2 (\bar{\epsilon} \epsilon m_e/m_p)^{1/2},$$

(13)

will in our case be about 3 percent of the speed of ordinary sound. This relatively slow speed is mainly attributable to the very small value of the foregoing estimate for $\bar{\epsilon}$, which has nothing to do with the values of physically adjustable coupling constants, but is an ineluctable concomitant of the flabbiness of flexible flesh, or even cartilage, as contrasted with the rigidity of woody celluloid matter in plants, for which the corresponding botanical characteristic velocity would be considerably higher, though still subsonic. (To emulate the strength of vegetable matter, animal bodies do of course incorporate rigid bone structure, but the extent to which that is feasible is limited by the ensuing sacrifice of flexibility and mobility. I therefore differ from Press [19] in my opinion that the properties of bone itself are of secondary importance, and that the essential restrictions on animal size are attributable to the finite strength of the flexible tissues that hold the bones in place.)

Assuming that such a velocity $\bar{v}$ (of the order of 10 m/sec in our own case) characterises the relevant energies, pressures, and tensions (as involved for example in the pumping of blood) in an animal body, it will provides a rough upper limit,

$$2 g \ell \lesssim \bar{v}^2,$$

(14)

on the supportable value of the gravitational energy per unit mass associated with a height difference $\ell$ between different parts of the body of the organism. When applied to solid crystalline matter, for which the relevant velocity will be of the order of that of sound (whose square, as remarked above, must be of the order of a thousandth of the square of the escape velocity) analogous reasoning [22].
indicates that the maximum possible height of a mountain will be comparable with 
the thickness of the bulk of the atmosphere, and thus of the order of a thousandth 
of the planetary radius, which in our terrestrial case provides an (observationally 
verifiable) estimate of the order of $10^4$ metres.

It is instructive to see how the limit (14) can be derived in a manner similar to 
that used by Press [19], who considered the total energy, $\bar{E}$ say, needed to break the 
bonds with energy $\Theta_\oplus$ binding the molecules on a 2-dimensional shear-disruption 
surface with area $\ell^2$. In terms of the relevant molecular dimension $\bar{a}$ say (which 
for the large protein molecules considered here will be some tens of times larger 
than the Bohr radius $e^{-2}m_e^{-1}$) the number of molecules in the surface layer will 
be of order $(\ell/\bar{a})^3$ which gives $\bar{E} \approx \Theta_\oplus(\ell/\bar{a})^2$. This disruption energy has to be 
supplied by the action of gravity on the mass, $\bar{M}$ say, in the corresponding volume 
of order $\ell^3$, which will be given by $\bar{M} \approx m(\ell/\bar{a})^3$. The viability condition proposed 
by Press was that the energy liberated in an animal’s fall through its own height $\ell$ should be insufficient to provide the disruption energy, which gives a limit of the form 
$g\bar{M}\ell \lesssim \bar{E}$.

My own opinion is however that animals can learn how to take care to avoid such 
dynamical falls, and that what really matters for viability is the condition for static 
support against gravity, which will hold so long as the disruption energy cannot be 
provided by a displacement comparable with half the molecular separation distance $\bar{a}$, which means that instead of the preceding Press type inequality one gets a limit of the form $g\bar{M}\bar{a}/2 \lesssim \bar{E}$, with the factor $\ell$ replaced by $\bar{a}/2$. This replacement does 
not of course eliminate the dependence on $\ell$, which is implicitly involved through 
both $\bar{E}$ and $\bar{M}$. Ultimately it is the dependence on $\bar{a}$ that cancels out, leaving a 
static support condition of the simple form (14).

This simple result contrasts with what would be obtained from a dynamical 
survivability condition of the kind proposed by Press, which reduces to the not 
quite so simple form $g\ell^2 \lesssim \bar{a}\bar{v}^2$. For the actual application [19] of this latter 
formula to hard bone – instead of the fleshy tissue considered here – the molecular 
radius $\bar{a}$ has to be replaced by the ordinary Bohr radius $a_0 = e^{-2}m_e^{-1}$ and the very 
low value of the zoological velocity $\bar{v}$ used here has to be replaced by the much 
larger velocity value that is obtainable from (12) or (13), simply by setting $\bar{e}$ to unity.

8 Characteristic timescale of human perception

On the basis of the static support condition (14), the preceding considerations 
impies that (whereas a land plant or a sea animal may be able to be larger) a 
land animal will be able to have at most a maximum size $\bar{\ell}$ and a corresponding
biological clock timescale $\bar{\tau}$ given by

$$\bar{\tau} \approx \frac{\bar{v}}{v} \approx \frac{\bar{v}}{2g}.$$  \hspace{1cm} (15)

Using the preceding estimates (10) and (13) for $g$ and $\bar{v}$ one obtains the formula

$$\bar{\tau} \approx \frac{1}{4e^3 m_e^{3/2} \bar{m}^{1/2}}.$$  \hspace{1cm} (16)

which is independent of the previously introduced Press coefficient $\epsilon$. It does however have a weak dependence on the newly introduced coefficient $\bar{\epsilon}$ when expressed in terms of the mean coupling constant $\langle m \rangle^2 \approx 10^{-40}$ defined by (2), taking the form

$$\bar{\tau} \approx \frac{(\bar{\epsilon} m_p/m_e)^{1/2}}{4e^3 \langle m \rangle^2}.$$  \hspace{1cm} (17)

Since the factor $1/4 e^3$ is only of the order of a hundred, and the dimensionless combination $\bar{\epsilon} m_p/m_e$ can be expected to be rather smaller than unity, it is the factor $1/\langle m \rangle^2$ that is overwhelmingly dominant, so the expectation of an essentially gravitational explanation is confirmed.

9 Strong anthropic reasoning

The idea of what I called the strong anthropic principle [6] was to extend the arena of application of the weak anthropic principle to scenarios in which the relevant (anthropically weighted) a priori probability measure is not limited to the part of the universe about which we have direct observational knowledge, but extended to other hypothetically existing parts of what may be termed a multiverse [7], in which fundamental parameters, such as the fine structure constant $e^2$ and the gravitational coupling constant $\langle m \rangle^2$, might have values different from those (respectively 1/137 and $10^{-40}$) with which we are familiar. In particular I suggested that given the value of the former (electromagnetic) coupling constant the weakness of the latter (gravitational) coupling constant might be explicable in such a framework as due to a selection effect – giving it the maximum value, proportional to a very high (the twelfth) power of the fine structure constant – on the basis of the requirement of stellar convection [8] as a prerequisite for the necessary planetary formation.

Starting with the application to the marginal nuclear binding condition (1), arguments of this strong anthropic kind have since been put forward [23, 24, 25] to account for relations involving other parameters, such as those controlling weak interactions. However – in the absence of plausible mechanisms for the cosmological parameter variations that had to be invoked – such explanations did not become fashionable until the situation was revolutionised [26] on the theoretical side by
the rise of modern superstring theories and the attempts to unify them in M-theory, and on the observational side by the discovery (which surprised everyone, including superstring theorists) that the expansion of the universe is not undergoing gravitational deceleration but actually accelerating.

The logic leading to the formula (17) for the zoological clock timescale $\tilde{\tau}$, and to the corresponding space dimension,

$$\tilde{\ell} \approx \epsilon^{1/2} \tilde{\epsilon} / (4 \epsilon_m m_p),$$

(18)

is based on the assumption that, natural selection will tend to maximise the latter (within the limits imposed by the ambient Galilean gravitational field $g$) in order to obtain as large as possible a value for the corresponding corporal particle number, as given by $\tilde{N} \approx \tilde{n} \tilde{\ell}^3$ in terms of the particle number density $\tilde{n} \approx (\epsilon^2 m_e/2)^3$ of water. The value

$$\tilde{N} \approx (\epsilon^{1/2} \epsilon / 8 m_p)^3,$$

(19)

thus obtained for the body – of which the brain, in the human case, is a significant fraction – will of course be a wide overestimate of what, in view of the haphazard nature of natural selection, is actually likely to be achieved in practice, but the limit given by (18) has occasionally been approached in a few gigantic cases such as that of the brontosaurus. As a fraction of the number $N_{\oplus} \approx M_{\oplus}/m_p$ this is expressible as the relation

$$\tilde{N}/N_{\oplus} \approx (\epsilon/16)^3 \approx 10^{-17},$$

(20)

in which the right hand side is a purely arithmetical quantity whose extremely small value does not depend on any empirical parameter (such as the proton mass $m_p$ with which it is numerically comparable) but is just a consequence of the complexity of biochemical processes. Its cube root – of the order of a millionth – characterises the maximum size ratio, $\tilde{\ell}/R_{\oplus}$, for a land animal with the same kind of biochemistry as ours, not just on any inhabitable planets within our own or nearby galaxies, but even in other parts of the multiverse (where quantities such as $\epsilon$ and $m_p$ need not have the values that are familiar). More particularly and memorably, on any such planet, the maximum land animal size $\tilde{\ell}$ will be of the order of a thousandth of the atmospheric thickness (and the maximum mountain height) which – as remarked above in the discussion of (14) – will itself be of the order of a thousandth of the planetary radius $R_{\oplus}$ given by (8).

In conclusion, assuming that mental processing benefits from maximisation of the number of particles in the brain and therefore of its host body, it can be seen from (19) that the strong anthropic principle will favor regions of the multiverse in which the ratio $\epsilon/m_p$ is very large, that is to say where the ratio of gravitational to electric coupling is very small.
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References

[1] B. Carter, “Anthropic principle in cosmology”, in Current issues in Cosmology, ed. J.C. Pecker, J. Narlikar (Cambridge U.P. 2006) 173-179; arXiv: gr-qc/0606117.

[2] B. Carter, “Anthropic interpretation of quantum theory”, Int. J. Theor. Phys. 43 (2004) 721-730; arXiv: hep-th/0403008.

[3] B. Carter, “Micro-anthropic principle for quantum theory”, in Universe or Multiverse?, ed. B.J. Carr, (Cambridge U.P. 2007) 285-319; arXiv: quantum-ph/0503113.

[4] F.J. Dyson, “Time without end: physics and biology in an open system”, Rev. Mod. Phys. 51 (1979) 447-460.

[5] D. Page, “Sensible quantum mechanics: are probabilities only in the mind?” Int. J. Mod. Phys. D5 (1996) 583-596; arXiv: gr-qc/9507024.

[6] B. Carter, “Large Number Coincidences and the Anthropic Principle in Cosmology”, in Confrontations of Cosmological Theories with Observational Data (I.A.U. Symposium 63) ed. M. Longair (Reidel, Dordrecht, 1974) 291-298.

[7] P.C.W. Davies, “Multiverse cosmological models”, Mod. Phys. Lett. A19 (2004) 727-744; arXiv: astro-ph/0403047.

[8] B. Carter, “The significance of numerical coincidences in nature”, preprint (DAMTP Cambridge, 1967), arXiv: 0710.3543 [hep-th]

[9] F.J. Dyson, “Energy in the universe”, Sci. Am. 225 (1971) 50 - 59.

[10] T. Pochet, T., J.M. Pearson, G. Beaudet, H. Reeves, “The binding of light nuclei, and the anthropic principle”, Astron. Astroph. 243 (1991) 1-4.

[11] H. Bondi, Cosmology (Cambridge U.P., 1960).

[12] R.H. Dicke, “Dirac’s cosmology and Mach’s principle”, Nature 192 (1961) 440-441.
[13] B. Carter, “Mechanics and equilibrium geometry of black holes, membranes, and strings”, in Black Hole Physics, ed V. de Sabbata, Z. Zhang (Kluwer, Dordrecht, 1992) 283-357; arXiv: hep-th/0411259.

[14] J.B. Hartle, M. Srednicki, “Are we typical”, Phys. Rev. D75 (2007) 123523; arXiv: hep-th/0704.2630.

[15] F.J. Dyson, “Reality bites”, Nature 380 (1996) 296.

[16] J. Leslie, “Time and the anthropic principle”, Mind 101 (1992), 521-540.

[17] B. Carter, “The anthropic principle and its implications for biological evolution”, Phil. Trans. Roy. Soc. A310 (1983) 347-363.

[18] C.H. Lineweaver, T.M. Davis, “Does the rapid appearance of life on earth suggest that life is common in the universe?”, Astrobiology 2 (2002) 293-304; arXiv: astro-ph/0205014.

[19] W.H. Press, “Man’s size in terms of fundamental constants”, Am. J. Phys. 48 (1980) 597-598.

[20] D.N. Page, “The Height of a Giraffe”, arXiv: 0708.0573.

[21] W.H. Press, A.P. Lightman, “Dependence of macrophysical phenomena on the values of the fundamental constants”, Phil. Trans. R. Soc. Lond. A310 (1983) 323-336.

[22] V.F. Weisskopf, “Search for simplicity: mountains waterwaves and leaky ceilings”, Am. J. Phys. 54 (1986) 110-111.

[23] B.J. Carr, M.J. Rees, “The anthropic principle and the structure of the physical world”, Nature 278 (1979) 605-612.

[24] C.J. Hogan, “Why the universe is just so”, Rev. Mod. Phys. 72 (2000) 1149-1161; arXiv: astro-ph/9009295.

[25] D.N. Page, “Anthropic Estimates of the Charge and Mass of the Proton”, arXiv: hep-th/0302051.

[26] R. Kallosh, A. Linde, “M theory, cosmological constant, and anthropic principle”, Phys. Rev. D67 (2003) 023510; arXiv: hep-th/0208157.