The Argument from (apparent) Design

You can just see what each part is for

Three kinds of design argument:

1. Analogy: Similar effects probably have similar causes . (Ancient Greeks)

2. Inference to the best explanation. (William Paley, ID theorists)
   - Biological function and complexity
   - Fine tuning of the cosmos

3. Physical systems cannot create information

Also Socrates' Design Argument

With such signs of forethought in these arrangements, **can you doubt** whether they are the work of chance or design?

(concerning sex organs being for the purpose of procreation, he concludes:

Undoubtedly these too **look like** the contrivances of one who deliberately willed the existence of living creatures.

- as reported by Xenophon in *Memorabilia* (I, iv, 6-7)

1. Argument from Analogy

Premise: *If the effects (or causes) resemble one another, then the causes (or effects) probably do as well.*

- E.g. if this exoplanet has liquid water (like earth) then it probably has life (like earth)
- If other people display similar behavior to me (speech, facial expressions, actions) then they probably also have conscious mental states.

Similarity between eyes and cameras?

1. Cameras have a *function* – the different parts work together to do something useful. The same is true of eyes.
2. In order to function well, cameras and eyes both have to be extremely intricate and complex.
3. The component parts of a camera have purposes that are easy to see, and so do the parts of an eye.
4. For a camera to carry out its function well, the parts have to be shaped and arranged very precisely to match each other. (The same is true of eyes)

$\therefore$ Cameras and eyes are similar in many respects

All these various machines, and even their most minute parts, are adjusted to each other so precisely that everyone who has ever contemplated them is filled with wonder. The intricate fitting of means to ends throughout all nature is just like (though more wonderful than) the fitting of means to ends in things that have been produced by us - products of human designs, thought, wisdom, and intelligence. Since the effects resemble each other, we are led to infer by all the rules of analogy that the causes are also alike, and that the author of nature is somewhat similar to the mind of man, though he has much larger faculties to go with the grandeur of the work he has carried out.

– Hume, *Dialogues concerning Natural Religion,* p. 181. (in the character of Cleanthes)

Main Argument

1. Cameras and eyes are similar in many respects, such as having precisely shaped, well-matched parts that work together to perform a useful function.
2. Cameras are designed by human engineers
3. If the effects are similar, then the causes are probably similar as well

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∴ Eyes were probably designed by something similar to human engineers

Argument from Analogy

- This is an inductive (probable) argument, and so has some degree of strength (e.g. strong or weak).
- The strength of the argument depends on the degree of similarity between the observed effects.
- How strong is it?

Hume's criticisms

1. There's no evidence from design that God is single, infinite, omnipotent, good, etc.
2. (God would be evil, in fact!)
3. Perhaps matter can produce order from itself? ("self-organization")
4. Who made the designer?
5. What's so special about *thought*?
6. We only have a sample size of 1.

The character Philo argues that while it might be reasonable to believe that the universe arose from something like design, there's no evidence of a single designer, or that the designer is *perfect*, *infinite*, etc. It is possible, says Philo, that

This world, for aught he knows, is very faulty and imperfect, compared to a superior standard; and **was only the first rude essay of some infant deity**, who afterwards abandoned it, ashamed of his lame performance: **it is the work only of some dependent, inferior deity**; and is the object of derision to his superiors: **it is the production of old age and dotage in some superannuated deity**; and ever since his death, has run on at adventures, from the first impulse and active force which it received from him."

Even just a stupid mechanic?

"If we survey a ship, what an exalted idea must we form of the ingenuity of the carpenter who framed so complicated, useful and beautiful a machine?

And what surprise must we feel, when we find him a stupid mechanic, who imitated others, and copied an art, which, through a long succession of ages, after multiplied trials, mistakes, corrections, deliberations, and controversies, had been gradually improving?"

(p. 220)

(Similar to Darwin's idea. But could it really happen?)

The problem of evil

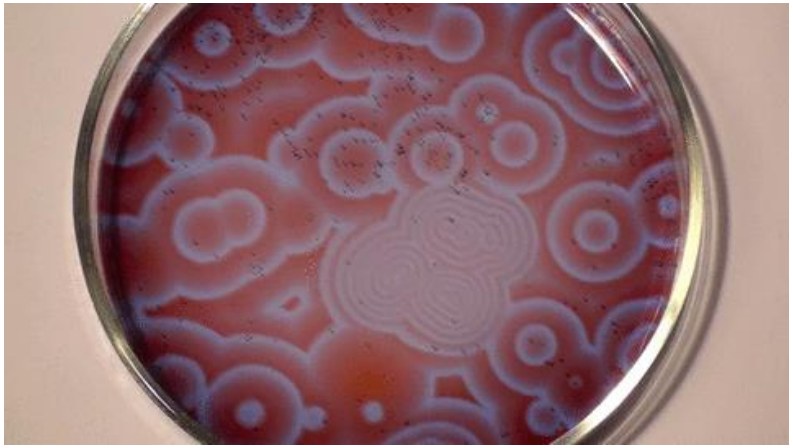
The whole earth, believe me, Philo, is cursed and polluted. A perpetual war is kindled amongst all living creatures. Necessity, hunger, want stimulate the strong and courageous; fear, anxiety, terror agitate the weak and infirm. The first entrance into life gives anguish to the new-born infant and to its wretched parent; weakness, importance, distress attend each stage of that life, and it is, at last, finished in agony and horror. (p. 277)

Why not self-organization?

"For all we can know *a priori*, matter may have a source of order within it, just as mind does, having it inherently, basically, not acquired from somewhere else. When a number of elements come together in an exquisite arrangement, you may think it harder to conceive that they do this of their own accord than to conceive that some designer put them into that arrangement. But that is too quick and careless."

Some scientists (Stuart Kauffman, Brian Goodwin, Leo Kadanoff, etc.) have suggested theories along these lines. But most biologists are unimpressed with the (in)ability of self-organization to produce *functional* things.

Exquisite arrangements (but not functional)



Belousov-Zhabotinsky reaction

Regress problem?

- Thought precedes matter, according to the design theorist.

- But if the material world needs a designer, then surely the designer needs one even more! (And the designer's designer also needs a designer …)

> "If the material world rests upon a similar ideal world, this ideal world must rest upon some other; and so on, without end" (Hume, p. 219)

Dawkins agrees

"Organized complexity is the thing that we are having difficulty in explaining. Once we are allowed simply to *postulate* organized complexity, if only the organized complexity of the DNA/protein replicating machine, it is relatively easy to invoke it as a generator of yet more organized complexity....

But of course any God capable of intelligently designing something as complex as the DNA/protein machine must have been at least as complex and organized as that machine itself...

To explain the origin of the DNA/protein machine by invoking a supernatural Designer is to explain precisely nothing, for it leaves unexplained the origin of the Designer." (*The Blind Watchmaker*, p. 140)

Replies

1. Alvin Plantinga: "… this argument doesn't depend on the facts of biology; it is substantially independent of the latter."
   - So Dawkins would make the same argument, even if all genomes had "Made by Yahweh" written in them?

2. As a *necessary* being, God's existence is fully explained (or perhaps needs no explanation).
   - We can see the argument from design as a supplement to the cosmological or ontological argument.

2. Inference to the Best Explanation

- Paley's argument is sometimes misrepresented as being an argument from analogy.
  - The argument is actually an inference to the best explanation.
- Note that *Paley doesn't use the premise (2) of the design argument from analogy*, i.e. that cameras (watches, etc.) are designed.
- Paley *argues* that watches are designed, rather than using it as a premise.

Were there no example in the world, of contrivance, except that of the eye, it would be alone sufficient to support the conclusion which we draw from it, as to the necessity of an intelligent Creator. It could never be got rid of; **because it could not be accounted for by any other supposition** …

- An "inference to the *only possible* explanation"?

Paley's argument

1. A watch shows the marks of design, such as having parts with obvious purposes, etc.
2. Watches couldn't have come about any other way. (E.g. not by self-organization.)

$\therefore$ Watches are obviously designed

(And similar reasoning applies to living organisms.)

Inference to the best explanation

- IBE is a competition. We should believe the *best* explanation.

- There are two *legitimate* strategies in IBE arguments:
  - Show that your explanation is good (positive)
  - Attack the alternatives (“go negative”)

- (Similar to political election campaign ads.)

Inference to the Best Explanation

- An explanation (of some data, i.e. observed objects or events) is a story about what *caused* that data, i.e. how it came to exist or occur.

A good explanation is:

(i) ***Adequate***: the proposed cause must be sufficient to *predict* the object or event. (It "fits the data")

(ii) ***Plausible***: the proposed cause must be reasonably likely to exist, according to our general worldview.

- E.g. a friend of mine once woke up lying by the side of a road, with his bicycle next to him. He had no obvious injury, or memory of how he got there. What happened?

1. He and his bike were abducted by aliens, and later dropped off there.
2. He was struck by a passing car and knocked out.
3. He felt light-headed, got off the bike, lay down, then fainted.

How good are they?

- #1 is adequate, but not plausible.
- # 2 is plausible, but doesn't predict the absence of injuries.
- #3 is adequate (?) and reasonably plausible as well.

Paley's Argument

- If you were crossing a heath and found a watch, you would be rightly convinced that the watch had a maker, someone who "comprehended its construction and designed its use". (Paley, p. 213)
- You would be convinced of this by examining the watch, seeing what each part is for, and how they work together elegantly to produce an obvious purpose (measuring time).

"... when we come to inspect the watch, we perceive ... that its several parts are framed and put together for a purpose ..." (Paley, p. 177)

- It is complex, in a very specific way, in order to achieve an obvious purpose.

- On the basis of these observed facts, Paley *argues* that watches are obviously designed by some intelligence. This is best explanation of it.
  - An odd conclusion, perhaps, since we *already know* that watches are human artifacts!

- Paley then says that, *by exactly the same reasoning*, living organisms were designed.
  - "Every indication of contrivance, every manifestation of design, which existed in the watch, exists in the works of nature …"

Paley anticipates objections

1. We wouldn’t know that watches were designed if we hadn’t seen them made.
2. Flaws in the watch shows that it’s not designed.
3. The watch has parts that seem to have no purpose.
4. The arrangement of matter into a watch is just as likely as any other specific arrangement.
5. Watches don’t reproduce.

Objection 1

I. We only know that watches are designed because we've seen watchmakers (or heard about them). If we just found a watch, then we wouldn't know where it came from. Also, if we didn't know how to make a watch, we wouldn't infer this one had been made.

Paley's Response:

"... all this being no more than what is true of some exquisite remains of ancient art, of some lost arts, and to the generality of mankind, of the more curious productions of modern manufacture..."

- Or the hand of a T-800?

(We’ve never see one made)

2. Design flaws

- The watch sometimes goes wrong. Surely if it were designed it would work perfectly?

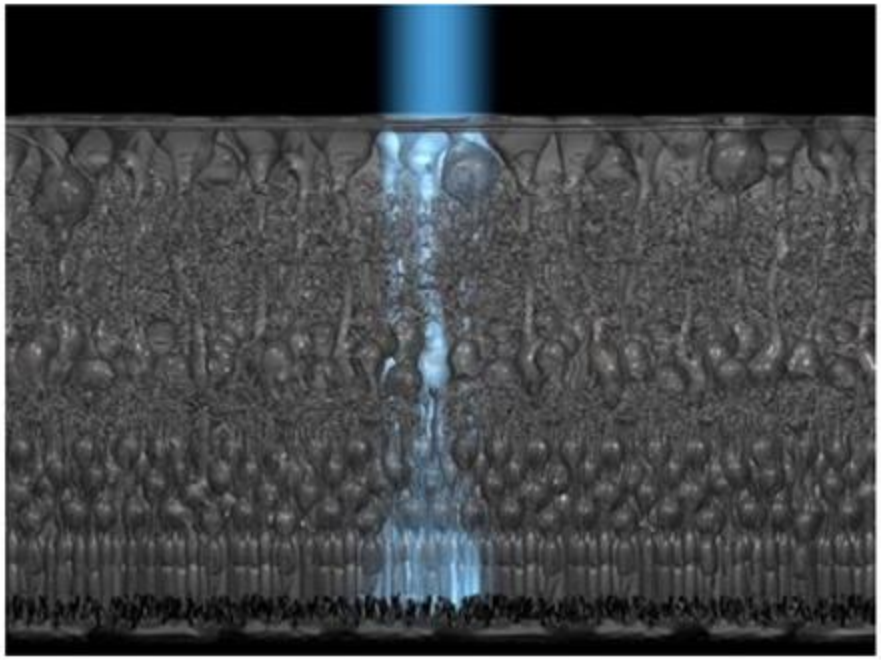
Paley's Response: Most designs are imperfect. You can still tell that the thing is *designed* though.

"The purpose of the machinery, the design, and the designer, might be evident, and, in the case supposed, would be evident, in whatever way we account for the irregularity of the movement …"

"… these last [apparent blemishes] ought to be referred to some cause, though we be ignorant of it, other than defect of knowledge or of benevolence in the author" (p. 178)

Fiber optic light pipes in the retina do much more than simple image transfer

Jul 21, 2014 by John Hewitt report



Muller Cells appear to act as living optical fibers. Credit: vision-research.eu

(Phys.org) —Having the photoreceptors at the back of the retina is not a design constraint, it is a design feature. The idea that the vertebrate eye, like a traditional front-illuminated camera, might have been improved somehow if it had only been able to orient its wiring behind the photoreceptor layer, like a cephalopod, is folly. Indeed in

"The idea that the vertebrate eye, like a traditional front-illuminated camera, might have been improved somehow if it had only been able to orient its wiring behind the photoreceptor layer, like a cephalopod, is folly."

3. The watch has parts that seem to have no purpose.

Paley's Responses:

(a) The part may have a purpose that we haven't discovered yet.

(b) The part may have no purpose. But we can *still* see that the watch is designed. (E.g. a bike may have a useless part if it's too expensive to retool.)

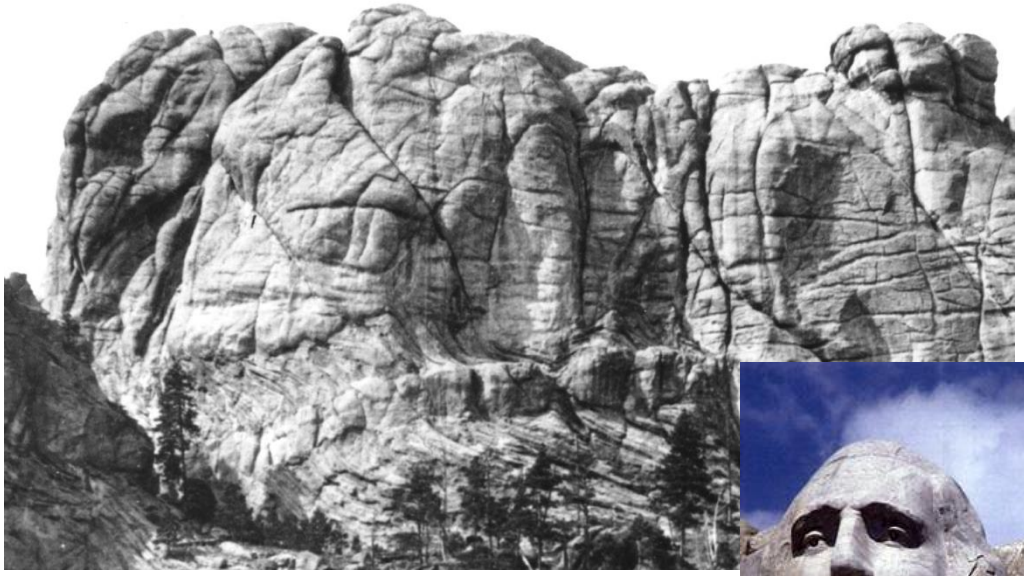
4. The matter had to be arranged *somehow*

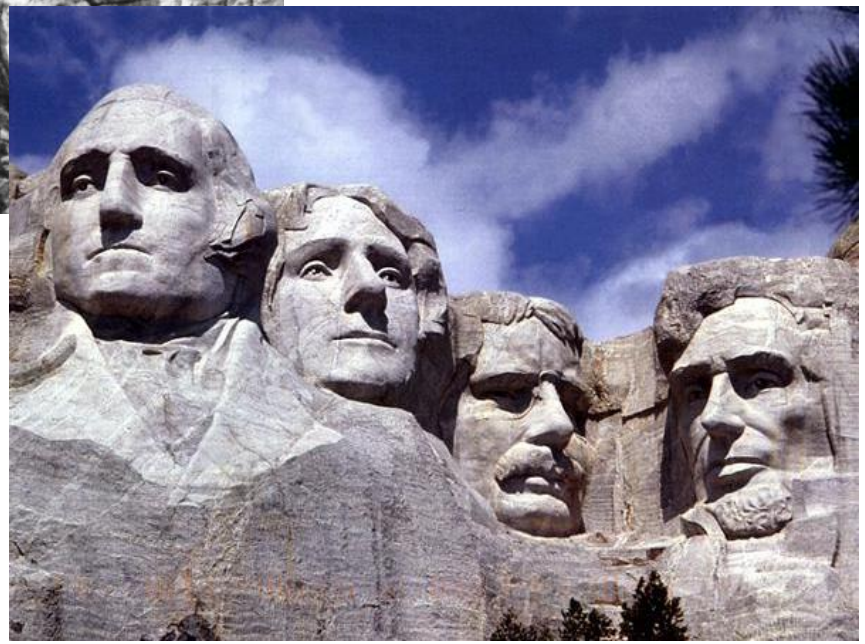
("Sure. It's very unlikely that the golf ball would land on this particular blade of grass. But it had to land somewhere …)

"Nor, fourthly, would any man in his senses think the existence of the watch, with its various machinery, accounted for by being told that it was one out of possible combinations of material forms…"

- (*Usual Response*: There are very few arrangements of matter that are *functional* – ones that walk, fly, swim, etc. IBE tells us to prefer a hypothesis that predicts such an arrangement.)

The mountain must have *some* shape!





B.C’s answer to Mount Rushmore

“the most annoyingly obtuse argument in philosophy”

“Now there are two errors to be avoided when thinking about extremely low probabilities. The first is to suppose that the extreme improbability of a chance process resulting in a certain state of affairs is a reason *by itself* to doubt that this state of affairs was the result of chance. …

The second mistake in thinking about low probabilities is an overreaction to the first. It is to dismiss any doubts that something was due to chance simply on the grounds that something had to happen, and whatever did happen was bound to be highly improbable.” (Roger White, NOUS 41:3 (2007) 460-1)

[Peter van Inwagen calls the second mistake “the most annoyingly obtuse argument in philosophy” (*Metaphysics*, p. 67).]

Watches don’t reproduce!

- A big difference between watches and living organisms is that *watches can’t reproduce themselves*.
- Thus, for example, it would be impossible for watches to evolve in Darwinian fashion.

- Is this the basic reason why the “design inference” concerning watches cannot be extended to organisms?

"Suppose ... it possessed the unexpected property of producing in the course of its movement another watch like itself – the thing is conceivable; that it contained within it a mechanism, a system of parts – a mold, for instance, or a complex adjustment of lathes, baffles, and other tools – evidently and separately calculated for this purpose ..."

(Paley, Chapter II.)

According to Paley, this would *strengthen* the case for design, for the watch is now found to be even more complex and improbable than was initially realized!

Enter Darwin

- Paley didn't foresee Darwin's objection to his argument, that evolution by natural selection is a *better explanation* than design.

- Paley's design argument notes that living organisms are *functional* (they do stuff) and are (therefore) complex and intricate.
  - What cause, other than an engineer, is thus "biased" toward making functional objects?

“Functional bias”

- Natural selection is also “biased” toward making functional structures (which will, of course, have to be intricate and complex).
  - Less-functional variants will be driven to extinction, in the “struggle for existence”.

- The winners of this struggle will be:
  - fitted to their environments (‘adaptive’)
  - full of parts that *seem* purposeful

- Stephen J. Gould: the essence of Darwinism and the modern synthesis is, “Natural selection *creates* the fit.”

Does selection work though?

- Most philosophers and scientists say "Yes!"
- E.g. Earl Conee:

  "This natural sort of explanation [natural selection] does work. It gives an explanation of the machine-like organisation that we observe in things like molecules, marsupials and marshes."

  "… the two explanations [design and nature] seem equally capable of explaining the phenomenon in question."

History of evolutionary thought

- Nowadays, when scientists talk about “the theory of evolution” they usually mean the *modern synthesis* (MS), a modification of Darwin’s theory of evolution, in which selection explains function, developed around 1940.
- Before the MS, there were other theories of evolution (e.g. Lamarkian, Darwinian, mutationist, orthogenesis). Since the MS, new alternatives have been proposed (e.g. symbiogenesis, mutationism, natural genetic engineering).
- *Evolution* is a fact, but *the MS* is (somewhat) controversial.

Evolution is a well-established scientific theory.

It is the cornerstone of modern biology, enabling us to understand the history of life on Earth–including that of humans.

There is ample evidence for evolution.

Scientists have discovered millions of fossils that provide evidence for how one life form evolved into another over time. In the case of human evolution, the evidence includes fossils of more than 6,000 early human individuals representing 6 million years of evolution. Comparisons of DNA, anatomy, and behavior provide other critical evidence that tells us how living organisms are related and how they evolved over time.

In addition, scientists have developed more than a dozen highly reliable methods for determining the age of fossils, human artifacts, and the sediments in which they are found.

Smithsonian *National Museum of Natural History*
David H . Koch "Hall of Human Origins" Educators Guide

- Evolution *is* well established, but the role of natural selection (as the creator of functional gizmos) is much less clear.

"… the book's contention that **natural selection's importance for evolution has been hugely overstated represents a point of view that has a growing set of adherents.** (A few months ago, I was amazed to hear it expressed, in the strongest terms, from another highly eminent microbiologist.) My impression is that evolutionary biology is increasingly separating into two camps, divided over just this question.

On the one hand are the population geneticists and evolutionary biologists who continue to believe that selection has a "creative" and crucial role in evolution and, on the other, **there is a growing body of scientists** (largely those who have come into evolution from molecular biology, developmental biology or developmental genetics, and microbiology) **who reject it**."

Adam S. Wilkins, review of James Shapiro's *Evolution: A View from the 21st Century*, in *Genome Biology and Evolution*, January 2012.

Natural selection or bust …

- It's pretty clear that natural selection is capable of *optimising* existing systems.
- We don't have any direct evidence that natural selection is capable of producing the major changes seen in the fossil record. (No theoretical arguments, or empirical evidence.)
- Why then is natural selection believed to be responsible for those changes?
  - It's the only natural mechanism we can think of, that is biased toward functional, or 'adaptive', structures.

Natural selection or bust …

The arguments from paleontological evidence for the importance of natural selection largely concern the observed long-term trends of morphological change, which are visible in many lineages. **It is hard to imagine what else but natural selection could be responsible for such trends**, unless one invokes supernatural or mystical forces such as the long popular but ultimately discredited force of "orthogenesis."

Adam S. Wilkins, review of James Shapiro's *Evolution: A View from the 21st Century*, in *Genome Biology and Evolution*, January 2012.

E.g. Jerry Coyne

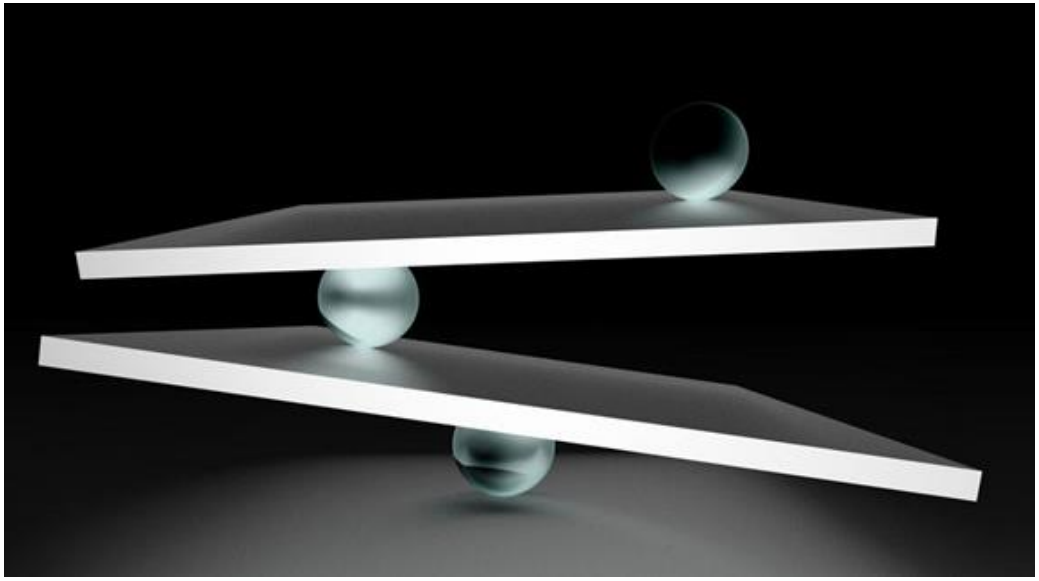
- Jerry Coyne is professor of biology at the University of Chicago, and author of *Why Evolution is True* (2009).

- On his blog (April 26, 2009) Coyne discussed a letter received from someone sceptical about the ability of selection to account for novelty (e.g. eyes).
- Coyne replied:

  "… we can … invoke the idea that we know of no process other than selection that could create such adaptive change. **That is satisfying to scientists**, but perhaps not so convincing to people like the gentleman who wrote me."

Cosmological Fine Tuning

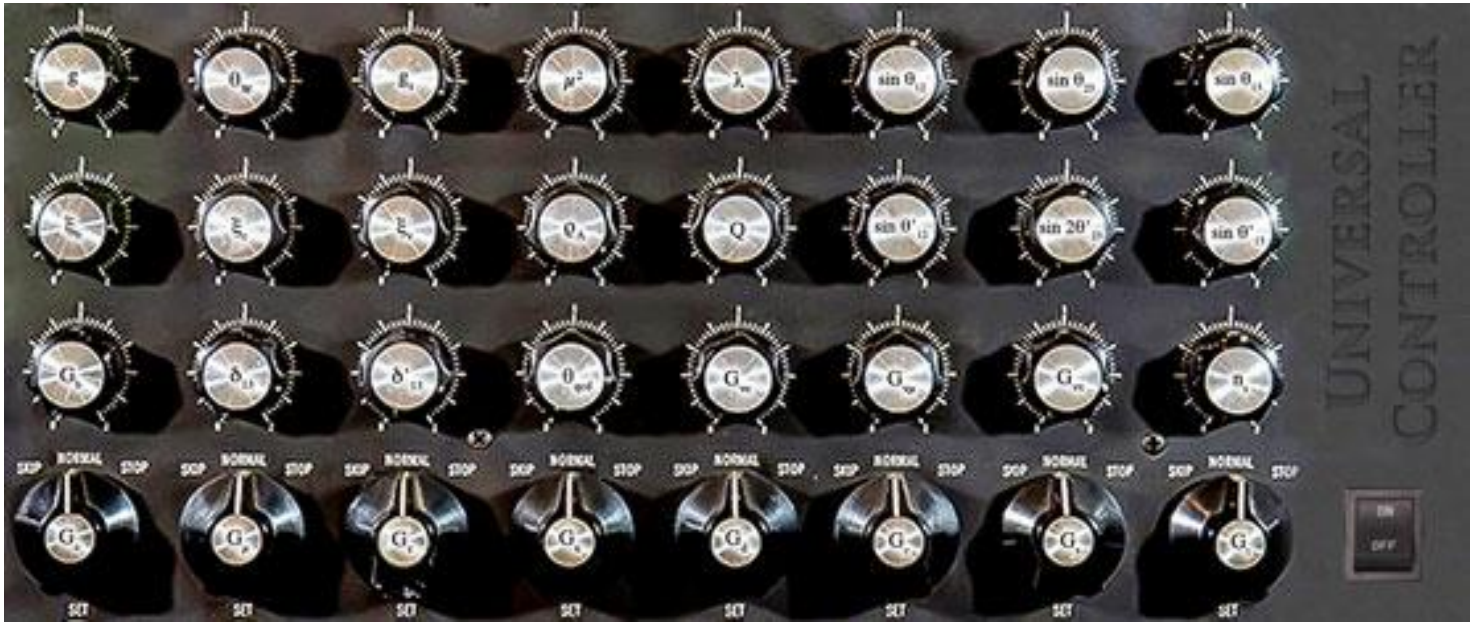
- The cosmos that we observe seems to be “fine tuned” for intelligent life.
  - See Robin Collins, p. 187-195 in the textbook.



Cosmological Fine Tuning

- The cosmos we observe is defined by many many "parameters" (fixed numbers) whose values seem arbitrary.
  - E.g. why does light travel at 299,792.458 km/s?
  - Why is the gravitational force between protons 10^{36} times smaller than the electric force?
  - Why do the elementary particles have these particular masses? Neutron = 1836.68 electrons, Proton = 1836.15 electrons.
  - Etc.

33 Dials



- Max Tegmark (cosmologist at MIT) says that the properties of our universe are determined by 33 basic parameters.
  - Many of these have to be adjusted very precisely to make life possible.

Options

- **Theism**: The self-existent being chose the dial settings, intending life to emerge. (Hence the self-existent being understands physics and biology.)
- **Anthropic Principle**: The dial settings are explained as an 'observation selection effect'. No observer could possibly see any other settings.
- **Multiverse** (+ anthropic): There are many universes, each with its own random setting of the dials. With enough universes, at least one will be fine tuned for life. (And only such universes can be observed.)

Anthropic principle

- Is a multiverse needed?

- Can we explain why the universe we observe is 'biophilic' simply by saying that *no other kind of universe could be observed*?
- ['biophilic' = favourable to life]

- John Leslie's firing squad analogy seems to suggest not.

Some selected issues

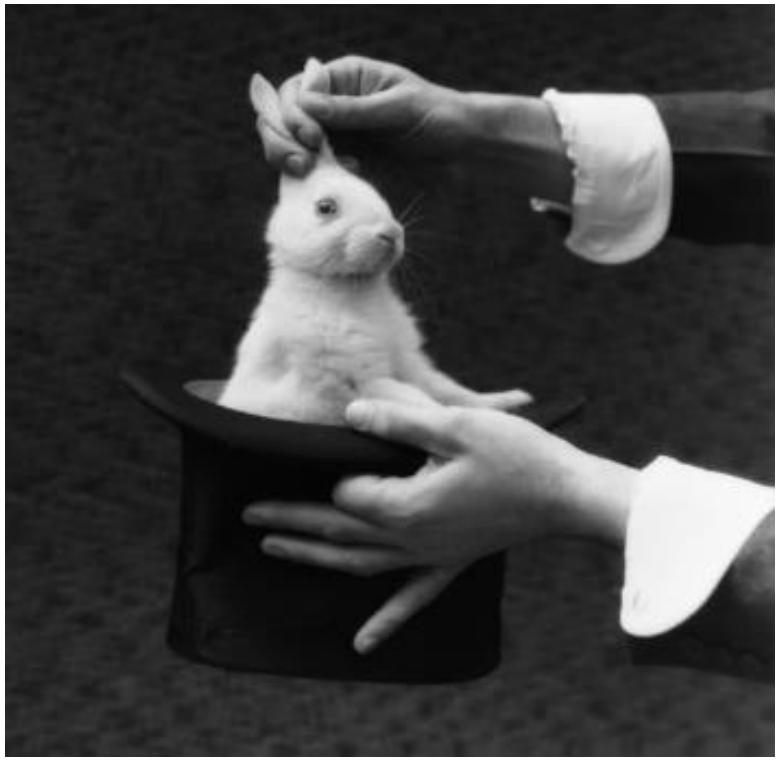
- Perhaps the fine-tuning argument suffers from a lack of imagination?
  - Maybe a very different kind of life could exist in possible universes that seem sterile to us?
- Perhaps the dials are set by some deeper physical laws? (Or even by logical necessity?)
- The usual physical theory that provides a multiverse is the 'cosmic inflation' theory, that posits a brief period of rapid expansion, just after the big bang.
  - One problem here is that inflation itself seems to require fine-tuned conditions in order to occur.

3. Complexity from nowhere?

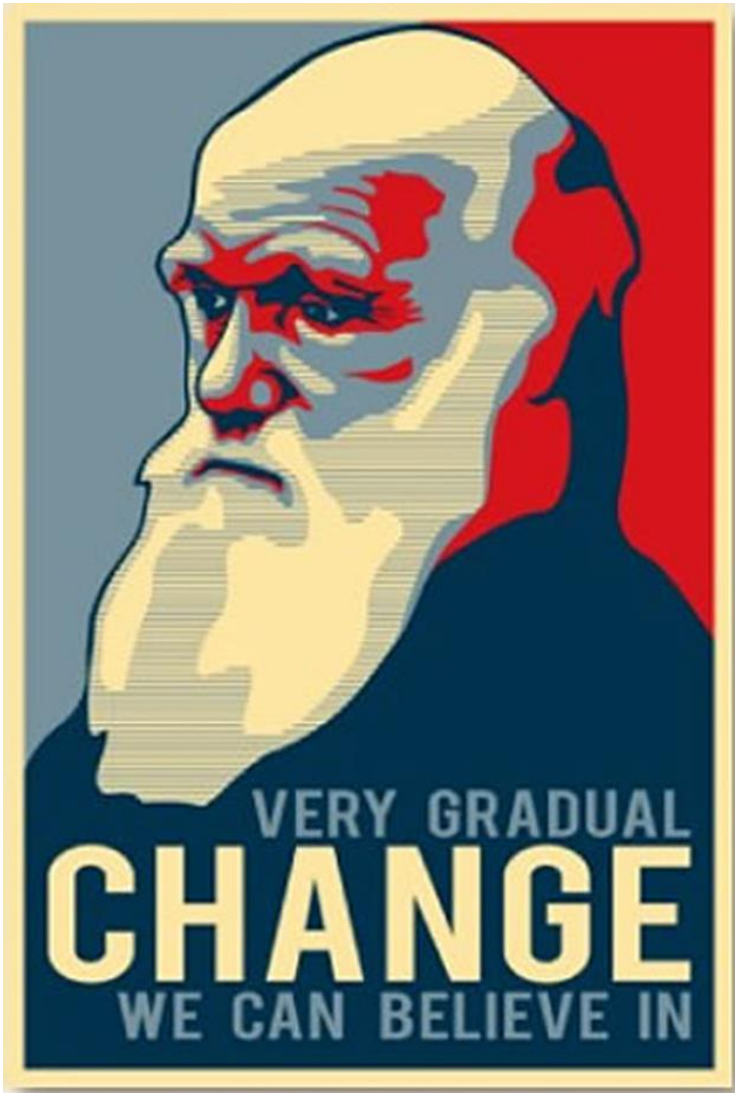
- Naturalistic views of evolution (e.g. the modern synthesis) claim that (under the right conditions) *matter organises itself* into living organisms.

- Initially, the earth is sterile. Later it contains spiders, cedar trees and humans. *And it had no help*.

- This idea strikes many people as absurd, but is it?



Complexity from nowhere



Complexity and Embryology

How does it happen?

- **Preformation** (then called “evolution”): The embryo ‘unrolls’ or ‘unfolds’ according to a pre-determined plan. (E.g. the adult structures exist from the start, in miniature.)

- **Epigenesis**: The embryo is initially formless, so that its structure emerges gradually, over time.

Structure from nothing?

“Matter in motion, by itself, would not seem to have the capacity to produce these results. How could matter become formed when it was not? How could the emerging form acquire the capacity to function without some vital force or factor that was not strictly material? This was the problem for materialists.”

Maienschein, *Stanford Encyclopedia of Philosophy*, entry on epigenesis.

Complexity and Embryology

"From our perspective today, the epigeneticists were right; organs differentiate sequentially from simpler rudiments during embryological development; there are no preformed parts. But the preformationists were also right in insisting that **complexity cannot arise from formless raw material**—that there must be something within the egg to regulate its development."

Stephen J. Gould, *Ever Since Darwin* (1977) 205-6.

Appeal to an old earth

- **Problem**: According to the MS, the development of life is like epigenesis. Complexity arose from formless raw material.
- One might see a simple solution here: The earth is vast, and mind-bogglingly *old*.
- Given enough space and time, anything will happen, so the usual principle that **complexity cannot arise from formless raw material** doesn't apply.

E.g. Monkeys and Typewriters

- Given enough monkeys, and enough time, one monkey will write the complete works of Shakespeare.

Not enough time for that

- But of course the time needed for this is to happen (with reasonable probability) is ridiculous.
- The same will be true of life appearing in the visible universe, in the first 14 billion years, *if the laws of physics we have don't strongly favour living over non-living arrangements of matter*.
- There are just too many possible arrangements of the matter in (say) a rabbit, and almost all of them are gunk.

"Of all the trillions of trillions of ways of putting together the parts of a body, only an infinitesimal minority would live, seek food, eat, and reproduce. True, there are many different ways of being alive – at least ten million different ways if we count the number of distinct species alive today – but, however many ways there may be of being alive, it is certain that there are vastly more ways of being dead! We can safely conclude that living bodies are billions of times too complicated – too statistically improbable – to have come into being by sheer chance."

- Richard Dawkins, "The Improbability of God", *Free Inquiry*, Vol 18, No. 3, 1998.

Are the laws of physics special?

- So the modern synthesis (and other naturalistic theories of evolution) require that the laws of physics are very special.
- They must be ‘fine-tuned’, in order for matter to self-organise into living organisms.

A dilemma

- If this reasoning is correct (is it?) then naturalists face a dilemma here.
  1. The laws really are fine tuned for life, to an astonishing degree – *far* more than the physicists are saying. How do we explain this?
  2. The laws of physics we have (simple, local, symmetric, etc.) could not possibly favour the formation of life that strongly. But then life is a statistical miracle.

Swinburne opts for #1

"So our question becomes—why are there not just any laws of nature, but laws of a particular kind such that together with the initial matter-energy at the time of the 'Big Bang' would lead to the evolution of human bodies. … **I shall argue that the laws and initial conditions being such as to lead to the evolution of human bodies is very improbable *a priori*,** but fairly probable if there is a God who brought it about, and so we have a further substantial C-inductive argument for the existence of God."

Richard Swinburne, *The Existence of God*, 2nd edition (2004), p. 172.

I've argued for #2

Synthese (2011) 181:255–275
DOI 10.1007/s11229-010-9801-8

Self-organisation in dynamical systems: a limiting result

Richard Johns

Abstract

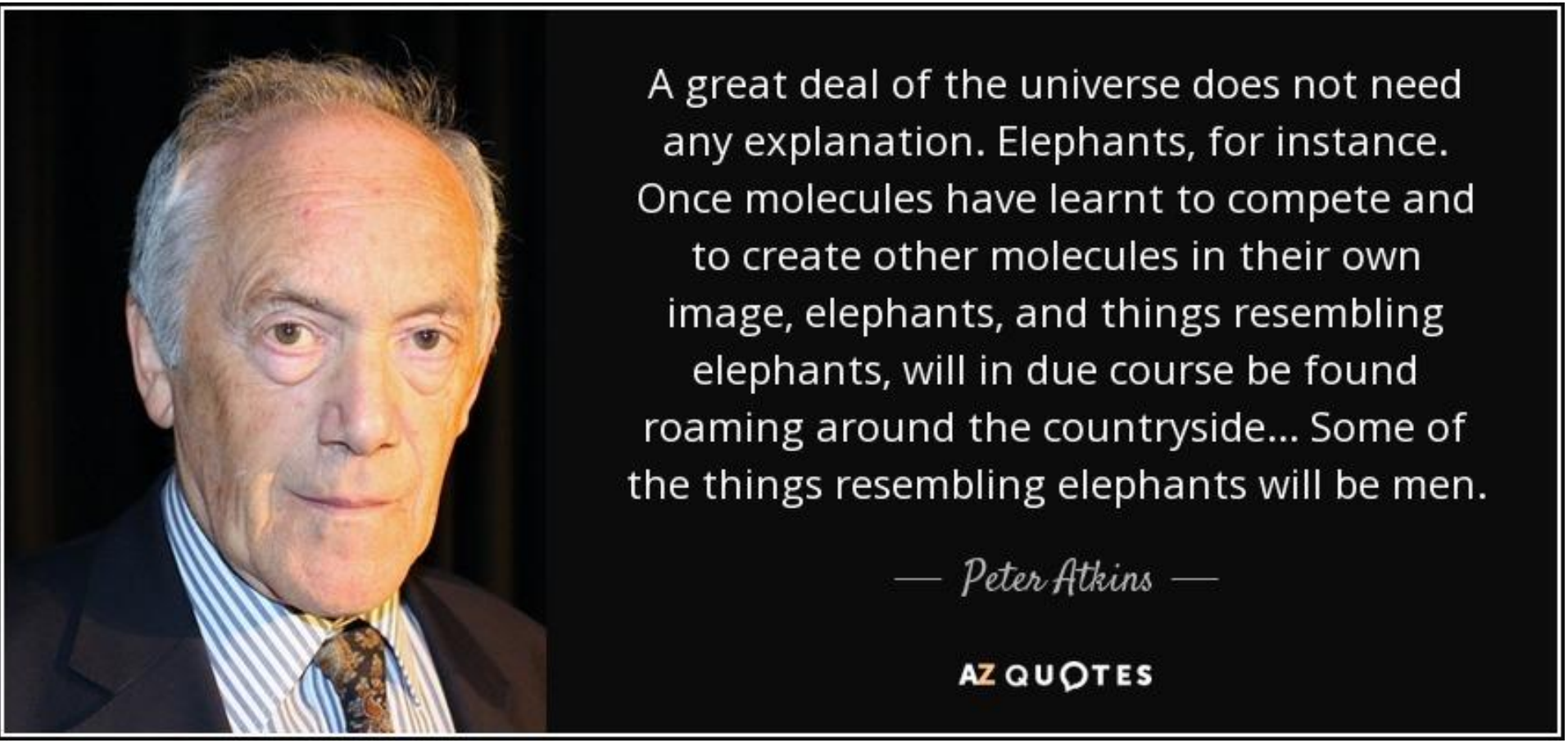
…

dynamical laws, due to their large size and high degree of irregularity. In particular, it is shown that since dynamical laws operate locally, and do not vary across space and time, they cannot produce any specific large and irregular structure with high probability in a short time. These arguments suggest that standard evolutionary theories of

Doesn't *natural selection* solve this?

- Advanced life (e.g. elephants) is *very* unlikely to appear by *ordinary* physical processes.
- But if simple self-replicating molecules come to exist (by chance) then **the process of evolution by natural selection gets started**.
- This mutation-selection mechanism is strongly biased toward function, so things like elephants are now probable.

e.g. Peter Atkins (chemist)



(Statistician and geneticist, co-creator of the ‘modern synthesis’ theory of evolution)

RA Fisher
1890 - 1962

“Natural selection is a mechanism for generating an exceedingly high degree of improbability”

In terms of probabilities

- Prob(elephants | Laws) ≈ 0
- Prob(elephants | Laws & self-replicators) $>> 0$
- Also, Prob(SR | Laws) $>> 0$

- However, *these statements are mathematically inconsistent*.

Probability and Information

- When dealing with very small probabilities, it's useful to work with logarithms.

- E.g. an event with probability of $2^{-1,000}$ can be defined as having "1,000 bits of information".

- **Definition**: $\text{Info}(A) = -\log_2[\text{Prob}(A)]$

- E.g. if you generate the sequence 01101111000101 by flipping a fair coin, then this has probability 2^{-14} and so has 14 bits of information.

Information can't be created

- Suppose that Info(elephants | laws) = some large number *N*, e.g. 1,000,000,000. (A very very very tiny probability $10^{-300,000,000}$)
- Also, suppose Info(elephants | Laws & self-replicators) = *m*, where *m* is much smaller than *N*.
  - E.g. *m* might be 40. (Giving a probability of 1 in a trillion)
- In other words, the presence of self-replicators reduces the information content of elephants by (*N* – *m*) bits.
- Then, using the rules of probability, Info(S | L) $\geq$ *N* – *m*.
  - I.e. self-replicators are massively unlikely to appear.
  - E.g. the probability might be $2^{-999,999,960}$.

(Always show your work!)

- E = elephants exist
- S = self-replicators (i.e. natural selection) exists
- (All probabilities are conditioned on the fundamental laws of physics L, and '¬' means *it's not the case that*)

Proof:

$P(E) = P(E \mid S)P(S) + P(E \mid \neg S)P(\neg S)$ (Theorem of total probability)

- N.B. $P(E \mid \neg S)$ is approx. 0.

Then $P(E) \geq P(E \mid S)P(S)$.

Taking negative logs to base 2:

$-\log P(E) \leq -\log P(E|S) - \log P(S)$

Hence $\text{Info}(E) \leq \text{Info}(E|S) + \text{Info}(S)$

Hence $\text{Info}(S) \geq \text{Info}(E) - \text{Info}(E|S)$, as required. ■