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Living Objects

Margarida Hermida and James Ladyman

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Abstract

This paper addresses the question ‘what is an organism?’. Extant theories of organismality only provide a partial answer because they do not include an account of composition on which an ontology of living entities can be based. Here we develop a new account of what organisms are, based on a naturalistic answer to the special composition question, the bound state view. We argue that physical structure, including the existence of a boundary, is essential for life, and that, therefore, organisms are a particular kind of composite physical object – living objects. The bound state account of composition explains how composite physical objects exist in the world, and the property ‘life’ distinguishes the subset of those objects which are organisms. Our view obviates the need for disjunctive accounts of composition for living and non-living entities, placing ‘organism’ within the context of a broader scientific ontology, while at the same time providing a clear criterion of organismality that can be used in adjudicating problematic cases of biological individuality.

1. Introduction

Biology is the (scientific) study of life, but most biologists do not study the nature of life itself, rather they study particular entities and processes within the living world. There are many kinds of biological thing. For example, species, ecosystems, organisms, genes, ribosomes, axons, nervous systems, etc, can all be said to be part of the living world and are studied by biologists.[1] Yet only organisms are alive.[2] Organisms are what instantiate the property 'life'. Organisms are living things.

This paper addresses the question 'what is an organism?'. An adequate theory of organismality should say which things are living organisms, how they can be individuated and counted, and what determines their spatio-temporal boundaries and their persistence conditions. It should illuminate the distinctive nature of organisms as living things, placing them in the context of wider scientific ontology. We develop a new account of organismality based on a naturalistic answer to the special composition question, namely the bound state view. Our account overcomes many of the problems of extant theories of organismality which tend to make (often implicit) problematic metaphysical assumptions.

The nature of life is notoriously elusive. It may be that, as Cleland (2019) argues, we are not in a condition to formulate an adequate definition or theory of life, especially in the absence of extra-terrestrial examples. Although we know a lot about life on Earth and how it works, since all life on Earth descends from a common ancestor, it is difficult to identify which of its features are contingent despite being universal or nearly so (e.g. so-called 'frozen accidents' such as the genetic

[1] 'Thing' is used here in a general sense to encompass objects, events, processes, etc.

[2] Cells in multicellular organisms are also alive. Our view is that they too should be considered organisms, in the same way as unicellular organisms (see §5). Readers who disagree that cells in multicellular organisms are organisms should understand our claims as being about 'organisms and cells' instead.

code) on Earth, and which ones are necessary. §2 considers how life is understood in exobiology to motivate the claim that metabolism is necessary for life (so A-life and other abstract entities are not alive). We explain the importance of physical structure for metabolism, and show that what makes organisms alive depends on the existence of a physical boundary between the organism's functional components and the environment. Hence, organisms are spatially bounded physical objects. Since the physical objects in question are not fundamental but composite, this requires an account of composition, and we draw on a recently developed naturalistic account, namely the bound state view (McKenzie & Muller 2017; Husmann & Näger 2018; Waechter & Ladyman 2019) (§3).

Our main thesis (§4) is that organisms are a particular kind of physical object, namely living physical objects. We argue that, if all composite physical objects are bound states of matter, and all organisms are composite physical objects, then all organisms are bound states of matter. Organisms differ from other physical objects, however, in being chemically open systems which actively exchange matter (as well as energy) with the external environment, in such a way as to have the capacity to maintain and produce new bound states within themselves, using energy and materials harvested from the environment, as part of their life processes. Hence, organisms are living objects.

Questions concerning the nature and individuation of organisms are often framed as 'the problem of biological individuality' (Clarke 2013; Olson 2021), where 'biological individual' is taken to be roughly synonymous with 'organism'. Several authors have pointed out, however, that these two concepts are distinct and should not be confused (Pradeu 2016; Okasha 2022). One reason for this is simply that there are many kinds of biological individual, so 'biological individual' can mean many different things. For example, one of the most important notions of individual in biology is that of an 'evolutionary individual' or 'Darwinian individual' (Godfrey-Smith 2009), which means, roughly, any entity which can function as a unit of selection. The problem is that many entities can be units of selection – often simultaneously, as in multi-level selection (Okasha 2006). Genes, viruses, cell lineages, populations, and species can all be evolutionary or Darwinian individuals, yet are not organisms. There is also a vast literature on the individuality of species, the main claim of which is that species are spatio-temporally restricted particular entities, as opposed to spatio-temporally unrestricted natural kinds. Either way, species are not alive, and nor are many other biological individuals mentioned above. Hence, the question of what organisms are is not the problem of biological individuality as such.

There are many other things in biology which are 'individuals' in the sense of being particular things which can be counted: chromosomes, organs, limbs, leaves, stamens, claws, etc, are all biological individuals in this sense – they are well-individuated entities which can be counted and are important in biological theory – yet are clearly not organisms. As recently pointed out by Okasha (2022), this reflects a deeper problem, which is that 'biological individual' does not express a sortal. To say that something is a 'biological individual' invites the question 'what kind of individual?' – unless it is implicit in the context. We do not discuss the question of biological individuality in general, but focus instead on the specific question of the nature of organisms, which are a particularly important kind of biological entity. Of course, there are questions about the individuality of organisms, some of which are addressed in §5, which discusses some applications of our view to well-known problematic cases.

Recently, Olson (2021) has pointed out that theories of organismality only say whether something is an organism given some metaphysical account of what material things exist. This is a problem for all extant theories of what organisms are, since they either fail to provide such an account, or make problematic metaphysical assumptions concerning what physical objects exist. Here we extend a naturalistic account of composition, the bound state view, to the case of organisms.[3] A naturalistic view of composition applied to organisms avoids many of the problems that plague other accounts of organismality, and is firmly within naturalistic metaphysics based on our best scientific knowledge. This makes our view particularly relevant for the philosophy of biology. Furthermore, naturalised metaphysics can play an important role in the unification of the sciences, as argued by Ladyman & Ross (2007). Here we contribute to the unification of biology and physical science.

2. Physical structure is essential for life

The most conspicuous features of life are its activity and high degree of organisation. Life involves a variety of processes which include metabolism, growth, self-maintenance and repair, reproduction, and evolution. Schrödinger famously described life as 'orderly and lawful behaviour of matter', considering that 'a piece of matter' may be said to be alive when it 'goes on "doing something", moving, exchanging material with its environment, and so forth' (Schrödinger 1948: 70). Living entities can carry out all this activity because they harvest free energy from the environment and use it both to maintain their own highly ordered structure, and to perform work on the environment (Schulze-Makuch & Irwin 2018: 20).

On Earth, metabolic reactions always involve electron transfer, whether the source of energy is light (photosynthesis), non-biological molecules (chemolithotrophy), or biological compounds (chemoorganotrophy) (Schulze-Makuch & Irwin 2018: 8-9). While there are inorganic analogues of these processes, in living entities these reactions do not occur randomly, but are controlled by the organism itself. They also involve a form of 'energy budgeting' where organisms

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[3] As a general account of physical composition, the bound state view also applies to other biological objects which are not organisms, including many of the biological individuals of different kinds mentioned in the previous paragraph.

harvest free energy from the environment and store it in a convenient molecular form, which can later be converted back into usable energy (Boden 1999: 236-238).[4] Metabolism, understood as the active exchange of energy and matter with the environment, regulated by the organism, involving various anabolic and catabolic chemical reactions which maintain the organism far from thermodynamic equilibrium, is thus usually considered a central feature of life.

Not all definitions of life take metabolism to be the most important feature of life; some focus primarily on reproduction or evolution. Partly this is because many definitions of life try to do two things at once, namely to define life as the collective phenomenon as in 'Life on Earth', and to define life as a property of some physical objects (the living objects of our title). Despite the importance of reproduction and evolution for life considered as a 'historical-collective phenomenon' (Ruiz-Mirazo et al. 2004), neither is strictly speaking necessary for something to be alive. Evidently, failure to reproduce, or even the absence of this capacity altogether, does not preclude an individual organism from being alive (Chodasewicz 2014: 43; Schulze-Makuch & Irwin 2018: 16).[5] Evolutionary criteria also cannot apply to individual organisms, but only to collective entities such as populations and lineages, and therefore presuppose the existence of the entities which form them. In fact, even definitions of life which use primarily an evolutionary criterion, such as NASA's working definition – 'life is a self-sustained chemical system capable of undergoing Darwinian evolution' (Joyce 1994) – presuppose the existence of metabolically active living entities, as evidenced by the explanation given for the requirement that the system be 'self-sustained': it 'refers to the fact that living systems

[4] For Earth life, this is usually ATP (adenosine tri-phosphate), which can be degraded into ADP (adenosine di-phosphate), releasing energy.

[5] Although some replication capacity is instantiated even in organisms that do not reproduce, but nonetheless replicate their macromolecular components (Schulze-Makuch & Irwin 2018: 16).

contain all the genetic information necessary for their own constant production (i.e., metabolism)' (Joyce 1994: xi).

Unlike other physical objects, organisms are chemically open systems that actively exchange matter with the environment, as well as energy. Inert physical objects, such as rocks, also exchange energy with the environment to some extent, e.g. by heating up and then cooling down; but they do so passively, and they do not exchange matter – although they may lose matter over time through erosion, or gain it through deposition. In contrast, organisms are constantly and selectively exchanging matter with the external environment, incorporating substances which are necessary for their maintenance and repair, and excreting waste products. In doing so, they are able to maintain a lower state of entropy within themselves, exporting the excess entropy to the external environment, as argued by Schrödinger (1948).

All of these exchanges of energy and matter, as well as the maintenance of a lower state of entropy compared to the surrounding environment, require a boundary. One of the main features of living cells is the distinction between the inside and the outside of the cell, a distinction which is maintained by the existence of a physical barrier, the cell membrane. Thus, the cell is a physical object that includes the cell membrane and all the contents located on the inside of this barrier (which may include solid, liquid, and even gaseous components), which are bound by electromagnetic forces to the space inside the cell membrane.

The importance of physical boundaries for the existence of life has long been recognised in astrobiology. Schulze-Makuch and Irwin consider it a fundamental characteristic of a living thing that it be a 'self-sustaining bounded local environment in thermodynamic disequilibrium with its surroundings' (2018: 19). In fact, cell membranes, cell walls, and other similar structures are important in at least four ways:[6]

(1) They contain the organism within a restricted spatial location, preventing its components from being lost (thus making the organism a coherent physical object), and maintaining close proximity between the substances involved in the various chemical reactions necessary for life.
(2) They allow the organism to engage in selective exchange of matter with the environment, not only by having a semi-permeable structure but also structures dedicated to passive selective transport (such as channel proteins), and even to the active transport of solutes against a concentration gradient, expending energy to do so (such as pump proteins). Therefore:
(3) They allow the organism to maintain a homeostatically controlled environment, where entropy is minimised, on the inside of the barrier.
(4) In addition, membranes (whether the cell membrane itself or, in eukaryotes, mitochondrial and chloroplast membranes) are fundamentally involved in the process of energy acquisition from the environment which, for all life on Earth, involves moving electrons (free electrons or from an electron donor) through a membrane, to an electron acceptor, and simultaneously pumping protons across a membrane to generate the energy used to produce ATP, the energy currency of the cell. While it is conceivable that other forms of life might use different biochemistry, the ubiquity and convenience of electrons as a free energy source suggests that energy acquisition mechanisms based

[6] All cells are surrounded by a cell membrane, which separates the inside of the cell from the external environment. Many bacterial and eukaryotic cells (especially in algae, plants, and fungi) also have a rigid cell wall, which provides structural support and can also function as an additional filtration barrier.

> on the movement of electrons across a membrane might be a universal feature of life (Cockell 2016).

In sum, for any entity to be alive it needs to have a boundary that is itself a physical object, and which is strong enough not only to hold itself together, but also to hold all the other necessary components for life on the inside. It must not however be completely impermeable, but must allow the organism to engage in selective exchanges of materials with the external environment. The fact that metabolism requires the existence of physical boundaries means that organisms are necessarily physical objects. The importance of physical structure for living entities is thus a consequence of the requirements of metabolism itself.[7]

Organisms have the impressive capacity to engage in and coordinate their own metabolism, growth, reproduction, and other life processes. But where do these capacities come from? They certainly don't come from a special vital force, or from anything other than garden variety physics and chemistry. These capacities can only come from the physical structure of the organism, some of which is produced by the organism itself, following genetic instructions laid down by evolutionary

[7] Although arguing that metabolism is essential for life, Boden (1999) rejects the claim that metabolism must be continuous at all times. Many organisms are able to survive for long periods of time in a state of cryptobiosis, for example in a frozen (e.g. wood frogs; many invertebrates) or dehydrated state (e.g. tardigrades; plant seeds) where their metabolic activity is suspended. As long as its structural integrity is preserved and the organism does not irreversibly lose the capacity for coordination of life processes, the organism might be said to be alive, even though it is temporarily ametabolic. Some biologists studying cryptobiosis have therefore concluded that the structural integrity of the organism has priority over its active metabolism. Death does not consist in the stopping of metabolism, which can be a reversible situation, and even forms part of the life strategy of many organisms that have this capacity; it is only when the physical structure of the organism is irreversibly damaged or destroyed that the organism dies (Keilin 1959: 187).

trial and error, and some of it is directly transmitted from one organism to another during reproduction, and is only maintained, not produced *de novo*, by each individual organism.

Given the importance of physical structure for life, organisms should be considered physical objects and, given the complexity of this structure, they are certainly not simples. Organisms are therefore a particular case of a composite physical object – they are physical objects which have the property 'being alive' or, in other words, living objects. As a consequence, any solution to the problem of organismality will require a naturalistic account of composition, i.e. an answer to the special composition question, which allows us to say what composite objects there are, and which can then be applied to the particular case of organisms, understood as living objects. The next section assesses a recently suggested approach which is particularly promising for our project since it is entirely compatible with a metabolic conception of life.

3. The bound state answer to the SCQ

The Special Composition Question asks when a plurality of things composes something or, more precisely, 'when is it true that ∃*y* the *x*s compose *y*?', where the *x*s refer to two or more things (van Inwagen 1990: 30).[8] Somewhat surprisingly, the most popular philosophical answers are extremely counterintuitive: some philosophers argue that it is never the case that a plurality of things composes something else, i.e., there are only simples – this is the *nihilist* view (defended for example by Sider 2013); others argue that any random assemblage of things always composes a further object – this is known as *universalism* (defended by Lewis 1986, among others) or, in its more

[8] Where 'the *x*s compose *y*' is an abbreviation of the expression 'the *x*s are all parts of *y* and no two of the *x*s overlap and every part of *y* overlaps at least one of the *x*s' (van Inwagen 1990: 29). Van Inwagen uses "the *x*s" as a plural referring expression to avoid talking about pluralities, multiplicities, etc, which sound a lot like entities themselves.

extreme version, *plenitude* (defended for example by Sosa 1987)[9]. In between lie so-called 'moderate', minimalist, or exceptionalist views, which consider some things as composite objects, but not others. For example, van Inwagen's own view about composition is that some things compose a further object when their activities constitute a life (1990: 82), whereas Merricks argues that persons, and perhaps some other cognitively sophisticated animals, are the only composite objects that exist (2001: 114).

Henceforth our concern is with the composition of physical objects. None of these views seems attractive, or even plausible in this context. The main motivation for them is the perceived need for a clear criterion of composition which avoids problems of arbitrariness and vagueness at all costs. In doing so, however, they either eliminate most ordinary and scientific objects, or else admit into the ontology arbitrary sums of bits and pieces of actual objects, such as a '*trog'*, a supposed object composed of a dog and a tree trunk (Korman 2015: 2). By comparison, a 'moderate' ontology like van Inwagen's, which accepts the existence of living organisms but no other composite objects, certainly seems like an improvement, but it still fails to account for most of the objects we encounter and manipulate in our daily lives, much less those studied and described by science.

Nihilist, universalist, and the exceptionalist views mentioned above are examples of what Humphreys (2013) disparages as 'speculative ontology': ontological landscapes which deliberately ignore the entire scientific enterprise, in favour of a priori assumptions and appeals to intuition.

[9] Plenitude is even more extreme in its permissiveness as, in addition to objects composed of arbitrary mereological parts, it also admits the existence of objects with extraordinary temporal and modal properties, such as the *incar*, which refers to any part of a car which is essentially inside a garage, and ceases to exist if the car is taken out of the garage (Hirsch 1982: 32); and the *snowdiscall*, 'an object made of snow, that has any shape between being round and being disc-shaped, *and* that has the following strange persistence conditions: it can survive taking on all and only shapes in that range' (Korman 2015: 17, from an example due to Sosa 1987: 178).

These extreme views have little to recommend them since they make no distinction between the composite objects endorsed by science and imaginary ones for whose existence there is no empirical evidence. For this reason, these accounts have little relevance outside of the ‘ontology room’.

Recently, however, some philosophers (McKenzie & Muller 2017; Husmann & Näger 2018; Waechter & Ladyman 2019) have argued for a naturalistic view of composition based on physical science: the bound state view.[10] Although the different extant versions of the bound state view are similar in many respects, this paper is based on Waechter and Ladyman (2019), whose account is more rigorously developed, and deals specifically with questions that are particularly relevant for the case of organisms, such as whether composite objects can themselves compose other composite objects. Waechter and Ladyman (2019: 109) summarise their thesis thus: ‘in order to compose something at t_0, physical objects must form at t_0 a connected plurality under the relation of forming a bound state’.[11] Roughly, a bound state is one in which the kinetic energy of the parts is less than their potential energy.[12] More precisely, then, the bound state view of composition can be stated as follows:

The *xs* compose *y* at t_0 iff the *x*s form a chain of bound states at t_0.

[10] Luper (2022) defends a ‘bonding’ criterion of composition, but he leaves the definition of ‘bonding’ intuitive and does not engage with physics.

[11] ‘Forming a bound state’ is a monadic predicate, but it nonetheless expresses a relational fact, just as ‘is a mother’ is a monadic predicate that expresses a fact that involves relations and not only intrinsic properties.

[12] This is a rough statement of a complex set of conditions. See Waechter and Ladyman (2019: 109-116) for a detailed discussion of how the bound state view should be formulated taking into account several complications (such as that not all bound states are formed by pairs of particles, that bound states can occur between pluralities of objects, and that composite objects can compose further composite objects).

The bound state view has a number of advantages: first of all, it can be applied to any number of constituents, and allows for composite objects made of other composite objects; it applies to all sorts of physical systems, including both quantum and classical ones, relativistic and non-relativistic, etc, and even to future physics; the criterion of composition is quite sharp, so vagueness is avoided; the account is extensionally adequate (i.e., it captures all objects we would want it to capture, while excluding arbitrary sums), without attributing to them properties which they do not have, such as having continuous boundaries (Waechter & Ladyman 2019: 116-120). It also fits well with the intuition that the way we trace the careers of objects is due to their being *separately movable* things, i.e. 'a detached thing that tends to move together with its parts' (Hirsch 1982: 86). Most importantly, the distinction between bound and free states captures a real feature of nature, which relates to the discrete nature of the different energy levels that may be occupied by quantum particles, a phenomenon which underlies the chemical bonds that hold most objects together (Waechter & Ladyman 2019: 117).

On this view, most ordinary physical objects are indeed composite objects not because they correspond to the objects of common-sense, but because the matter that composes them is in a bound state. In other words, there are physical forces acting upon the component parts of the object which hold them together. It may be objected that the bound state view says something trivial: things compose something when they're somehow bound together. That is indeed what the view says, but it is not a trivial statement; on the contrary, it is a scientifically relevant view, based on a valid criterion accepted in scientific practice. It is also not vague: in any given situation, there is a fact of the matter as to what the potential energy is and why. For example, the atoms composing a rock are held together by electromagnetism, and the nuclei of the atoms are held together by the strong nuclear force.

Van Inwagen suggests thinking about the SCQ in a practical way: if we had several nonoverlapping objects, what could we do to get them to compose something? (1990: 31). As it happens, we are familiar with a variety of ways in which new objects can be *made*, by bringing about chemical and/or physical processes that *bind* things together. In fact, as pointed out by Husmann and Näger (2018) in their discussion of van Inwagen's account, the putative criteria of composition involving 'some type of physical bonding' assessed and rejected by van Inwagen (1990: ch. 6), such as *fastening*, *cohesion*, and *fusion* can indeed generate new physical objects (whereas *contact* is clearly insufficient, because it does not produce bound states). For example, some pieces of paper can be stapled together to produce a new composite object; bricks and mortar together compose a wall; some organic compounds can be baked into a cake; a variety of different components are welded, screwed, or glued to each other in the production of a car; and some twigs and mud are glued together into a solid construction by a nesting house martin.[13]

Although all of these are examples of non-scattered objects, being in a bound state is not the same thing as being non-scattered, and there are indeed some scattered composite objects under the bound state view, namely ones that are gravitationally bound. In most objects with which we are familiar, the main physical force involved is the electromagnetic force, which holds atoms together and is responsible for solid objects maintaining their shape and for processes like gluing things together. This force is both attractive and repulsive, which is why no objects bound by it can be scattered. However, gravity is only attractive, so there can indeed be scattered objects which are nonetheless bound together by gravity; for instance, galaxies. We should point out, though, that the existence of certain scattered objects under the bound state view cannot be used as an argument for a plenitudinous ontology, because they are not arbitrary; they are held together by physical interactions.

[13] Although many of these examples refer to artefacts, they are considered here only as physical objects, and not *as* artefacts per se, although we agree with Waechter & Ladyman (2019) that any account of composition for artefacts should be compatible with the bound state view.

Similarly, we agree with Husmann & Näger (2018: 33) that objects that are not fixed to the Earth, like animals and loose rocks, still count as part of the planet, because they are gravitationally bound to it. The same is true of the oceans and other bodies of water on the surface of the Earth, as well as the atmosphere. It should be noted that these objects on the surface of the Earth do not by themselves compose a further object. It is only all the things in a potential well that form an object, not any random plurality of them. Subpluralities of a plurality in a bound state are not, ipso facto, in a bound state themselves – although some of them might be in a bound state together (composite objects can also form further composite objects).

The next section applies the bound state answer to the SCQ to the special case of organisms.

4. Applying the bound state account of composition to organisms

The main proponents of the bound state view clearly take organisms to be included in this framework. McKenzie and Muller (2017: 235) assume that '[c]ollections of particles that form a living physical object form a bound state', and Waechter and Ladyman state that any account of how the SCQ applies to organisms should be compatible with the bound state view (2019: 108-109). Here we extend the bound state view into the biological realm, by developing an account of organisms as living objects.

Our thesis is that organisms are physical objects of a particular kind, namely living objects. If all physical objects are bound states of matter, and organisms are physical objects, then organisms are also bound states of matter. Organisms are a subset of all composite objects, namely those composite objects that are alive. Hence, there are two conditions for something to be an organism: something is an organism if and only if (1) it is a composite object, and (2) it is alive. Assuming a metabolic criterion of life, this can be stated more precisely as follows:

(1) The *x*s compose *y* at t_0 iff they form a chain of bound states at t_0 [composition], and

(2) *y* is an organism iff the chain of bound states formed by the *x*s at t_0 has the capacity to engage in and coordinate metabolic activities [life]

As we saw in §2, the physical boundaries of organisms, whether in the form of cell membranes and cell walls, or in the form of various kinds of tegument, skin, exoskeletons, and other structures, which are themselves in bound states, are particularly important in making organisms physical objects, as the various component parts of the organism are contained within these boundaries (mainly by electromagnetic repulsion).

Besides these, many other bound states are found within organisms. In particular, weak bonds, which can form between molecules during relatively short periods of time, seem to be essential to a variety of life processes. Consider, for example, the short-term binding of oxygen to haemoglobin, or the temporary binding of molecular chaperones to protein products, which prevent their aggregation before the protein folding process is complete. DNA molecules in cells could also not function properly or even fit within the cell if they were not tightly wrapped around histones, positively charged proteins which bind to the negatively charged DNA molecule.

Organisms are highly complex composite objects which are themselves made of other composite objects. This is not compatible with van Inwagen's account, which admits only organisms and simples, and therefore cannot account for the existence of the organism's components, but is perfectly compatible with the bound state view, which can be extended to composite objects made of any number of other composite objects (Waechter & Ladyman 2019: 118), as long as they form a chain of bound states. This is a clear advantage of our view, since organisms are indeed composed of many composite objects, including complex structures such as ribosomes and cell membranes, without which they could not exist.

Van Inwagen (1990: 89) accepts one case in which organisms are composed of other composite objects: when those composite objects are themselves alive. This is the case of multicellular organisms, which are composed of living cells. However, this is clearly insufficient since not only do multicellular organisms also include non-living parts among their components (e.g., dead skin cells, hair, feathers, nails, tree bark, etc.), but many unicellular organisms, such as bacteria, are entirely composed of non-living parts, many of which are nonetheless composite objects. It is also not the case that any object composed of living parts is itself alive. For example, van Inwagen offers the hypothetical case of the paralysed handshakers – a case where two people shake hands and then cannot let go because their fingers become paralysed – as a counterexample to 'fastening' as a criterion of composition: "it is certainly not true that an object composed of you and me comes into existence at the instant our fingers become paralyzed" (1987: 31).[14] On the bound state view, however, an object thus composed *does* come into existence. This object is composed of two living objects forming a bound state, but it is obviously not itself alive. Organisms can also form composite objects with non-living objects. We have no objection to Husmann and Näger's (2018: 33) example of the gecko walking on a glass surface and temporarily forming a composite object together with the glass by adhering to it. More problematic cases of composition involving living and non-living objects are discussed in §5.

The living objects account of organisms obviates the need for a disjunctive criterion of composition such as that suggested by Husmann and Näger (2018), who argue that composition occurs if and only if bonding *or* life occurs; on the contrary, we argue that composition occurs only if there is a bound state; furthermore, some composite objects have the property 'life' (most, of

[14] Van Inwagen provides no reason *why* bonded organisms do not form a composite object; he just takes it to be obvious. Luper (2022: 24) suggests three possible reasons for this intuition: the fact that we usually tend to care about or be interested in organisms, but not in non-living objects made from organisms attached to each other; the fact that the object thus created is temporary; and the worry that organisms might cease to exist as objects in their own right when they become part of another composite object. The latter is not a worry on the living objects view, which allows for organisms to be parts of other composite objects (living or non-living), while continuing to be living objects themselves.

course, do not). This is preferrable not simply on account of being more parsimonious, but also because serious problems quickly arise if there are two separate criteria of composition, both of which can be applied to the same thing: for example, having a disjunctive criterion seems to imply that there are two co-located entities, a physical object and a living organism, with different criteria of identity, whereas on the living objects view, there is only one thing, a physical object which is alive. Husmann and Näger (2018) propose their disjunctive criterion because they believe it is possible for there to be organisms which are not physical objects, but are composed of scattered parts which do not form bound states, such as, for example, bee colonies or coral reefs (34). On our view, the bee colony cannot possibly be an organism because it is not even a *candidate* for being an organism, since there is no composite object which has the individual bees as parts.[15]

Olson (2021) argues that all accounts of biological individuality currently on offer are either inadequate or at least incomplete, as they only serve as criteria to decide whether or not something is an organism once there are already some candidate composite objects to begin with: ‘no definition of “organism” can be a theory of biological individuality on its own, but only in conjunction with a substantive claim about the ontology of material beings providing the candidates to which the definition is applied’ (Olson 2021: 79). For example, most people accept that, on the genetic view of biological individuality[16], two identical cells produced by mitosis would not be two organisms, but would instead be part of the same scattered genetic individual. But as Olson (72) correctly points out, this is so only *if* there is such a scattered object. He also suggests that the disregard for the question of composition in discussions of organismality is only appropriate if an unrestricted account

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[15] We have no objection, however, to the claim that the bee colony is a Darwinian individual (Godfrey-Smith 2009), or a unit of selection, or indeed that it exists. Many biological entities, including insect colonies, ecosystems, species, clades, etc, are quantified over by biology, and therefore there is good reason to think that these things exist. They are, however, neither physical objects nor organisms.

[16] One of the criteria of organismality currently on offer, though not a very popular one.

of composition, such as universalism or plenitude, is assumed as an unstated premise (75-76). This is indeed an unmotivated and highly non-naturalistic premise to accept, even more so in the context of philosophy of biology. Notwithstanding the autonomy of biology as a discipline, it makes little sense to develop an account of organismality which is entirely disconnected from any basis in physical science.

Olson's criticism may have gone too far, though, in that those who argue that, for instance, bee colonies, or a collection of scattered clones, are organisms do not need to assume plenitude or universalism; minimally, they are committed only to the view that there are at least some scattered objects. But on what grounds should we accept the existence of these particular scattered objects? Their proponents provide no metaphysical principle – unless they are indeed, as Olson thinks, assuming unrestricted composition. In contrast, on the bound state view, the existence of a physical object is always determined by a single principle: whether or not it is in a bound state.

While there are some scattered composite objects on the bound state view (e.g. large gravitationally bound objects discussed in §3), as far as we know no scattered objects can be alive, due to the scale at which metabolic reactions take place. The size of the bounded microenvironments which are essential for life as we know it is highly constrained by the sizes of molecules and the need to maintain a surface to volume ratio that allows diffusion to take place at sufficiently short time scales (Schulze-Makuch & Irwin 2018: 41). At such scales, electromagnetic forces are predominant, whereas gravity is too weak to form bound states.

On the living objects view, the bound state account of composition tells us what composite objects exist in the world, and a metabolic criterion of life determines which of those composite objects are alive. On our view, there are no organisms which are not living objects. Conversely, there are also no living objects which are not organisms. It might be tempting to think of isolated organs, such as an explanted liver prior to transplantation, as living objects but, strictly speaking, the liver itself is not alive. Rather, it is the liver cells that are alive – at least most of them, if the liver is still viable. Because most of the cells are still alive, there is indeed metabolic activity going on in this object, but this metabolism and its coordination are carried out by the individual cells, not by the liver as a whole. The liver has no life of its own. Although it is a composite object surrounded by a boundary and composed of living parts, the liver itself does not have its own metabolism, nor does it coordinate its life processes – the cells do, and so did the multicellular organism of which the liver used to be a part.

Although the bound state view is a synchronic account of composition, and does not provide an account of the persistence of objects over time, the living objects view suggests a criterion of persistence for organisms.[17] If something is an organism iff it is a living composite object, then plausibly it continues to be an organism if the following two conditions are fulfilled: (1) it continues to be a composite object (i.e., there is continuity of bound states, but replacement of parts is allowed), and (2) it continues to be alive (i.e., it continues to instantiate the capacity to engage in and coordinate metabolic activities).

Like all physical objects, an organism persists in virtue of bound physical states which maintain its physical integrity. However, in organisms these bound states are at least partly maintained, and new ones generated, by the activity of the organism itself, powered by energy extracted from the environment. Of course, all objects exist in an environment that may perturb them and so to persist they need to be robust enough. In terms of the bound state view, the kinetic energy needs not just to be lower than the potential energy, but low enough that standard perturbations are insufficient to raise it enough for the parts to escape. Organisms and other biological objects similarly need to be robust under the perturbations that they face in their environments, for example, currents and pressure in water.

[17] It it is unlikely that any account of composition can *entail* a thesis about the persistence of composite objects over time, though it may suggest one (van Inwagen 1990: 143).

Even very robust ordinary objects shed some of their material parts all the time. For example, a granite boulder is eroded to some degree by the wind. Organisms indeed continually exchange matter with the environment. However, over the timescales relevant to the organisms' biological processes, they are bound enough to lose a negligible proportion of their matter. Robin Hendry points out, in objection to the bound state view of organisms, that a cat is 'continuously shedding matter in various directions' (2021: 51). This is true but it is obviously compatible with the fact that the vast bulk of the cat stays bound together over the timescale of the cat's metabolic activity, and replacement of parts takes place gradually.

Organisms persist over time while enough of their physical structure is maintained which confers them the capacity to engage in and coordinate their own metabolic and other life processes (which include maintaining the bound states that constitute this structure); and die if their physical structure is damaged in such a way that those capacities are irreversibly lost. The destruction of the bound states which constitute the physical structures required for the activities of life amounts to the death of the organism. The living objects view therefore seems to cohere with the Termination Thesis, i.e., the thesis that organisms cease to exist when they die (Feldman 1992: 89-92), because death corresponds to the loss of the bound states which instantiate the physical structures or the organism that confer it the capacity to engage in and coordinate its metabolic processes. When this structure is irreversibly lost, the organism ceases to exist.

It might be objected that the living objects view assumes a clear-cut distinction between living and non-living, when in reality things are not so clear-cut (see for example Dupré & O'Malley 2009). It is true that our account does involve a distinction between living and non-living, but it need not be a completely sharp distinction. Despite this, it cannot be denied that there are many clear cases of living and non-living things – most objects are clearly either alive or not. Although we would not count viruses as organisms due to their lack of metabolism, they are certainly objects, and our account is compatible with the view that viruses are organisms due to their capacity to coordinate life processes within an infected cell.[18]

The bound state view provides a sharp criterion of composition (Waechter & Ladyman 2019: 117), thus avoiding the charge of vagueness which is often levelled at moderate accounts of composition. It should be noted, however, that bound states can have varying degrees of robustness, and there may be objects which are only very weakly bound. For example, a soap bubble is a bound state, but it's a very fragile one; the same can be said of water droplets (which are bound by the hydrogen bonds that attract water molecules to each other, generating surface tension, especially in contact with air).

In organisms it is likely that the capacity to metabolise and coordinate life processes may come in degrees. While it is possible to maintain the view that there must be a clear threshold for life (thus placing any remaining vagueness firmly on the side of our ignorance or our inability to accurately ascertain which is the case for any particular instance), we prefer to accept that it is not possible to avoid all vagueness, because some of it is inherent in the world. Thus there may be cases of objects which are neither clearly alive nor clearly not alive. Nonetheless, the living objects view succeeds in avoiding most of the vagueness that can reasonably be avoided, and provides a clear criterion to decide on the organismality of many problematic cases, as shown in the next section.

5. Problem cases

[18] Our view is, however, not compatible with the process view, according to which organisms are processes, not substances. On the contrary, we argue that organisms are physical objects which are engaged in a variety of processes, but which should not be identified with those processes. We take no view on what a substance is.

Organisms can be entirely composed of non-living parts, or composed of living and non-living parts. Prokaryotic organisms such as bacteria and archaea are entirely composed of non-living parts; the whole bacterium or archaeon is the minimum unit which may be considered alive. Eukaryotic organisms, on the other hand, are – or at least were, initially – partly composed of unicellular organisms living inside other unicellular organisms.[19] Multicellular organisms are clearly composed of living parts – the cells. Most multicellular organisms, however, also include non-living objects as parts.[20] The external protective structures of most animals, for example the outer layer of skin which is composed of dead cells, the insect's chitinous exoskeleton, or the calcareous shells of molluscs, are entirely composed of non-living material. The outer parts of tree bark are likewise entirely inert, and so is most of the xylem, the plant's water transport system. Yet in all of these cases, the non-living structures are clearly part of the organism, despite being metabolically inert. They are produced by the organism itself, as part of its life processes, and play a role in its self-maintenance.

Inert objects which are not produced by the organism can also come to be in a bound state with the living parts of the organism. For example, chickens are known to swallow stones which play a functional role in breaking down food in the gizzard. Yet not all material parts of the organism need be functional parts. Objects which are non-functional or even detrimental to the organism, such as kidney stones or a splinter lodged under the skin, can nevertheless be parts of the organism, forming a bound state with its other components, for example by being contained within its boundaries or attached to its structures.

Since the bound state view allows for objects to be composed of other objects, and given that, on the living objects view, organisms are a kind of object, they too can enter into the

[19] It is unclear whether contemporary mitochondria and chloroplasts are alive.

[20] In addition to the non-living parts of their cells.

composition of other objects, including other organisms. Cells in multicellular organisms should on our view be considered organisms which are also part of another living object. Although most of the cells in multicellular organisms usually originate by mitotic division from a zygote, cells with different origins can often become part of it, for example in cases of transplant, gestational microchimerism, embryo reabsorption, or colonisation of the gut, skin, and mucosae by microorganisms. The idea that microorganisms are part of their multicellular hosts is familiar from holobiont theory but, on the living objects view, there is no need to postulate an additional entity; rather, the microorganisms are simply part of the living object which is the multicellular organism. Questions of whether they contribute to the metabolic activities of the host or are tolerated by the immune system do not arise in this context, since material parts of the organism are not necessarily functional.

There is also no principled reason why multicellular organisms can't be part of other multicellular organisms. An example which is analogous to the case of cells in multicellular organisms is that of zooids in siphonophore colonies. Arguably, both the individual zooids and the colony (as well as the cells) have their own metabolism and coordinate their own life processes – for example, the zooids have their own individual nervous systems but there is also a colony-level nervous system (Mackie 1986). Physiologically integrated symbiotic partnerships, such as lichens, are also easily accommodated within the living objects view. But even multicellular parasites can also become parts of organisms to which they attach themselves. In fact, the difference between mutualistic and parasitic associations becomes unimportant for the purpose of individuating organisms, which are simply identified with the living objects present. This is a clear advantage of our view, as it is often hard to ascertain to what degree interspecific associations are beneficial or detrimental for each partner.

In the much-discussed case of mammalian pregnancy, the parthood view, i.e. the view that the foetus is part of the maternal organism, is often contrasted with the containment view, according to which the foetus is a separate organism which is merely contained within the maternal organism (Kingma 2019). On the living objects view, however, the foetus is part of the living object which is the maternal organism precisely *because* it is contained within it, since containment is a form of bound state. This makes it possible to reconcile the parthood and containment views and maintain that the foetus is *both* part of the maternal organism and an organism in its own right. It also allows us to extend the claim that foetuses are part of the maternal organism to all species with uterogestation, regardless of the degree of physiological integration, i.e. including both placental and aplacental viviparous species; and even to other forms of reproduction involving containment, such as the male pregnancy of seahorses.

Even in species with a very high degree of physiological integration, as in the case of humans, who have highly invasive haemochorial placentas, the fusion between mother and foetus is not complete; there is always a boundary at the maternal-foetal interface. The developing human organism, considered as the foetus plus the extra-embryonic membranes, is separated from the maternal environment by the chorion and placenta. Although in this kind of placenta foetal tissue comes into direct contact with maternal blood, the interface is delimited by the syncytiotrophoblast, a specialized barrier made of fused cells which is impervious to most pathogens and even maternal immune cells, while at the same time functioning as a semi-permeable boundary for exchange of nutrients and waste products. The foetus also has its own metabolism and coordinates its life processes to some extent, and is therefore an organism, despite also being a part of the maternal organism.[21]

[21] Kingma (2019) claims that the foetus relies on the maternal organism for many of its physiological functions. It is more accurate, however, to say that the foetus has its own metabolism; for example, it actively transports oxygen and nutrients to its cells using its own cardiovascular system, and exchanges oxygen, nutrients and waste products with the maternal environment at the maternal-foetal interface. It is true that the foetus does not engage in digestion or temperature regulation, but neither do many other organisms – for example, many

There are also cases in which two or more organisms form a bound state, but the resulting object is not itself alive. Van Inwagen's (1987) case of the paralysed handshakers, discussed in §4, is one; a less fanciful example is that of dogs temporarily locked in a copulatory tie.[22] Cell colonies and biofilms, in which individual unicellular organisms adhere to each other but do not form a multicellular organism, are also objects composed of organisms, but which are not themselves alive. Arguably, the same may be said of very early mammalian embryos in the blastula stage, which are composed of several functionally independent living cells held together by a glycoprotein membrane. This multicellular aggregate is in a bound state and moves as a single unit, but does not coordinate its life processes, is not physiologically integrated, and has no metabolism of its own (Brown 2019: 1039).

Finally, organisms can also form composite objects with inert objects. For instance, a lichen growing on a rock can become firmly attached to it and form a composite object with the rock, which has living and non-living components but is not itself alive. Many organisms routinely form bound states with inert objects, giving rise to further composite objects. For example, on the bound state view we should consider that a car is composed of all the objects contained within it or otherwise bound to the main structure, including the driver and any passengers. Though this may seem counterintuitive, it is not as strange as it sounds, since all those things effectively move as a unit, and we do treat them as a single object for some purposes (e.g. for calculating its trajectory). Granted, it may be a relatively short-lived object, but that does not preclude it being an object; in fact, all objects are temporary, they just have very different time spans. Waechter & Ladyman clearly

intestinal parasites do not digest their food since they absorb pre-digested nutrients; and most organisms are ectothermic.

[22] Conjoined twins are more problematic, due to the various ways in which they can be fused and the degree of physiological integration. It seems likely that some cases involve a single organism, whereas in other cases there are clearly two organisms (especially if the twins are only superficially attached).

state that their criterion of composition does not require the long-term stability of the target bound state, but only its existence (2019: 116).

The living objects view bridges the gap between general scientific ontology and specific biological concerns about organismality. Indeed, questions concerning the nature of organisms cannot be adequately addressed with approaches that neglect the question of which entities are alive, accept without argument neo-Aristotelian commitments such as the claim that something cannot be simultaneously an organism and part of an organism, or focus exclusively on biological concepts, while ignoring the ontology of material objects of which organisms are a particular case. In contrast, our view is grounded on a naturalistic account of composition which applies to all material objects, and makes no metaphysical assumptions that are not scientifically justified, thus placing 'organism' within broader scientific ontology.

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