A Case for Geographic Masses

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Abstract

Geographic masses, the stuff we deal with that cannot be categorized as geographic objects, comprise a crucial but largely unrecognized component of the core ontology of geographic information. Although masses have been rarely acknowledged in GIScience, they appear in geographic discourse just as often as objects. A concise but consistent formal definition of a geographic mass particular, which distinguishes a mass from an object, can be applied to any endurant phenomena, enabling a richer understanding of the geographic milieu, and more informed decision making during modeling and analysis processes.

2012 ACM Subject Classification Computing methodologies → Ontology engineering; Computing methodologies → Spatial and physical reasoning

Keywords and phrases Ontology, Masses

Digital Object Identifier 10.4230/LIPIcs.COSIT.2019.14

1 Introduction

There appears to be a hole in the core ontology of Geographic Information Science. What has become the conventional wisdom in our understanding of the world and how to represent it, including objects and fields, space and time, processes and attributes, is missing a substantial class of phenomena.

In my introductory GIS courses, when I present the classic core principle of the object and field views of the world, I am sometimes asked, "what about *stuff* like water, petroleum, vegetation, suburbia, and so on? Are they objects or fields?" My typical answer, "neither," is not very satisfying to the average college student. What should we do with these? Do they matter?

In other fields, such as philosophy and linguistics, these phenomena are most often called *masses*, [29] and they have been extensively (if incompletely) studied. The purpose of this paper is not to reinvent the concept, but to answer the question, "are masses relevant to geographic inquiry and geographic information science?" If so, I will further develop an understanding of masses in a geographic context, and how they can be incorporated into the core ontology of geographic information.

Over the years, the GIScience community has flirted with mass phenomena. Couclelis comes close in mentioning "extensive entities" that do not fit into the classic object model, [5] and Peuquet acknowledges the difference between "continuous properties" (fields) and "continuous matter" (masses) without saying much about the latter [22]. Galton acknowledges the existence of masses as an aside, without incorporating them into his geo-ontology [6]: later, outside the GIScience realm, Galton does incorporate "material" (masses) into an ontological framework, but does not fully develop a theory thereof [7].

14th International Conference on Spatial Information Theory (COSIT 2019).
Editors: Sabine Timpf, Christoph Schlieder, Markus Kattenbeck, Bernd Ludwig, and Kathleen Stewart; Article No. 14; pp. 14:1–14:14
Leibniz International Proceedings in Informatics
LIPICS Schloss Dagstuhl – Leibniz-Zentrum für Informatik, Dagstuhl Publishing, Germany

Smith and Mark mention "stuffs," but they express doubt that stuffs are relevant to geographic phenomena before they start their study, and they rarely appear in the resultant lists of typical geographic phenomenon [28]. However, this is at least partially due to the fact that the phrasing of their questionnaire is object-centric.[1]

2 What is a Mass?

The most common way the literature distinguishes phenomena as objects and masses is to simply say, "objects are things and masses are stuff," [4, 29] or to resort to examples: a building is an object, while the metal, wood, and concrete that comprise it are masses. The *Oxford English Dictionary* contains a number of definitions of *mass*, including some with closely related senses:

- A dense aggregation of objects having the appearance of a single, continuous body.
- A coherent body of matter of unspecified or indeterminate shape, and usually of relatively large bulk; a solid and distinct object occupying space.
- A large amount, number, or quantity of a thing or things, material or immaterial [1].

These and other definitions contain two basic characteristics of masses that differentiate them from prototypical objects: 1) they are *amorphous*, without regard for a defined shape or boundary; 2) they appear to be *continuous*, without regard for discrete parts [18].

This may seem precise, but definitions like the above have proven to be too vague to apply to many real phenomena, and contain two apparent contradictions that have vexed scholars for decades: 1) in the first definition, how can it simultaneously contain objects but appear continuous? and 2) how can a body/amount/quantity not have a shape or boundary? To develop the concept of a mass in geographic inquiry, these and other issues will need to be resolved.

A formal definition of a mass, if it can resolve these issues, should be more operational than these vague definitions. That is, it should help us more clearly distinguish objects and masses in edge cases, and know what we should subsequently do with them. While several formal general ontologies have been developed that include masses as a category [8, 27, 21, 13], I have yet to find one that fully formalizes the definition of a mass. So, I will try.

3 Ontological Framework

This work must fit within a general metaphysical and ontological framework. Given that multiple contradicting philosophies have been proposed and debated for hundreds of years, and none has emerged victorious, and because I have no interest in inventing yet another one, I will simply select the existing frameworks that make the most sense to me.

Firstly, and least controversially, we must distinguish between universals (kinds of phenomena) and particulars (individual phenomena); particulars may be thought of as instances of universals. Geospatial technology focuses on representing particulars, and that will be the primary focus here, but let us start by declaring a universal as follows:

[1] Their study gave each respondent one of five prompts to list geographic phenomena that came to mind. However, all five prompts were based on count nouns: "a feature," "an object," "a concept," or "something." They also note that fields appeared in the results even less often than stuffs. This is probably not intentional bias on the authors' part, because the prompts seem rather generic unless one were specifically looking for fields and masses. At best, the results of this study show that fields and masses are not so dominant in common-sense geography that participants woud think of them despite the wording of the prompts.

X (upper-case letter): A universal type of phenomenon. This could be as simple as a common noun, like "sheep" or "mountain;" but I relax the common definition to also include more specific concepts or forms of reference, like "those mountains" or "three sheep." In the latter case, note that X is not three actual sheep, just the notion of a group of three sheep.

Particular phenomena are more of a challenge, as there is some debate on the nature of their existence [25]. Poli, building on earlier theories, distinguishes three "strata of reality," with regards to a phenomenon being studied [23]: the *material* (the world as it actually exists independently of humanity), the *mental-psychological* (how an individual human conceptualizes the world), and the *social* (how people collectively organize the world through mechanisms such as language, institutions, or maps). Ontologists have tended to divide into camps according to which of these three strata they believe to be fundamental ("really real"), with the others seen as derivative, unstructured, or nonexistent: realists favor the material stratum, conceptualists the mental-psychological, and nominalists the social. We might call this tendency *stratum exclusivity*.

Furthermore, the scholarly dialogue concerning masses has followed three tracks that roughly correspond to Poli's strata: physics or metaphysics, cognition, and linguistics or semantics. By far, the latter approach has been the most common, probably because language structures are easier to access and study than mental ideas and physical reality. Frequently, studies have mixed the approaches, assuming a strong correspondence between physical masses, mass concepts, and mass terms, and using that assumption to make an argument or conclusion about one of the levels based on a characteristic of another level. We might call this *stratum conflation*. Laycock and Bunt both lament this tendency, and caution scholars to focus on one or the other [17, p.12] [2, p.49]. That is, evidence from any of the three realms may be suggestive of the nature of phenomena in another realm, but not proof.

I will attempt to be metaphysically neutral in keeping with Gracia, who acknowledges that all three strata, and all three lines of inquiry, can have equal validity, depending on the situation [11, p.199-205]. Such a neutral or hybrid stance is reminiscent of Lakoff's experiential realism, in which knowledge is equally influenced by reality, personal experience, and social experience [16]; as well as the post-positivist approach to scientific epistemology. It is also suggested in Herre's fourth *phenomenal* stratum of reality, consisting of phenomena that may or may not be "real" in the material-stratum sense, but are at the very least heavily motivated by real-world conditions; they may also be concepts, but are standardized by society and language to such a degree that we all recognize the same phenomenon, so they are indistinguishable from real [14, p.7]. For example, it may not be important whether a tree really exists as a distinct object, or as a conceptualization of sensory perceptions of an inherently unorganized reality, or as a term created by society to categorize an uncategorized reality, as long as I can point at something and we all agree that it is a tree. This all sounds like a lot of the phenomena we represent in GIS.

We can mediate the above strata and lines of inquiry by making a formal distinction between them:

a (lower-case letter): A particular geographic phenomenon in the material stratum. *Phenomenon* is defined very broadly to include anything that might be a subject of interest, with no restriction on its existence, nature, complexity, or spatiotemporal extent. *Geographic* limits the view to phenomena that occur or exist somewhere on Earth, at a medium to small scale (i.e., it could be shown on a map).

$\boldsymbol{a : X}$ *a categorized phenomenon*, in which it is assigned to a universal through mental and/or social processes.[2] This can be read as "a–as–X." This is only a claim, which may or may not be valid, hence the following:

$\boldsymbol{Xa}$ categorizability as a predicate: "a is (a/an) X," or more precisely, "a can be considered (a/an) X." This is a predicate, not a set theoretic membership ($a \in X$), because there is no requirement that X have an extension (a set of individuals).

Representing both the real-world phenemonon, and our conceptualization(s) thereof, as separate but equal entities, may be able to resolve much of the ontological debate described above. One could say that a realist believes in an extremely strong correspondence between a and $a : X$, the latter being a simple derivative of the former. Conversely, the nominalist could be said to believe in a very weak correspondence, such that a is not attainable from a study of $a : X$, and subsequently focuses solely on the latter. In fact, there is a continuum of correspondence: there are likely phenomena that can only be considered a single way, while others can be categorized in a number of different ways, and there are some in which the concept is only loosely based on real-world conditions.[3]

In terms of spatio-temporal ontology, objects and masses are both *endurants* (hereafter $End(a : X)$), as opposed to occurrents (processes and events). An endurant is informally defined in most top-level ontologies [8, 27, 21][4] as a phenomenon that endures through time; it is recognizable as a complete entity at any time during its existence. For example, at any moment, a tree is still recognizable as a tree; over time, it may change, but it is the same tree.

Although I am not doing a full formalization of temporal nature, we do need some definitions that place endurants in space and time, based on Simons (but with my own symbols) [26, p.132]:

$\boldsymbol{S(a)}$ the *footprint* of a, the minimal region of space in which it exists.

$\boldsymbol{t}$ any period of time, including intervals and moments of zero duration.

$\boldsymbol{T(a)}$ The *lifespan* of a phenomenon, the period of time during which a exists.

$\boldsymbol{F_t a}$ A *temporal predicate*, a claim that something about a is true throughout t [26, p.130].

$\boldsymbol{a_t}$ A *temporal restriction*, a as it exists at t, whether all of a, part of it, or none of it. This is formally defined by:

D1 $\forall t(F_t a_t \iff F_t a)$

Anything that is true of a during t is also true of a_t, and vice versa, including such predicates as part-whole relationships, attributes, and even existence. This does not require that t be part of $T(a)$; for any times outside its lifespan, a_t is empty.

3.1 Objects vs. Masses

The continuous and amorphous nature of a mass is manifested mereologically as *homogeneous reference*, perhaps first and best explained by Quine based on concepts from Goodman:

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[2] I am not distinguishing here between the mental and social strata, or between concepts and words. I am definitely not asserting that they are indistinguishable, and a distinction may be useful in the future, but for the formal definitions presented in this paper, the difference did not turn out to be important.

[3] this acknowledgement provides a way to circumvent the oft-debated *coincidence problem*, the seeming paradox in which a single body of matter can be both "some gold" and "a ring" at the same time [12], which frequently arises in discussions of masses. The problem is solved by acknowledging that a single real phenomenon can be simultaneously categorized in two ways without having to be two phenomena.

[4] I have yet to find a formal definition of endurant or occurrent that isn't fraught with issues. Some have even argued that this demonstrates that the distinction doesn't exist [25]. I have developed a solution based on the $a/a : X$ distinction, but it is beyond the scope of this paper.

masses are *cumulative* or collective (the combination of two amounts of "some water" is still "some water") and generally *divisive* or dissective (half of "some water" is still "some water") [24, p.91,99] [10, p.38]. Objects are neither: half of "a car" is not "a car" but scrap metal, and "a car" and another car combined is not "a car" but "cars." Note that the concept of homogeneous reference is not evaluated over time, but at a moment: Over time, a rock (object) can be broken into multiple rocks, but then it is no longer a rock; at a single instant, a rock is not composed of multiple rock objects.

Spatial cumulativity and *spatial divisiveness*[5] can be formalized in mereology[6] as follows:

D2 $CumS(a:X) := \forall b[\, (T(a) \circ T(b) \,\wedge\, \forall t(t \leq T(a) \,\wedge\, t \leq T(b) \implies S(a_t) \neq S(b_t)) \,\wedge\, Xb \,\wedge\, \exists c(c = a + b)) \implies Xc\,]$

A categorized phenomenon is spatially cumulative iff for any other phenomenon with the same label, which exists at least in part during the same time, and is never spatially coincident, and such that the two phenomena have a meaningful mereological sum, then the sum is also of the same category. For example, if a is some sand categorized as "a volume of sand," and b is any different volume of sand that existed at the same time as a, such that it makes sense to consider their combination as a phenomenon, than that combination can also be categorized as a volume of sand. Conversely, a "country" fails this test because for any other distinct but contemporary country, it may be meaningful to collect them as a single phenomenon (i.e., the mereological sum exists), but that phenomenon is "two countries," a different universal.

D3 $DivS(a:X) := \exists b, c, t(t \leq T(a) \,\wedge\, t \leq T(b) \,\wedge\, t \leq T(c) \,\wedge\, \neg(S(b_t) \circ S(c_t)) \,\wedge\, a = b + c \,\wedge\, Xb \,\wedge\, Xc)$

A categorized phenomenon is spatially divisive iff at some time during its existence, it can be divided into two spatially disjoint parts that are each of the same category as the whole. For example, a typical volume of sand a can easily be divided into two volumes of sand b and c.[7] However, a country (as a sovereign state) cannot be composed of two countries.[8]

A mass can thus be defined as an endurant ($End(a:X)$) that is spatially amorphous, while an object is the opposite:

D4 $Mass(a:X) := End(a:X) \wedge CumS(a:X) \wedge DivS(a:X)$

A mass is any endurant that is spatially cumulative and divisive.

D5 $Object(a:X) := End(a:X) \wedge \neg(CumS(a:X) \wedge DivS(a:X))$

An object has one or neither of these characteristics. It is possible for a phenomenon to be cumulative but not divisive, such as two "horses." The opposite is common with

[5] Most existing definitions of masses do not distinguish homogeneous reference in space and time, but I have found this distinction to be crucial, because spatial parts and temporal parts have very different implications. Treatments of masses in space and time, such as Galton and Mizoguchi [7], would be more clear with this recognition. Spatial homogeneity distinguishes masses from objects, while temporal homogeneity (not discussed here) distinguishes occurrents into processes and events.

[6] In formal mereology, there sometimes seems to be as many notation systems and axiomatic systems as there are mereologists. I am using extensional mereology, **CEM** in the classification of mereological systems by Casati and Varzi [3], and the following notation: $\leq$ for part (proper part or equal), $\circ$ for overlap (having shared parts), $+$ for mereological sum. Note that mereology is employed only on the material-stratum phenomena, space and time, not on the categorized phenomena; this circumvents many of the issues with **CEM** pointed out by Simons and others [26].

[7] Yes, there is some very small volume of sand that can only be divided into two collections of a couple grains of sand, not a mass. More on this later.

[8] The United Kingdom is no exception; England is called a country, but it is still a different kind of entity from the UK as a whole.

Figure 1 What is this? See Table 1.

linear and layer phenomena: a river can be cut into two parts, each called a river, but it is possible to find another river that combine to form "rivers."[9] In both these cases, it makes sense to classify them as objects.

How is this definition of objects and masses based on homogeneous reference equivalent to the earlier definition based on continuity and boundedness? The necessary boundary of an object clearly separates it from any neighboring object. Thus, when we consider them together, the intervening boundary makes us see them as two objects rather than one. Conversely, the boundary of a mass instance (say, a patch of water in the midst of the ocean) is at best arbitrary and inconsequential; so when two adjoining masses are considered together, their boundaries can be easily ignored (if they were ever recognizable to begin with) and the two considered as a single entity. Furthermore, the fact that a mass is divisive, able to be divided a number of ways without ontological change, suggests that the boundaries of each division are arbitrary and inconsequential.

The above definitions only apply to a single particular phenomenon categorized in one way. Each of the definitions could be extended to an entire universal category, iff every phenomenon that uses that category is classified the same way:

D4c $Mass(X) := \forall a(Xa \implies Mass(a : X))$
D5c $Object(X) := \forall a(Xa \implies Object(a : X))$

Likewise, they could be extended to a particular phenomenon in general, if every possible way of categorizing the phenomenon falls into the same ontological class:

D4p $Mass(a) := \forall X(Xa \implies Mass(a : X))$
D5p $Object(a) := \forall X(Xa \implies Object(a : X))$

The formal definitions can now be used to categorize actual phenomena. For example, the phenomena at the center of Figure 1 can be categorized in a number of ways, as shown in Table 1.

This example demonstrates the applicability of the formal definitions, but should not be taken as an inference of general patterns. For example, the last column is blank only

[9] This occurs because linear and layer objects are crucially bounded in one dimension, but not in the other(s).

Table 1 Categorizations of the phenomena shown in Figure 1.

X	CumS	DivS	$a : X$	X	a
A mountain	no	no	object	object	–
Limestone	yes	yes	mass	–	–
A geologic formation	no	yes	object	object	–
The mountains	yes	yes	mass	–	–
Mountainous landscape	yes	yes	mass	–	–
A mountain range	no	no	object	object	–
Terrain	yes	yes	mass	–	–
Elevation	yes	yes	mass	–	–

because I specifically chose a situation that could be classified many ways; there may be many phenomena that can only be classified one way. That said, it does show that categories and particulars may not be able to be universally classified as either mass or object. This demonstrates the real power of the formal distinction between a and $a : X$; previous attempts to define masses formally have generally either tried to define Mass(X) without reference to a (i.e., a nominalist approach), or to define Mass(a) without $a : X$ (i.e., a realist approach), or just conflate them, all of which have frequent exceptions, which have only served to strength opposition to the existence of masses.

4 Against Masses

Opinions are mixed on the existence of mass particulars [29]. Every few years since the 1960s, authors from various disciplines have proselytized the existence of masses, whereupon others have quickly responded to refute them. Each phase of the debate seems to repeat many of the same points, which I summarize here.

Arguments against the existence of mass particulars often involve two closely related assertions: 1) mass nouns (water, wood, metal) are strictly universals [30], because 2) any instance thereof (e.g., "the water in this lake") must have a boundary, and is therefore an object by definition. Perhaps the best refutation of these dates back to Chappell [4]. He accepts that instances of masses are different from their universals; he refers to the former as "parcels of stuff," using the most generic container term he could muster. However, he refutes the first argument by demonstrating that these parcels are still significantly different from object particulars (his "substances") in the same way that mass universals are different from object universals (i.e., having homogeneous reference), and should thus still be considered a separate kind of phenomenon.[10] The formal definition of a mass given above works just fine for these parceled particulars: if a is a parcel of water, and b is another parcel of water, then if $a \oplus b$ makes sense, it is a parcel of water.

[10] Laycock rejects Chappell's explanation on the grounds that requiring us to talk about plurals and masses in singular terms violates their inherent non-singularity [17]. In fact, Laycock doubts that mereology, set theory, or the entire predicate calculus can even apply to plurals and masses for this reason. However, he does not develop an alternative formalism, and those alternatives that have been published tend to have their own semantic and ontological problems; they may hold promise, though [19, 20]. Laycock's argument is compelling, but I believe Chappell's approach is still useful as long as the parcels are recognized as only temporary samples of the phenomenon, not the phenomenon of study (a solution mentioned in passing by Laycock). Simons follows a similar approach to fitting the predicate calculus and mereology to masses and plurals [26, pp.151–162].

On the second point, Chappell concedes that these parcels must have boundaries and a form, even if they are vague. However, he points out that they are "indifferent to form," that is, the boundaries and shape of a mass particular are not relevant to its identity and characteristics as a mass; as Jackendoff puts it, "one can think of the boundaries as outside the current field of view." [15, p.19] Furthermore, example mass particulars often used to argue against their specialness, such as the gold that constitutes a ring or the water contained in a cup, are clearly bounded and object-like, but they are straw man examples; it is just as easy to find masses that are practically impossible to bound and objectify, like the salt dissolved in the ocean or the moisture in soil.

It is not just that the boundary is vague; objects can also have indeterminate boundaries, but if so, their vaguely defined form is still crucial to their definition. For example, a mountain is usually vaguely bounded on the sides and bottom, but the form of its boundary (especially the profile shape of its upper surface) is absolutely crucial to its being a mountain. On the other hand, the rock that makes up the same mountain can be recognized, described and analyzed at length without ever referring to its boundary or shape.

Another issue that has been raised is that the common definitions of a mass, including the formal definition above, test positive for some phenomena that do not seem like prototypical masses. These include:

- Immaterial but not abstract phenomena (i.e., occurring at a location but having no mass), such as magnetism and field properties like temperature or population density.
- Phenomena that use mass terms, but are visibly discontinuous, such as vegetation or infrastructure.
- Uncounted plurals, such as "some people."

Each of these types of phenomena meet the formal definition of mass; do they meet the original intended definition, or is this a sign that the formalism is not faithful to the intent? All of them meet the requirement of being amorphous, because their boundaries are not relevant to their meaning.

Magnetism is continuous, and thus meets both of the requirements. As to its immateriality, note that none of the definitions require that a mass actually has mass: that is just an unfortunate coincidence of terminology, but every other term that has been proposed for this ontic category, such as substance or material, has the same problem. Immaterial continuous phenomena and field properties behave like masses, so I propose they should be considered a kind of mass.

The problem in the other two cases listed above is that they are not "really" continuous, but are composed of clearly visible individuals, unlike prototypical masses, such as water and metal; these are often called *collective nouns*. However, this distinction isn't as clear as it seems; it is just a matter of scale. Even most masses that appear continuous, such as water, are composed of objects at a sub-visible scale and are thus not infinitely divisive; this lower-limit mass decomposition is often called *Quine's minimal parts hypothesis* [24, p.99].

To talk about this scale effect, let use define the *support* of a phenomenon category as the smallest size that it can be and still be recognizable as that category; for a mass, it would be the approximate diameter of a collection of "several" constituent individuals that could be amassed.

It turns out that for almost any size support, one can come up with an example mass that is aggregated at that scale, as shown in Table 2. Where should we draw the line between a "true" mass and a collective? Yes, this argument rings of one of those classic Greek continuum paradoxes, but the point is that wherever we chose to draw the line would arbitrarily divide very similar phenomena. I have grouped them into four classes based on the relative perceptibility of the mass and its constituents, but even these have vague boundaries that depend on the particular phenomenon.

Table 2 Continuum of scales at which objects are aggregated into masses.

Mass	Constituent	Support	
magnetic force	truly continuous		MICRO-MASS
gold	atom	10^{-9}m	
water	molecule	10^{-8}m	only mass visible,
air	mix of molecules	10^{-6}m	object microscopic
clay	grain	10^{-5}m	
silt	grain	10^{-4}m	MINI-MASS
sand	grain	$10^{-2.5}$m	object visible,
grain	seed	10^{-2}m	mass common
gravel	stone	$10^{-1.5}$m	
grass	blade	10^{-1}m	
brick	brick	$10^{-0.5}$m	MESO-MASS
lumber	board	10^{0}m	object and mass
brush	plant	$10^{0.5}$m	equal
wildlife	animal	10^{1}m	MACRO-MASS
populace	person	$10^{1.5}$m	
woodland	tree	10^{2}m	object common,
the desert	plant, rock, etc.	$10^{2.5}$m	mass at distance
the country	farm, house, road	10^{3}m	or in abstract
the mountains	mountain, valley	10^{4}m	

Instead of trying to make the distinction at all, it seems more straightforward to just acknowledge that when we categorize these phenomena as masses, we are (temporarily) ignoring the individuals. As Bunt puts it, masses are treated "as if they did not consist of discrete parts," regardless of whether discrete parts physically exist or can be perceived [2, p.45]. This is much easier with the mini-masses than with the macro-masses, but it is the same cognitive leap. In fact, macro-masses have occasionally been acknowledged elsewhere. DOLCE, one of the general ontologies that have been published, has a category for "visual landscape," which includes phenomena such as The City, The Mountains, or The Desert, which are clearly macro-scale, and makes it a subcategory of "Amount of Matter" (its term for mass) [8].

Plurals are a little different in this regard; they acknowledge the existence of their constituent individuals, but they are still considered as less important than the collective mass.[11] Some are more mass-like than others, especially *pluralia tantum*, terms that occur only in plural form and cannot be counted [9, p.612], such as woods, outskirts, and suburbs. It occasionally works the other way too: some mass terms (in English) reflect universals that behave more like class aggregates than mass aggregates; they are a shortcut for talking about a variety of similar objects, but still recognizing them as distinct objects. The classic example is "furniture." It is entirely valid to refer to a single chair as "this furniture," which identifies it with a class, not a mass. A geographic-scale example would be a GIS layer called "infrastructure," which would likely consist of individual objects, not a single blob.

This intentional ignorance of boundaries and constituent individuals may seem offensive, especially if one is only concerned with things "as they really are," but it is not a problem

[11] The similarity, if not equivalence, of plurals and masses, is covered at length by Laycock and others [17]. Some, like Nicolas, have even attempted to combine them the other way by making masses look like plurals, but his model is a linguistic abstraction that makes little sense ontologically [19].

for our conceptual framework; it is just an example of a slightly weaker correspondence between a particular a and a choice of $a : X$. In fact, this framework minimizes the effect of Quine's minimal parts hypothesis by not expecting universal homogeneity. Considering a huge amount of water as a mass does not depend on what we would do with an unrelated microscopic collection of a few water molecules. Bunt recognizes this for linguistic analysis at least: "nothing in the use of a mass noun indicates a commitment ... to the existence of minimal parts." [2, p.45]. Essentially, the minimal parts hypothesis is an example of stratum conflation, imposing a material-realm expectation on a conceptual/social-realm entity.

One argument against assuming a strong correspondence is the fact that the mass/count term distinction varies from one language to another; some languages have more mass terms, some have less; very few have as many cases as English in which both are available to describe the same phenomenon (e.g., wildlife/animals). At the extreme, the Asian *classifier languages*, such as Indonesian and Cantonese, deal with almost all nouns in a very mass-like grammar, but this does not mean that they conceptualize everything as mass or that more masses exist in China than in England.

Another issue with assuming a direct correspondence between linguistic syntax and cognitive structure is that while languages evolve to express ideas, they are eventually standardized and regulated to a high degree. In English, some words are count and some are mass because that's what the OED says they are. In fact, I wonder if more could be learned about the linguistic/cognitive correspondence by studying bad grammar than by studying grammatical rules. For example, common mistakes by non-native speakers, and the perennial issue that students have with "data is/are," probably say more about their cognitive structures than their level of intelligence.

5 Do Masses Matter in Geography?

For whatever reason, masses have been occasionally mentioned in GIScience ontologies, but have never found their way into the common conceptual framework thereof. It is fair to ask, "Is that even an issue?" Perhaps they exist, but just do not matter enough to consider.

To investigate this, I took a look at what the field finds important, by surveying the subjects discussed in a spectrum of journals: the *International Journal of Geographic Information Science* (for a GIScience focus), the *Annals of the AAG* (for a broader geography perspective), *International Journal of Remote Sensing* (more of a remote sensing, physical geography, and raster focus) and *ArcUser* (for a GIS practitioner perspective).[12] In all, 91 articles were reviewed. The subject matter of each article was classified as either predominantly *physical geography*, *human geography*, or *environmental geography* (a mix of human and physical).

In each article, I recorded any endurant particular that was significantly discussed or studied. As best I could, I avoided occurents (especially processes) and universals (which typically meant skipping over the literature review and theoretical sections, and I generally skipped review articles), although one could probably debate the inclusion of a few of the items in my list. I documented 750 references to endurants (not unique; things like counties and cities were listed in many articles), an average of about 8 per article.

These were classified as either object or mass using the formal definitions above. Within the masses, I identified each as a field if it was clearly a property. Plural terms required

[12] Specifically, the issues mined were *IJGIS* V.22 #10, V.33 #1, V.33 #2 (21 total articles); *Annals* V.106 #1 January 2016, V.108 #3 March 2018 (28 total articles); *IJRS* V.40 #1 (20 articles); *ArcUser* V.19 #4 Fall 2016, V.21 #3 Summer 2018, #4 Fall 2018 (23 total articles). The sample was neither random nor strategic; these issues were at hand.

further consideration. They tended to fall into three conceptual groups, as evidenced by the narrative context: 1) the set of individuals was conceptualized as a single whole (e.g., "the group of people who were at the event"), in which case it was tagged as a single object; 2) the focus was on the individuals (e.g., "each of the 245 animals we saw..."), in which case they were tagged as objects; or 3) an uncounted plural that behaved as a mass concept (e.g., "farms lined the highway"), which was tagged as a type of mass. One test of the last type was whether the plural could be replaced by a synonymous mass term without changing the meaning (e.g., "farmland lined the highway").

This bibliometric study was not intended to be a rigorous analysis of the ontology of the entire discipline of geography or GIScience, only to get a feel for whether masses appear in geographic inquiry. They do.

Table 3 Phenomena listed in sampled geography, GIScience, and GIS articles.

	Objects	Masses	Field-Masses	Plural-Masses	Total
Human	50.9%	20.9%	12.4%	15.8%	387
Annals	79	42	15	29	165
IJGIS	38	11	18	9	76
IJRS	5	3	6	2	16
ArcUser	75	25	9	21	130
Environmental	48.2%	26.1%	12.2%	13.5%	245
Annals	60	33	3	23	119
IJGIS	10	5	5		20
IJRS	13	9	11	4	37
ArcUser	35	17	11	6	69
Physical	33.3%	29.9%	29.9%	6.8%	117
Annals	9	1	6		16
IJGIS	8	10	9		27
IJRS	22	19	25	8	74
Total	354	180	113	102	749
	47.3%	24.0%	15.1%	13.6%	

The listed phenomena are classified in Table 3. At least one mass particular was mentioned in almost every article, and overall, they were mentioned more often than fields. As one might expect, masses and fields were more common in physical geography papers than in human geography (with the latter tending to focus on human-built objects).

Although Mass phenomena were mentioned very frequently, they were never discussed more than in passing, often immediately being transformed into objects or fields for modeling. Very few articles reflected on the ontology of their subject matter at all, and of those that did, none acknowledged masses as an ontic category. For example, one paper discussed at length the ontology of terrain characteristics (slope, aspect, etc.) as fields, but never mentioned the ontology of terrain itself.

I also evaluated the mass and field-mass phenomena with regards to the earlier scale discussion, and encountered geography and GIS projects that were concerned with all of these scales. There were 73 mentions of micro-scale masses, 63 mini-scale, 18 meso-scale, and 139 macro-scale masses. One would expect micro-scale masses to be very common, simply because these are the prototypical masses that appear continuous to the naked eye. The large number of macro-scale masses is largely due to the fact that these are the scales at which geographic inquiry generally takes place, at which most individual objects are too small to be considered separately. I did not fully classify the plural-masses, but in passing they appeared to be almost exclusively macro-scale. The relatively small number of meso-scale masses is likely due to a combination of its narrow range of scales, and the fact that these are the "table-top" scales at which prototypical objects are so prevalent. Also, many of the mass terms that do occur at these scales, such as silverware, are not very relevant to geography.

So, the fact is that masses of various aggregation scales are already represented in GIS, without overtly recognizing it. For example:

- A polygon layer representing trees (as opposed to digitizing every tree). Yes, the polygon shape suggests that an object is being represented, but this is an artifice of the vector data model. The phenomenon is a plural-mass, in which individual trees have been aggregated and then disregarded, and the polygon is merely a rough attempt to show where the trees-phenomenon is present. Common attributes of trees-as-mass, such as Percent Canopy Cover and Species Composition (themselves field-masses), would never make sense for individual trees.
- An isarithmic map of population density. Computing a continuous field of density using methods such as kernel density estimation is an overt act of aggregating and subverting individuals into a population mass, of which density is a property.
- A sensor network, such as a set of weather stations, which are essentially sample locations for measuring the characteristics of the air mass. Note that the network does not dictate a definition of the boundary of the air mass, and we can talk about the measured characteristics without any regard for such a boundary.

The "mass-ness" of some of these applications is greater than others. It may be that the mass concept is so embedded in a processing method that users don't need to know that it is there.

However, in other situations, a mass ontology could greatly benefit the design and implementation of data and procedures. For example, an impetus for this research was a paper submission I reviewed for a journal. The authors had obtained several layers of points representing different kinds of phenomenon, but they needed raster datasets for their model. Some of these were distinct objects and should have been rasterized by a mass-aggregation method such as kernel density estimation, while others were samples of a field, and should have been rasterized by an interpolation algorithm. However, it appeared that they chose their rasterization methods for each dataset randomly, and in almost every case, chose the wrong method. At best, they may have learned some sort of rubric in school to remember which is which, but forgot. At worst, they didn't care to learn which is which. Furthermore, the methods they used to combine and analyze the fields they generated were inappropriate for their ontological nature, resulting in a "solution" that had no real meaning. In this situation, a clear understanding of the phenomena their source data represented, and of the phenomena their model results represented, would have gone a long way toward making wiser design and analysis decisions, and a more coherent interpretation of the results.

This case is not alone in my experience. I'm not saying that all GIS analysis out there is being done incorrectly; the published work I collected above did not have glaring ontological errors, because adept GIScientists and GIS professionals have learned proper practice, even if they do not consciously think about masses. That said, just as a sound understanding of the nature of fields leads to better spatial analysis (especially using raster tools), an understanding of the role of masses in the geographic world and in geographic inquiry will lead to fewer mistakes of this type.

In a related way, perhaps one reason why masses are not widely recognized in geospatial theory and practice is because the intuitive pairing between the common dichotomies in conceptual and data models (field with raster, object with vector) is so strong, to the point that exceptions to the correspondence (e.g., vector isolines representing a field) can cause confusion. I have seen such confusion lead to incorrect analyses, especially among students. Perhaps altering the ontology and/or conceptual model will break the assumed correspondence, helping people think more about what they are really trying to represent, and the data models and analysis tools they use.

Is there a need for new mass-based data models and analysis tools? Probably not. Because a mass does not have a strong identity like objects do, there is not much need for representing it as a unified entity. Typically, the study of geographic masses is the study of the geographic distribution of their attributes, which are nearly always fields. Since models, methods, and tools for representing and analyzing fields are mature, there is probably little need for more software.

That is, as long as we use what we have wisely. And being wise requires that you think about what you're doing. And part of what you're doing involves masses.

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