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Rethinking 'Space as a Container': Is Everything Signal Variation?

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ABSTRACT
A common use of the word 'space' refers to it as a *container* of things, commonly so in cartography as well as other spatial disciplines. According to this way of thinking, space contains phenomena; we live *in* it, and we move *through* it. This notion has carried over into fundamental theories of various scientific fields such as spatial cognition, geography and some engineering disciplines. Even though the conceptualization of space as a container makes intuitive sense at first, space cannot be defined as a container without a reference frame, and a reference frame cannot be defined without space. To avoid this circular logic, in this paper, we argue that the concept of space can be defined with respect to our experience of *signal variation*, just like anything else. This line of thinking suggests that *everything is spatial* because space is an abstraction of all other experiences.

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Introduction

In cartography and its sister fields that deal with graphical abstraction, there is a (debated) discourse around how '80% of all data is spatial' (e.g. Hahmann and Burghardt, 2013; Forrest, 2023), which begs the question of how *spatial* is defined at a fundamental level. In this position paper, we argue that our sense of *spatial* is built through an abstraction of all other experiences, and everything we experience is defined by *signal variation* – and if we take this view, everything is also spatial. A change in the signal that stimulates sensory receptors, i.e. *signal variation* or *heterogeneity*, is needed to produce any perceptual experience, including those that are visual, auditory, olfactory and/or tactile. Signal variation can be processed top-down to *reconstruct* (the constructivist perspective) or bottom-up to *pick up* (the ecological perspective) coherent information from a constantly changing environment. While the top-down control of perception (e.g. how our experience of the immediate environment relies on our previous experience) presents an important bridge between cognition/memory and perception/sensation, both ecological and constructivist perspectives implicitly assume that information exists at different levels of abstraction (i.e. from specific to general) and that the external environment is composed of entirely unique elements at the lowest level of abstraction. However, they disagree with respect to where the process of abstraction occurs. From the ecological perspective, abstraction arises from the interaction between an observer and unique elements of her or his external environment. From a constructivist perspective, abstraction occurs in the mind of the observer and is based on a subset of available sensory details. From both perspectives, an observer's understanding of space can be considered the highest level of abstraction and cannot exist independently of the observer.

Signal variations are gradually combined into more abstract concepts, and at the highest level of abstraction, the combination of all signal variations forms the basis of the human concept of *space as a container*. We present our position supported by evidence found in relevant literature that (a) all sensation is based on signal variation, (b) perceptual experience disappears in the absence of signal variation, (c) all memory systems rely on variations in perceptual experience, and (d) the experience and concept of *space as a container* represents the highest level of abstraction in these memory systems. We will also briefly discuss the implications of our fundamental theory of signal variation for scientific disciplines that rely heavily on the concept of *space as a container*, such as cartography, geographic information sciences, spatial computing, extended (virtual, augmented and mixed) reality, astronomy and similar. We believe that challenging this fundamental characterization of space (as a 3D container) is important for a better understanding of human experience in general and human experience

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of space in particular. Revisiting how we think about space may also have implications for how studies about space are conducted and communicated.

Sensation and Perception

At the most basic level, sensation can be based on light, pressure and/or chemical stimulation. While these three types of stimulation are very different, in all cases, constant stimulation eventually results in a reduced or absent signal downstream, comparable to a lack of stimulation (Avant, 1965; Yuan *et al.*, 2011). For example, light energy can be transduced to an electrochemical signal via photoreceptors such as rods and cones in the human retina. These photoreceptors change between hyperpolarized and depolarized states in the presence and absence (respectively) of a particular intensity and wavelength of light. In species with eyes, the hyperpolarization of a photoreceptor results in the propagation of an electric signal along nerve cells in the visual pathway, but even in species without eyes (e.g. plants), the hyperpolarization of a photoreceptor results in the release of a hormone for relatively slow, long-distance signalling. While repeated exposure to something in the presence of an alternative (e.g. stimulus absent vs. present) might lead to *sensitization* at first, lack of variation in sensory signals results in what is termed *habituation* over time (Peeke and Petrinovich, 1984; McSweeney *et al.*, 1996). In other words, *sameness* in any sensory dimension appears to be equal to no information at all, i.e. eventually nothing to process for our perceptual/cognitive system. In the perception literature, this tendency for the perceived strength of a stimulus to decrease with repetition is called *perceptual habituation*.

Electrochemical signals from individual sensory receptors are almost always aggregated spatially and/or temporally in order to produce an ecologically relevant response. We would characterize this spatiotemporal aggregation of signals as another source of signal variation at a higher level of abstraction rather than the loss of information. If one receptor is receiving constant stimulation while other receptors are not, the aggregated signal might still persist. In this manner, signal variation at a lower level of abstraction results in a persistent signal at a higher level of abstraction. This *principle of abstraction* is similar to that of Bertrand Russell (see Nasim, 2009) and can be visualized as different levels of a hierarchy in which higher levels are more likely to persist when lower levels are more likely to vary (as shown in Figure 1). For human concepts, we would argue that these levels range from *variations in the stimulation of individual receptors* up to the concept of *space as a container*.

The abovementioned sensory basics are the foundation of human perceptual experience. Consequently, without signal variation, the entire human experience simply would disappear. Such a lack of (partial or total) stimulation can also lead to extreme perceptual experiences, varying from illusions to hallucinations, evident in the literature on sensory and perceptual deprivation experiments. Let us examine a visual perception example: The human concept of colour is derived from our experience with lights of different wavelengths. If the wavelengths that approach an observer's retina do not vary over time, then the observer's visual experience becomes completely 'grey' and featureless (Hochberg *et al.*, 1951; Gibson and Waddell, 1952). Our understanding of these variations in wavelength over time becomes our concept of colour. While

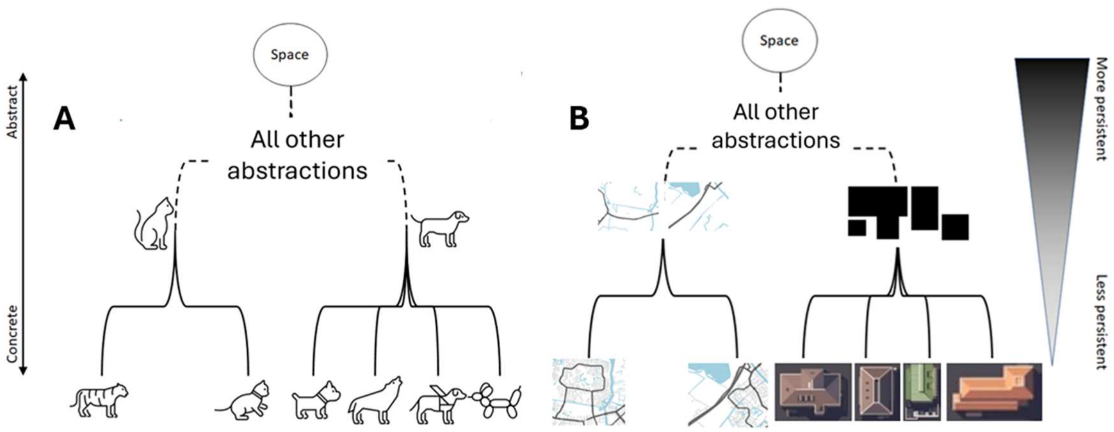

Figure 1. Example of the proposed abstraction hierarchy. Higher levels of abstraction are associated with more persistent concepts compared to lower levels of abstraction. The step from the example prototypes to a mental representation (or a sense) of space assumes that we abstract all things we experience, which, with accumulation over time, becomes our understanding of space. Left (A): In the cat and dog examples above, the dog prototype would also be more persistent than the cat prototype because the specific instances represented by the dog are more variable. Right (B): This type of abstraction is very common in cartography; in fact, it is at the heart of all concepts related to *cartographic generalization*, a persistent research challenge in the field (Çöltekin *et al.*, 2017).

predominantly demonstrated in vision experiments, similar effects based on constant stimulation have been observed for other senses as well (Ritter *et al*., 1968; Grunfeld *et al*., 2000). The generated effect is broadly known as the *Ganzfeld effect* (Wackermann *et al*., 2008).

When it comes to perception of space, *movement*, and thus the signal variation generated by it, is essential (Gibson, 1954, 1958). Movement, whether it is locomotion or movements of the body parts (such as eye movements for visual variation, hand movements for tactile variation), is the dominant source of signal variation for perception and cognition of space. The common conception is that we move *through* space, whereas we argue that our cognitive system can construct space *because of* movement (also see Gibson, 1979). In sum, space *is* a signal variation, and from this perspective; fundamentally, it is not qualitatively different from other phenomena.

General Multi-Memory-System Framework

In contrast to sensation and perception, which occur in the present moment, memory can be considered the aggregation of information for near real-time information processing (e.g. working and/or short-term memory) and over time for later retrieval (e.g. episodic and/or semantic memory). Whether one considers implicit or explicit long-term memory, this can be understood again using the *principle of abstraction*. For example, we may remember seeing a dog or a building at several points throughout our lives. There are specific episodic memories involving that specific dog, or that specific building, and a more general semantic understanding of dogs or buildings in general. Whether one considers episodic and semantic memory the same or different memory systems (Ashby and Ell, 2002), either the encoding or the retrieval of semantic memory is based on the aggregation of episodic memories. There are two schools of thought on this matter: On the *prototype* side of this debate, researchers argue that semantic memories are encoded into a more general representation and then elaborated during retrieval (Smith and Minda, 2000). On the *exemplar* side of this debate, researchers typically argue that memories of individual experiences are stored and combined to reflect a general understanding during retrieval (Nosofsky, 1986). Some exemplar theorists posit the existence of a unifying code that underlies memory, whereas some prototype theorists claim that there are several different memory systems that work in parallel. Either way, abstract concepts in semantic memory appear to arise from a set of many different perceptual experiences. In laboratory experiments, the number of perceptual experiences that form the basis of a concept, as well as variation in those perceptual experiences (Homa and Vosburgh, 1976), define the extent to which the resulting concept will generalize from one context to another. Specifically, larger sets of experiences and more variable sets of experiences produce a concept that is more abstract and easier to generalize. This demonstrable fact follows the hierarchical organization described above. More variation at lower levels of the hierarchy leads to more persistence at higher levels of the hierarchy.

Different semantic concepts can be placed at different levels of this hierarchy of abstraction. For example, a general concept of a cat and a general concept of a dog are both included in the (more) general concept of an animal. The highest level of this hierarchy (i.e. space) represents abstraction across all other concepts, and is the most persistent one.

Why This Conversation Matters in Cartography: A 'Spatial' Example of Abstraction

Researchers in various scientific disciplines often distinguish between concepts that are spatial (e.g. maps) and those that are not (e.g. text), such as in the seminal work referred to as *the Pequet triad* (after Peuquet, 1994), where space (spatial view), time (temporal view) and attribute (semantic view)' are proposed as fundamental dimensions on which spatial data, and corresponding visual complexity, are organized (Schnur *et al*., 2018). Here, we demonstrate how maps fit into our more abstract definition of space and argue that both maps and text can be abstracted to form space.

A map is often (though not always) an abstraction of a real place. For example, a person might move through a city and measure the distances and directions between several buildings. The person could then draw a diagrammatic representation of these measurements to form a map, which is typically highly generalized through geometric and semantic operations such as *Selection, Simplification, Smoothing, Merging, Aggregation, Typification, Collapsing, Reclassification, Displacement* (Shea and McMaster, 1989). The arrangement of places on the map and the metric associated with these measurements represents space in the traditional sense. At the same time, this map is an abstraction of variation in the signal being measured. In a similar manner, the concept of maps as a type of diagrammatic representation can be abstracted from our everyday interaction with different specific maps. For example, one may use a digital map with routeing instructions to navigate from their home to a new restaurant downtown. When they arrive at the restaurant, they use a map of the parking garage to remember where they parked. Of course, both of these specific maps are examples of the more abstract concept of maps.

In contrast to maps, texts are traditionally thought to be non-spatial, perhaps because texts do not have a consistent metric. Specific texts (e.g. this paper, newspapers, the Tao Te Ching) can be very different, but variation among these texts can still be abstracted into the general concept of texts. This pattern from variation in the signal (e.g. different specific maps or texts) at lower levels of the abstraction hierarchy to the more persistent concepts (e.g. maps or texts) can be extended to the most abstract and persistent concept, space itself. We would argue that variation in all our experiences and associated concepts, whether traditionally considered spatial or not, is abstracted to form the most persistent concept of space.

Space as a Container

We argue that 'space as a container' is a consequence of our mental abstraction and does not necessarily 'exist' as such in the external, physical universe. In other words, at the highest level of the abstraction, hierarchy is what is commonly referred to as 'space'. One possible origin for the myth of space as a container or medium in which everything interacts may be the fact that we often create containers and call them spaces. For example, a country may be considered the 'space' occupied by a particular group of people. However, the fact that a country contains these people does not necessarily mean that the country is a subset of a larger space container. Similarly, our concept of time is an abstraction of many separate events, whether we experience these events directly or via some instrument or recording.

This refinement in our understanding of *space as a container* does not necessarily invalidate our previous understanding but provides several benefits to scientists and engineers in various fields. First, in philosophy, this refinement provides definitions of space and time that are not circular. Second, in the field of cognitive science, different theories of spatial cognition and navigation can be formalized and compared across vastly different scales and types of environments (i.e. without relying on a predefined set of explicit or implicit 'spatial' constraints). Third, in the fields of geography and cartography, new personalized visualizations that match the conceptual hierarchy of individual users based on the everyday signal variation they experience can be developed (Thrash *et al.*, 2019).

One limitation of this signal variation framework is that it becomes impossible to know whether this signal variation, arising from the external physical universe, is random, stochastic, chaotic and/or deterministic. In other words, by asserting that everything we understand is based on the naive and scientific concepts that arise from signal variation, the nature of signal variation itself becomes somewhat opaque.

Although individual agents are clearly capable of systematically affecting signal variation by acting on the external world, we argue that this interaction between the agent and the external world does not require a medium such as space as a container. This notion is difficult for us humans to grasp because all of our concepts appear to be embedded in different spaces, but we argue that space as a container is a consequence of abstraction rather than the material that is abstracted or the medium through which material is abstracted.

In geography and cartography circles, a commonly heard claim has been '80% of all data is spatial', with scholars in the field debating what that means and how that figure could even be measured (e.g. Hahmann and Burghardt, 2013; Forrest, 2023). Here, we would argue that all data could be considered spatial in that the concept of space is abstracted from all data. In this framework, a non-spatial dataset, excluding any variation, is difficult to imagine.

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Notes on the Contributor

Tyler Thrash is currently pursuing a PhD in Biology from Saint Louis University and working at the Danforth Plant Science Centre. His current work is focused on developmental, environmental, and genetic influences on resource allocation in perennial members of the sunflower family. Previously, he had completed a PhD in Psychology with a focus on spatial cognition and virtual reality systems. He has also worked as a postdoctoral researcher in Cognitive Science at ETH Zurich and Geographic Information and Visualization Analysis at the University of Zurich.

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