Place and form: A case study in the disunity of core knowledge

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Abstract: Core knowledge theory holds that human cognition originates from a small set of innate modular systems, each of which is informationally encapsulated from the others. We subject this theory to scrutiny by critically examining one influential division within it: the distinction between an encapsulated core knowledge system for place (representing where things are) and an encapsulated core knowledge system for forms (representing object structure). Reviewing behavioral, developmental, and comparative evidence long taken to establish a double dissociation between these systems, we argue that the case for either system's encapsulation is considerably weaker, and the counterevidence more extensive, than typically acknowledged. In place of their strict encapsulation, we propose that place and form systems are better distinguished not by the information they have access to but by the proprietary algorithms that govern how they prioritize and process spatial information. In turn, these results suggest that core knowledge probably does not constitute a single, architecturally uniform, psychological kind, but a heterogeneous family of systems that vary in the nature and degree of their modularity.

Keywords: Core knowledge, Geometry, Form, Place, Informational Encapsulation

One of the foremost goals of cognitive science is to understand the origins and organization of human knowledge. What knowledge is innate versus learned? Is knowledge acquired via flexible, domain-general learning mechanisms, or rigid, domain-specific ones? Are there distinct modules in the mind that map onto distinct domains of knowledge? If so, what are they?

Perhaps the most prominent attempt to systematically address such questions is the hypothesis that human knowledge originates from pre-wired domains of 'core knowledge.' In its latest rendition, the theory posits six domains, devoted to knowledge of objects, number, places, forms, agents, and social beings, respectively (Spelke, 2022; Spelke & Kinzler, 2007). Each domain maps onto its own distinct and specialized modular system, embodying innate and special-purpose knowledge therein. These modules are then seen to scaffold subsequent learning, enabling the characteristically flexible modes of thought found in appropriately enculturated adult humans. Putting these threads together, the core knowledge theory presents an elegant and unified theory of human knowledge that promises to account for both its origins and its development.

In the present treatment, we take a critical look at the core knowledge theory and the modular divisions it posits. Our inquiry is guided by a conviction that these modular divisions matter: Beyond the observation that core knowledge theory purports to provide a map for the development of all human knowledge, these divisions offer to explain otherwise puzzling dissociations in children's behavior as well as intuitions that persist into adulthood. Yet, we are skeptical that these modular divisions stand up to scrutiny, and to such an extent that this commands a reconceptualization of both *what core knowledge is* and *how it is organized in the human mind*.

To frame our discussion, we focus on one specific modular division proposed by the core knowledge theory — the division between knowledge of places (roughly, knowledge of *where things are*) and forms (roughly, knowledge of *object structure*). We focus on this case study for several reasons. First, the domains of form and place both concern spatial and/or geometric knowledge. Core knowledge theory suggests that all geometric knowledge — and all the incredible technological, engineering, and mathematical human achievements that result from it — is built up from distinct geometric primitives that originate in these systems (Spelke & Lee, 2012). But since we are skeptical that a modular

division between form and place withstands scrutiny, we worry that current formulations of the core knowledge theory have set theorizing about the development of spatial knowledge off on the wrong foot. Second, the proposed distinction between place and form representation is often treated as a theory of spatial cognition in its own right, independently of its broader bearing on the core knowledge hypothesis (e.g., Lee, Sovrano, & Spelke, 2012; Spelke et al., 2010). Throughout this paper, we refer to this theory as the *two-system view*. Despite the influence of the two-system view, there has been little attempt to critically evaluate the modular division it posits (but see Newcombe, 2018), and there has been scant attention paid to what an alternative framework might look like. These are lacunae that the present paper fills. Third, spatial cognition is one of the best-studied topics in cognitive science. As such, it provides ample behavioral, computational, and neuroscientific evidence on which to adjudicate these issues and to explore their wider ramifications for the core knowledge hypothesis.

To clarify: While the distinction between form and place is but one modular division that proponents of the core knowledge theory posit, we believe that problems with this division raise concerns for the core knowledge theory more broadly. The aim of this paper is, thus, to articulate problems with the two-system view of spatial knowledge, and to explore the ramifications this has for our understanding of core knowledge as a distinctive psychological kind.

We proceed as follows. In §1, we clarify the core knowledge theory and the modularity of the systems it posits. In §2, we review the history of, and motivations for, the two-system view, explaining how it naturally aligns with the core knowledge theory, thus construed. In §3, we critically evaluate the evidence that has been marshaled in support of the two-system view, arguing that we should doubt the strict modular dissociation between the form and place systems that core knowledge theorists posit. In §4, we discuss what a revised view of geometric and spatial knowledge might look like, provisionally introducing an alternative *diverging algorithms framework*. Finally, in §5, we discuss where this leaves us with respect to core knowledge more broadly. We argue that the lessons gleaned from our discussion have implications for how core knowledge systems should be conceptualized: While some core knowledge domains have a genuinely modular architecture, we suggest that the a-modularity of core spatial knowledge undermines the grounds for thinking that core knowledge constitutes an architecturally unified kind.

1 | Clarifying core knowledge

According to the core knowledge hypothesis, human thought originates from a small number of prescribed and innately hardwired domains of 'core' knowledge. Its latest rendition posits six such domains, devoted to knowledge of objects, number, places, forms, agents, and social beings, respectively (Spelke, 2022). While one might quibble with the term "knowledge" in this context, denying that these systems' representations are factive rather than heuristic (Carey, 2009; but see Davies, 2015, for relevant discussion), a key claim has been that these early emerging systems structure the "flexible skills and belief systems" (Spelke & Kinzler, 2007, p. 89) that are subsequently acquired throughout the lifespan. In this respect, the core knowledge hypothesis charts a middle ground between classical empiricism, which emphasizes purely domain-general system(s) of cognition and learning (Locke, 1689; Rumelhart & McClelland, 1986), and evolutionary perspectives which have analogized the entire mind to a "Swiss army knife" (Pinker, 1994), comprising vast swathes of innate and highly specialized "mental organs" (Cosmides & Tooby, 1994; Pinker, 1997; Carruthers, 2006).

It should be acknowledged that the precise number of core knowledge domains remains open to revision. Further domains might be discovered or — as we will argue here — proposed borders between established domains might erode under critical inspection. To even assess these possibilities, however, it is important to note that extant versions of the hypothesis regard each domain as distinct on account of its being modular, in Fodor's (1983) sense of the term (Carey, 2009; Spelke, 2022).[1] Before turning to our central case study — the *two-system view of spatial knowledge* — it is worth clarifying exactly what this appeal to Fodorian modularity involves.

On Fodor's account, modular systems are computational mechanisms that differ from the mechanisms of central cognition in their tendency to possess nine distinctive properties, including *fast processing*, *fixed neural hardware*, and *domain specificity*. Chief amongst these

[1] Carey states that "the entities in core domains of knowledge are identified by modular innate perceptual-input devices" (2009, p. 11) and emphasizes Fodor's characterization of modules as informationally encapsulated systems (p. 10). Spelke is even more emphatic: She states that the systems and domains of core knowledge "are modular, in *all* the respects described by the philosopher and pioneering cognitive scientist Jerry Fodor in his Modularity of Mind" (2022, p. xx., *our emphasis*).

is *informational encapsulation*, a property which serves as the "essence of a system's modularity" (Fodor, 1983, p. 71).[2] To wit: Classical computations rely on access to information or content to perform intelligent input-output functions. For instance, the visual system has been said to rely on information that light comes from a single source (above) when inferring shape from shading (Ramachandran, 1988; Mamassian et al., 2002). Thus, the system takes information about shading as input and uses this to infer estimates of 3D shape as output in a quasi-rational manner (Rescorla, 2015). In saying that this process is underwritten by an informationally encapsulated module, it is proposed that while the visual system might utilize *this information* when estimating 3D shape, it lacks computational access to *other information*, even when this other information is located within the same organism's head and might be helpful in its operations. As such, the module is unable to use this other information to inform its computations, no matter how relevant it might be for its task functions. The module is *encapsulated* from this other information.

To clarify this proposal, Fodor (1985) characterizes encapsulated modules as systems which rely exclusively on information stored in private "proprietary databases". This allows for a graded notion of encapsulation: A module X can be regarded as *encapsulated* from a system Y *to the extent* that X's database fails to include information in Y's (Quilty-Dunn, 2019). As a result, an encapsulated module might share or be influenced by information used by other modular or non-modular systems (see also Coltheart, 1999). Indeed, Fodor emphasizes as much when taking the mechanism(s) of speech perception to serve as his exemplar of a modular system. To explain phonemic restoration effects, he urges that "on any remotely plausible account" [his own included] the language module will have access to the speaker's knowledge of the lexicon (1983, p. 77). Thus, Fodor was not opposed to — and, indeed, welcomed — the suggestion that a paradigmatically modular and encapsulated system might have access to the speaker's knowledge (in this

[2] Philosophers of science have become increasingly wary of "essences" in their characterization of natural kinds (Khalidi, 2013), particularly in the life sciences. Fodor's view was not classically essentialist, however. He took modularity to come in degrees, with the encapsulation of a system simply increasing the likelihood that it possesses other markers of modularity, such as *speed* (cf., Brooke-Wilson, 2023) and *domain specificity* (cf., Margolis & Laurence, 2023). Plausibly, then, encapsulation was viewed as more like a sustaining mechanism in a homeostatic property cluster, with Fodor's terminology reflecting the fact that he was writing ~ten years before the distinction between essentialism and property clusters was clearly formulated by philosophers of biology (Boyd, 1991; 1999).

case, knowledge of words) which is accessed and used in thought (as when we, e.g., think about word meanings and formulate sentences). What is critical is that encapsulation remains *architecturally prescribed*: It marks a fixed constraint on what information/content *can* be synchronically accessed by the system and (hence) used to inform its computations. Thus, the claim is not simply that encapsulated systems neglect to consider certain information in their computational procedures (as when we neglect our beliefs about star signs and clownfish while deciding which hummus to buy at the supermarket). Rather, the claim is that there is an architectural boundary which determines what information *can* be accessed or used by the cognitive mechanisms involved. This is how the visual system's encapsulation from thought offers to explain why known illusions persist. Even when you believe things that should rationally alter your visual system's analyses, and even when you reflect on these, your visual system's encapsulation from thought implies that it lacks access to such beliefs. This renders your beliefs incapable of informing or altering the system's input-output function and reorganizing your percept accordingly when sensory inputs are held fixed. By contrast, your beliefs about star signs are not encapsulated from your hummus-related-shopping decisions. While we might neglect to consider such beliefs, they are accessible and can be brought to bear on the decision-making process if their relevance becomes salient (e.g., if we learn that Libras like their hummus creamy and that we are shopping for the 36 Libras attending dinner).

Thus, when proponents of the core knowledge hypothesis allude to Fodorian modularity, they hypothesize that – beyond the perceptual "input" modules that animated Fodor (1983) – there is an encapsulated module that corresponds to each domain of core knowledge. By suggesting that there are six such modules (Spelke, 2022; Spelke & Kinzler, 2007), Spelke commits to each of these modules being individuated by their possession of a unique and architecturally prescribed proprietary knowledge database (see also Carey, 2009). Following Fodor, these databases delimit what information *can* be accessed by each system in the performance of its domain-specific input-output function. Accordingly, Spelke and other proponents of the core knowledge theory find evidence for distinct modules underlying small and large numerical discriminations (Feigenson et al., 2004), the representation of agency (Spelke et al., 1995), object tracking (Spelke, 1990), and the spatial representation of forms and places (e.g., Lee, Sovrano, & Spelke, 2012; Spelke et al., 2010). In each case, these assessments are premised on the conjecture that each system differs in the information that it utilizes in their computations. The basic

theoretical move, to be highlighted in Section 2 (and scrutinized in Section 3), is that the best explanation for *why* these systems differ with respect to the information that they utilize in their computations is that they differ with respect to the information that they *can* access in their computations — that the architecturally prescribed encapsulation of the systems dictates this.

2 | A "two-system" view of spatial knowledge

Having introduced Fodorian modularity, let us now consider how it plays out in the context of our central case study: the two-system view of spatial knowledge.

2.1 Historical precursors to the "two-system" view

Early motivations for the two-system view can be traced to Cheng (1986), whose pioneering work led him to posit a *geometric module* — i.e., a domain-specific navigation system that is encapsulated from non-geometric information. This conjecture was motivated by Cheng's empirical results. In a working memory paradigm, Cheng placed food-deprived rats in the center of rectangular environments in which walls were marked by non-geometric features (e.g., colors, spots, or stripes; see Figure 1A) that rodents ably discriminate in other contexts (see, e.g., Julian et al., 2015). During each trial, rats would find a partially hidden food item at a given location within the enclosure. They would then be removed from the enclosure and placed in the center of a second, rotated but otherwise identical rectangular environment. They would, thus, need to reorient themselves within the second environment to locate its corresponding food item.

The rectangular environments were constructed such that if rats freely integrated non-geometric information (e.g., visual, tactile, and olfactory information in the corners) with geometric information (concerning the angles, lengths, directions, or distances of/between the walls) whilst reorienting in the room, they should have no trouble finding the correct location of the food in the second enclosure. However, if the rats relied only on *non-geometric* information (e.g., if they simply encoded the location relative to a striped wall), they should search only near the corresponding learned feature. Finally, if rats relied only on *geometric* information, they should search equally often at the correct location as well as a separate, geometrically equivalent location in the second enclosure. The guiding thought was that systematic errors made by the rats would reveal the

information they had used to reorient themselves within the rectangular environments employed.

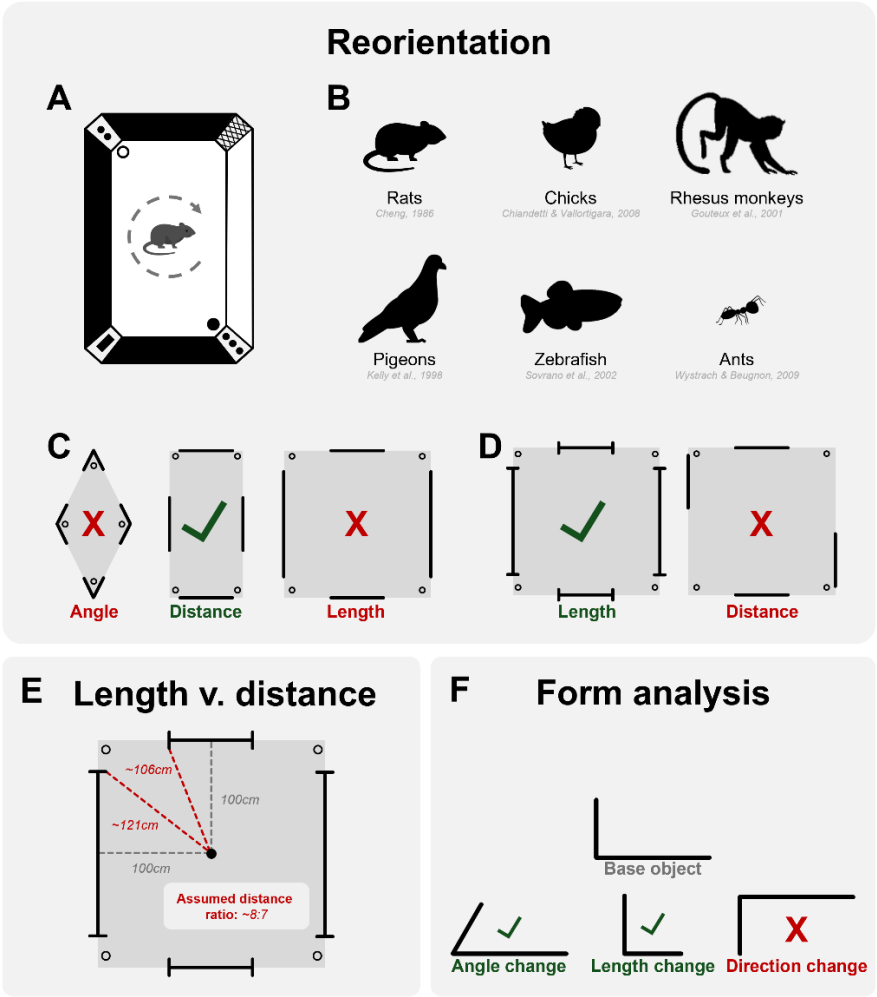


Figure 1. Reorientation and form analysis tasks. (A) Geometric and non-geometric information in the original reorientation task, as seen from above (Cheng, 1986). The room's rectangular shape creates two rotationally equivalent and diagonally opposite corners. The filled circle indicates the desired target, while the open circle indicates the geometrically (rotationally) equivalent corner. The patterns on the walls indicate non-geometric features of the room, which in principle could be used by the rats. (B) A depiction of other species that have been studied in similar tasks. (C) Conditions from Lee, Sovrano, and Spelke (2012) in the reorientation task with 2-year-olds. Starting from left to right, each scheme indicates a tested feature: angle, distance, and length. The symbol "✓" indicates evidence of using the cue, and "X" indicates evidence of not using the cue. (D) Conditions from Yousif and Lourenco (2017) in the reorientation task with young children. In the left scheme, perpendicular "appendages" were added to the end of each wall, and young children used them to reorient. In the right scheme, distance was manipulated while maintaining the overall square shape of the environment. Although the two-system framework predicts that children should use distance in this condition, they were unable to do so. (E) An illustration of how children may

have used distance information (with respect to the appendages) to solve the 'length' task used by Yousif & Lourenco (2017). (F) A simple form analysis task from Izard and Spelke (2009) in which children were tasked with identifying the odd-one-out given various geometric changes. They detected angle and length, but not direction changes.

Where, then, did the rats search? Cheng found that they searched equally often at the correct location (i.e., the specific location where the reward was actually hidden) and its geometric equivalent (i.e., the location directly opposite where the reward was hidden).[3] This indicated that (a) the rats had relied on geometric information of the room to reorient themselves, and that (b) the rats hadn't integrated this geometric information with non-geometric information, which would have otherwise disambiguated the target location.

To make sense of these results, Cheng conjectured that the rats had initially relied on a 'purely geometric module' to reorient in space, citing Fodor (1983) in this connection. Just a few years later, others replicated his original findings and took them to strongly support this modular hypothesis (Margules & Gallistel, 1988), with these researchers emphasizing the encapsulation of this system (Gallistel, 1990). On the resulting view, it was thereby conjectured that rats possess a geometric module that is informationally encapsulated from non-geometric information: It has computational access to geometric information alone, while non-geometric information remains strictly *inaccessible* to the system even when that information is relevant to the reorientation task it is engaged in. Sometimes it is objected that this modular hypothesis does "little more than label the findings" that Cheng and subsequent researchers reported; that it merely redescribes the observation that rats utilized geometric information while neglecting to integrate non-geometric cues (Butterfill, 2007, p. 453). It is, however, important to stress that this is not so: The postulation of a geometric module is a substantive theoretical conjecture that goes beyond these results, in ways that offer to genuinely explicate them.

To illustrate, suppose we accept results (a) and (b) and thereby accept that rats' reorientation behavior is responsive to geometric information and insensitive to non-geometric information. The postulation of a geometric module offers to explain why this might be by appealing to the architecture of the mechanisms involved. Boldly stated, it

[3] In a reference-memory version of the task, however, in which food was always hidden in the same corner, rats learned with repeated training to distinguish the correct corner from its geometric equivalent (Cheng, 1986; see also Wall et al., 2004).

explains a pattern of observed behavior by appealing to a hypothesis at a lower (algorithmic) level of analysis. Mirroring modular explanations for the recalcitrance of known illusions, described in Section 1, the theoretical gambit was this: *the best explanation* for why rats fail to utilize non-geometric information in reorientation studies is that the system responsible for their reorientation lacks computational access to non-geometric content. That is, the system is *encapsulated* from non-geometric content, as dictated by its architecturally prescribed proprietary database.

Crucially, this modular hypothesis is no foregone conclusion. In principle, we might make sense of Cheng's original results in other ways, supposing that the system(s) involved had access to non-geometric content but failed to utilize this during reorientation for other reasons. This might be akin to the way that we sometimes use heuristics to solve complex reasoning problems and thereby fail to integrate things that — on reflection — we know to be relevant (Simon, 1955; Tversky & Kahneman, 1974). In these cases, it's not that our faculty of reason *cannot* access such knowledge. Such knowledge may not be accessed when cognitive shortcuts are available, perhaps as a means of conserving valuable cognitive resources. Either way, it remains *accessible* to our faculty of reason. For, if its relevance is pointed out to us, we can freely integrate it into our thinking, hence why we are often able to appreciate the error of our ways once the fallibility of our methods is made apparent.

Nevertheless: While Cheng's appeal to modularity is no foregone conclusion, it was certainly striking that the rats tested in his studies systematically failed to use information that strikes us (mature adult humans) as transparently relevant to the reorientation procedure these (food-deprived) creatures were motivated to perform. For this reason, the proposed encapsulation of their reorientation system deserved to be taken seriously as a possible explanation for the observed results.

2.2 From rats to children

Forty years on, Cheng's work remains a cornerstone of the field. In its wake, studies were conducted with other animals, some yielding analogous results (e.g., Lee et al., 2013; but see: Chiandetti & Vallortigara, 2008; Gouteux et al., 2001; Kelly et al., 1998; Vallortigara et al., 1990; Wystrach & Beugnon, 2009). Insofar as these findings are indicative of a

"geometric module," which is encapsulated from non-geometric information, the module is often assumed to be evolutionarily ancient and widespread in nature.[4]

Perhaps the most striking of these results came almost a decade after Cheng's original paper, when Hermer and Spelke (1994, 1996) adapted Cheng's reorientation paradigm to test young human children's navigational abilities (18-24 months). Using a setup that closely mirrored Cheng's, Hermer and Spelke tested whether human adults and children would integrate featural (non-geometric) information with geometric information when reorienting. Human adults were not fooled: Unsurprisingly, they flexibly reoriented using both geometric and non-geometric information. More surprisingly, however, Hermer and Spelke found that 18- to 24-month-old children failed to integrate featural information with geometric information; like rats, young children seemed to reorient based on geometric information alone.

Why do children fail where adults succeed? Hermer and Spelke argued that humans, just like rats, have a geometric module that supports spatial representation and reorientation, where this system is encapsulated from non-geometric information throughout the lifespan. Unlike other species, however, they observed that appropriately enculturated humans develop linguistic abilities. Hermer and Spelke thereby conjectured that these linguistic abilities enable the outputs of distinct modular systems to be combined across otherwise distinct cognitive domains in adults, thus enabling geometric and non-geometric cues to be reasoned with in tandem (see also Spelke, 2003).

What is striking about this latter conjecture – for our purposes – is that it effectively doubles down on the proposed encapsulation of the faculties involved: Without language, Hermer and Spelke suggest that the geometric module is incapable of accessing contents processed by other systems, nor of even combining the outputs of these systems with those of others that "present the world to thought" (Fodor, 1983, p. 40).[5] Hence, the

[4] An alternative possibility is that its emergence in distantly related species reflects a process of convergent evolution (compare: Nieder, 2021), where evolution has selected for some such system many times over; perhaps because the prioritization of geometric information reflects an optimal navigation strategy in natural environments where featural content (e.g., the color of decaying leaves) is often more changeable than the gross geometric structure of the landscape (e.g., Gallistel, 1990, ch. 5).

[5] While we are skeptical, the hypothesis that language enables the outputs of modules to be combined is quite different from the claim that language enables these systems' encapsulation to be violated. The output

geometric module was considered unavoidably encapsulated from the featural content represented by sensory modules. Furthermore, it was conjectured that it is only with the maturation of language that humans acquire an ability to combine the outputs of this system with those produced by others (as when we think, e.g., *LEFT OF THE LONG RED WALL*). These conjectures ultimately laid the foundation for Spelke's postulation of a modular, evolutionarily ancient place system, for reorientation and navigation, which remains a foundation of the core knowledge hypothesis today (Spelke, 2022).

2.3 From historical precursors to the contemporary proposal

The preceding discussion sketches important historical precursors to the two-system view. However, the contemporary proposal did not crystallize until Lee, Sovrano, and Spelke (2012) found that children would not use *all* geometric information in reorientation paradigms. Using enclosures with walls of differing lengths, forming different angles, and/or that were placed different distances apart (see Figure 1C), Lee and colleagues reported that children reoriented exclusively based on the distances between the walls and their directions from each other (i.e., sense information); they did *not* use information concerning the lengths of these walls nor the angles between them. Indeed, this result persisted with subtle geometric cues: children continued to reorient based on distance and direction, even when the distances between opposing walls differed only slightly, by a ratio of just 8:9 (Lee, Winkler-Rhoades, & Spelke, 2012). While we will see that these findings have been challenged (see Lourenco et al., 2009; Yousif & Lourenco, 2017), they underpin Spelke's contemporary view on spatial representation, according to which we must differentiate two modular core knowledge systems for space: a *place* module for representing and navigating large-scale spaces and a *form* module for representing the spatial structure of objects. It is this modular division which constitutes the two-system view of spatial knowledge.

The key motivation for this modular division was a proposed double dissociation between place and form analysis. Building on Lee et al.'s results, the two-system hypothesis posits that children use distance and direction (sense) cues while ignoring

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of a module is a representation that the module produces and makes accessible to other systems of the mind, with or without the aid of language. By contrast, encapsulation pertains to a restriction on the information, content or representations that are utilized in its production of those outputs. For discussion of this issue, see Clarke (2021).

length and angle cues in reorientation paradigms. Proponents of the two-system view take this to refine the postulation of a geometric module, noted above; rather than simply remaining encapsulated from non-geometric content, *writ large*, they take this to show that the place system is encapsulated from certain geometric contents as well, namely length and angle, and that it must rely entirely on the dedicated sense content it has access to within its proprietary database.

This is then contrasted with children's recognition of objects and 2D shapes (Spelke, 2022: ch. 6), where an orthogonal collection of geometric cues is used (Dehaene et al., 2006; Izard et al., 2011; Schwartz & Day, 1979). For instance, Izard and Spelke (2009) tasked young children with identifying which of six objects deviated from the others geometrically. Throughout this experiment, all the objects used were two-dimensional shapes with an L-shaped structure (see Figure 1F). Where they differed was simply in (a) the lengths of the lines that these L-shapes comprised, (b) the angle between these lines, or in (c) the direction of the lines with respect to each other (e.g., whether the target L-shape was a mirror image of the others). During testing, a clear pattern emerged: All age groups ably identified deviant shapes/objects when these were distinguished by variation in the lengths of the lines they comprised or in the angles between them. In other words, it proved relatively easy to distinguish the *odd-one-out* when it was distinguished by the very geometric features that seem to be neglected in reorientation paradigms. Meanwhile, participants proved relatively *in*sensitive to direction information of a sort that *is* used in reorientation paradigms. As a result, they were poor at recognizing deviant forms which were distinguished by being mirror images of other items. In fact, the studies revealed that differences in angle and length routinely interfered with one another, such that on trials where the target shape was distinguished by its unique angle, varying the line lengths across the other objects served as a distraction that adversely affected participants' abilities to detect the oddly-angled target; by contrast variation in sense/direction content had no such effect, suggesting that it was not even considered. Summarizing these results, Spelke, Lee, and Izard (2010) conclude that in object recognition, "sense is difficult to detect and easy to ignore" despite sense content dominating performance in reorientation studies (p. 872).

These latter findings hence motivated the postulation of a second, distinct and autonomous, module for the representation of forms — a module that has access to

specific geometric information, like angle and length, while remaining encapsulated from direction information that is accessible to the place system used in reorientation. Since these results mirrored previous findings, where adults from communities that lack relevant linguistic labels showed analogous dissociations to the children described above (Dehaene et al., 2006), Spelke, Lee and Izard (2010) take this to further evince the hypothesis that language is needed to combine the outputs of distinct and encapsulated core knowledge systems, like those for *form* and *place*.

Summing up: The two-system view of spatial knowledge posits two geometric modules (see also Huang & Spelke, 2015). First, there is a *place* module that facilitates reorientation behavior. Crucially, this system has access to information concerning "absolute distance and sense [i.e., direction] … but not relative length or angle" on account of its encapsulation from the latter. Second, there is a module for *form analysis* that "does the reverse", making free and flexible use of length and angle information while remaining encapsulated from sense information (Spelke & Lee, 2012, p. 2789). In both cases, the proposed modularity of the systems is a weighty conjecture that goes beyond observed patterns of behavior. It is a theoretical conjecture, pitched at an algorithmic level of analysis (Marr, 1982), which offers to explain why children behave as they do in the studies described, responding to and making use *of* orthogonal geometric cues in reorientation paradigms and studies of visual form analysis, respectively. As articulated above, the guiding assumption is that the best explanation for these diverging patterns of cue usage in these studies is that the observed behaviors are guided by distinct and autonomous modules, each relying on access to information stored within an independent proprietary database. Critically, this leaves either system *encapsulated* from the geometric information that is made use of by the other. It is only with the aid of extraneous resources — most notably, *language* (Hermer & Spelke, 1994; Spelke, 2003; see also Pyers et al., 2010) — that the outputs of these modules can be combined or even considered concurrently with content from other systems and modules.

One final point: It is worth flagging that proponents of the two-system view sometimes take their position to find independent support from cognitive neuroscience. To this end, they note that (most) scene regions of the brain (the occipital place area [OPA] and retrosplenial cortex [RSC], but *not* parahippocampal place area [PPA]) *are* sensitive to left-right information, whereas the posterior fusiform sulcus, an object region, is not (Dilks et

al., 2011). More recent work has shown that the same scene regions that respond to sense information also respond to egocentric distance information (Persichetti & Dilks, 2016). And, interestingly, the scene region that does not respond to sense and distance information, the PPA, *is* sensitive to the geometric properties associated with object recognition — length and angle (Dillon et al., 2018). Since these dissociations appear to mirror the behavioral dissociations which motivate the two-system view's modular division between place and form systems, these findings have led to the suggestion that, within the scene network, there are dissociable neural systems for recognizing scenes and navigating through them (Persichetti & Dilks, 2018). While it is unclear to us if or how such neuroimaging evidence bears upon the hypothesis that the form and place systems are encapsulated modules, we flag this because such evidence is sometimes cited as strong evidence in favor of the two-system framework (Spelke, 2022), perhaps owing to the idea that if each of the systems it posits are implemented in independent neural hardware this is suggestive of the view that independent data structures are guiding its computations. Whether or not this inference is warranted, it is widely supposed that such neural data is consistent with, and perhaps congenial to, the two-system view, as it is articulated in the literature. We return to these points below.

3 | Problems with the two-system view

The two-system view paints a pretty picture: It posits two modules, one for the spaces we *navigate*; another for the objects we *recognize* and *manipulate*. One module is for *places*; the other is for *forms*. Conveniently, Euclidean properties of distance, length, angle, and direction fit neatly into this framework: The former system, *the place module*, traffics in distance and direction, while the latter system for processing objects, *the form module*, traffics in length and angle. Moreover, it is hypothesized that the reason for this clean dissociation is that each system is encapsulated from the geometric representations that are made use of by the other; it is only through the deployment of further cognitive resources (in particular, the resources of *natural language*; see Hermer-Vazquez et al., 1999) that the outputs of these encapsulated modules can be combined, as when mature and enculturated adult humans reason about objects that are individuated by their *shape, color, and location* and thereby reorient in ways that infants and non-human animals cannot (e.g., Hermer & Spelke, 1994).

At any rate, that is the theory. We believe it to be mistaken. The current section highlights reasons to be skeptical of the clean modular division that the two-system view posits, thereby motivating the development of our alternative framework within which to understand pre-linguistic spatial cognition.

Concern 1: Encapsulation from non-geometric content

To begin, consider Cheng's (1986) original postulation of a 'geometric' module. While this posit has been superseded by the postulation of two distinct geometric modules, for form and place respectively, Cheng's hypothesis remains the bedrock on which this more contemporary view is built.

To remind the reader: Cheng (1986) found that rats neglect to use salient non-geometric information, such as colors, spots, or stripes, when reorienting. Subsequent studies found the same to be true for many other creatures, including young toddlers (Hermer & Spelke, 1994; 1996). A modular hypothesis was introduced to make sense of such results, recommending that reorientation is facilitated by a system which is encapsulated from non-geometric information (Cheng, 1986; see also: Gallistel, 1990). Thus, it was conjectured that rats and other creatures fail to utilize non-geometric information in their reorientation behavior because the underlying system that enables their reorientation is architecturally prevented from accessing such information; these cues are systematically inaccessible to the underlying system involved. They *cannot be accessed by the system*; the architecture of the system prevents this.

Subsequent formulations of the two-system view build upon this modular hypothesis but submit that it did not go far enough. On these more recent proposals, the place module that enables reorientation remains encapsulated from non-geometric cues; however, it is now deemed to be encapsulated from certain geometric representations as well (namely, those representing length and angle). But for this reason, it is at least suggestive of problems with the two-system view that the researcher who first posited a geometric module later came to doubt its existence (Cheng, 2008; see also Cheng & Newcombe, 2005). Indeed, the concerns with the posit have since mounted. For instance, Duval (2025) objects that place cells — putatively the underlying neural locus of the place system — appear to encode not only geometric information but also non-geometric information, in at least some contexts. Meanwhile, Twyman and Newcombe (2010) offer a wide-ranging

"*Five Reasons to Doubt the Existence of a Geometric Module*". In what follows, we develop one of these five reasons that we find particularly compelling when attention is paid to the relevant commitments of Fodorian modularity in this context.

Notice that if reorientation behavior depends on a purely geometric module — which is literally encapsulated from non-geometric information — it would be surprising to find that creatures' failure to use non-geometric information is fragile and depends heavily on the parameters of the experiment. After all, we take it that the basic reason to posit a geometric module is that this offers to explain why rats and children don't incorporate featural content when reorienting; that, by hypothesis, this is a result of the fact that the underlying system *cannot* access the relevant representations, no matter how helpful these might be. This is akin to the way that encapsulation offers to explain why known illusions persist; even when one reflects on their knowledge of the illusion, and its relevance to their perceptual system's analyses, this knowledge is (by hypothesis) inaccessible to an encapsulated perceptual system and, thus, strictly incapable of altering or informing its input-output function, no matter how helpful or salient it might seem.

The trouble is, the failure to use non-geometric information in reorientation paradigms — i.e., the very thing that modularity is invoked to explain — is *remarkably* fragile. When researchers manipulate the size of the room used in reorientation experiments, say, the failure to integrate non-geometric information often disappears (see Cheng et al., 2013). Specifically, in large enclosures, children (Learmonth, Newcombe, & Huttenlocher, 2001; Learmonth et al., 2002), human adults (Ratliff & Newcombe, 2008), and non-human species (Sovrano & Vallortigara, 2006) reorient using non-geometric features (Lee et al., 2020; but see Shusterman's findings, reported in Newcombe et al., 2020). While one might reply that some core knowledge modules only operate within certain parameters or ranges and that – outside of these – other mechanisms must be engaged (see Feigenson et al., 2004; Clarke, forthcoming), the abovementioned discrepancies are surprising since it is typically claimed that insofar as a geometric place module exists, it functions to represent large-scale spaces specifically (e.g., Spelke et al., 2010). Thus, these findings are at least suggestive of the idea that featural information is not strictly inaccessible to the place system (and hence encapsulated from it). On the contrary: Such information can become integrated into the system's computations in precisely those situations where the

system is expected to operate, at least under certain conditions. This is so, even if featural information fails to be used or prioritized in other contexts.

To address these concerns, Shusterman and Spelke (2005) reply that while the place module lacks access to non-geometric information (and remains fully encapsulated from featural information), domain-general associative processes can enable organisms to proceed as if reorientation computations are being performed over featural representations. On their proposal, true reorientation still requires young children to employ a geometric place module that proceeds independently of non-geometric content. Nevertheless, associative processes can sometimes enable them to associate specific features with responses, targets, or outcomes, thereby allowing these features to serve as "beacons" which can be directly approached. In saying this, Shusterman and Spelke stress that these associative processes do not facilitate genuine reorientation computations since they simply encode for one target and fail to license further inferences about directional or sense relations; they *only* enable creatures to directly approach target locations (features). Nevertheless, when rooms are made larger – and featural cues are scaled accordingly, as they were in the abovementioned studies – it is proposed that children and other creatures may succeed in locating a target by simply associating it with a salient feature and approaching this, thereby bypassing the distinctive signature limitations of the geometric place module entirely.

We find this unconvincing. To our minds, Shusterman and Spelke's response is either falsified by subsequent results, or it accommodates these but inadvertently leaves the postulation of an encapsulated place module unmotivated.

Consider that, in another study, Newcombe and colleagues (2010) found that 3- and 5-year-olds *could* use featural information to locate a toy duck, making flexible inferences when reorienting in an eight-sided space comprising two sets of four geometrically equivalent corners. This space was made of fabric sheets that were stapled to the floor and fastened together so that they stayed taut and mimicked walls. Under these conditions, children were able to use a red wall to selectively reorient toward one of three geometrically equivalent, white-walled corners. To accomplish this, they needed to represent and utilize a red feature, attribute it to a given corner, and then use this stored information to conceptualize and organize the space as a whole. In other words, they

needed to combine non-geometric content with geometric information such that identically colored white corners could be distinguished by their spatial relationship to the feature. Hence: The children could not have completed this task by simply associating RED or RED WALL with TOY DUCK since the red wall was not adjacent to the target location they selectively approached. They also could not have completed the task by simply associating the geometric and non-geometric features of the all-white target corner with TOY DUCK since doing so would have led them to approach the target corner and the other white and geometrically equivalent corners with equal likelihood. Rather, it appears that they represented RED, attributed this to a specific location, and then used this attribution to structure and distinguish the target corner from otherwise identical white angled corners within the octagonal space — representing that (e.g.) the target corner is *the first corner to the left of the red wall that has certain geometric properties*.

How might Shusterman and Spelke explain this further result? It seems that they must make one of two concessions, neither of which is palatable on their association-based account. One option would have them concede that, in this more recent study, featural content really was being accessed by the geometric place module, conceding that it is not strictly encapsulated from featural information after all. In other words, this first option would have them abandon the full-blown encapsulation of the place module from non-geometric content. While this might be welcomed by those who stress that modularity comes in degrees, and who thereby hold that full-blown encapsulation is simply an ideal (Coltheart, 1999), it is important to note that this amounts to more than a gentle weakening of their view. On the contrary: It appears to rob the postulation of a geometric place module of its explanatory power. For once it is allowed that the place module can *sometimes* access non-geometric content, it is no longer clear how positing a geometric place module is meant to explain children's and rats' failures to integrate featural information in classic reorientation paradigms: Why don't they make use of featural information hereabouts if, strictly speaking, this information is accessible to the system? Indeed, it is no longer clear what empirical predictions fall out of the view. Without some principled explanation for patterns of non-geometric feature integration, the postulation of a geometric place module simply predicts that children and rats will neglect to use non-geometric information in reorientation studies — except when they don't.

Absent some such explanation, Shusterman and Spelke might favor a second option when addressing these concerns. Where the first option would have them weaken their hypothesis that there is a genuinely encapsulated geometric place module, this second option would instead have them reformulate their understanding of the associative mechanisms that allow this system's limitations to be bypassed. Take Shusterman and Spelke's (2005) claim that such associative mechanisms merely enable children to associate features with target locations, such that children can find these by directly approaching the features in question. To accommodate the above, it might be replied that Newcombe and colleagues' results show that this underestimates the flexibility of the associations produced. In reality, Newcombe and colleagues might be seen to have shown us that these are sufficiently flexible that they can support the appearance of sophisticated navigational reasoning, enabling associations to be formed between target locations and complex nexuses of geometric and featural cues, such that a child might treat (e.g.) *the white corner with such and such an angle, that is one left of the red corner* as a beacon. The trouble with this second proposal is that if such rich associative processes are available to young children, it is unclear what benefit a more restricted place system continues to afford, or why these associative processes would not save the day in the studies that motivated positing a geometric module to begin with. If, for instance, an association can be formed that enables children to treat a complex nexus of features as a beacon, it is unclear why children tested by Hermer and Spelke's (1994; 1996) were unable to form the much simpler associations needed between (e.g.) a blue wall and a target object such that they would routinely disambiguate the geometrically equivalent corners.

Either way, it seems that Newcombe et al.'s (2010) results problematize the postulation of a geometric place module that is encapsulated from non-geometric content. At best, they force a weakening of the hypothesis that robs it of explanatory power; at worst, they blunt the very reasons we had for taking the hypothesis seriously.

Proponents of the two-system view might shrug off these concerns. It might be replied that the modular dissociation between a form and place module is not strictly dependent on either system's encapsulation from non-geometric content; what is vital is simply that each of these systems is encapsulated from *orthogonal* geometric contents. After all, this orthogonality generates the double dissociations that motivate positing independent modules for form and place, regardless of whether these systems access non-geometric

content. The trouble is: We will now see that the arguments for thinking these systems encapsulated from orthogonal geometric contents prove similarly problematic to those regarding the systems' encapsulation from non-geometric contents.

Concern 2: Encapsulation from orthogonal geometric cues

In early formulations of the two-system framework, Spelke considered three Euclidean properties, not four: direction (or sense), angle, and distance — the last of which was used interchangeably with length (Spelke et al., 2010). Distance and length were later separated following admirably thorough investigations of children's reorientation behavior by Lee, Sovrano, and Spelke (2012), who described distance as the spatial extent between two objects and length as the spatial extent between two points along a single object. To recap: Lee and colleagues found that children would reorient based on the distances between walls but not on the lengths of the walls (see Figure 1C). Fodorian modularity was then deployed to make sense of this division. If there are fixed constraints on the cues that each system can access in its computations, then dissociations of this kind are just what we should expect. For if the place module cannot access representations of length (if it is *encapsulated* from them), then those representations are simply not positioned to alter the system's input-output function. An analogous point is meant to hold for the form module, which is hypothesized to be encapsulated from an orthogonal collection of geometric cues.

There are, however, exceptions to the sharp dissociation between these systems' use of length/angle and distance/direction, respectively. Borrowing the general design of Lee, Sovrano, and Spelke (2012), Yousif and Lourenco (2017) found that preschool-aged children (1) *can* use length information to reorient under certain conditions (e.g., when the lengths are made more salient by adding small 'appendages' to the end of each wall segment), and (2) *will not* use distance information to reorient under other conditions (e.g., when the 'global shape' of the environment forms a square, which lacks meaningful geometric information because all sides of the imputed shape are the same length; see Figure 1D). These findings are complementary: The first shows children using a cue that the place module is supposed to be unable to access, while the second shows them neglecting a cue on which it is supposed to rely. Together, they suggest that the system(s) underlying reorientation *can* access more spatial information than the distance and

direction cues that the two-system view allows, and that the use of any given geometric cue is context sensitive in ways that the two-system view disavows.

Against this, a critic might reply that the appendages in Yousif and Lourenco's study served as landmarks relative to which children computed and used distance information. After all, the distances from the center of the enclosure (i.e., the child's initial position) to each appendage were not equated (see Figure 1E).[6] On this reading, children succeeded not by using length, but by using distance — the very cue the place module is supposed to exploit. But, while this rival interpretation is conceivable, we think it an unlikely reading of the data, for at least two reasons.

First, the rival interpretation requires children to have relied on distance cues that seem especially unlikely to guide their behavior. To be sure, children have been known to represent and then reorient based on the geometric properties of small items (Lee & Spelke, 2011), and thus could, in principle, use appendages as landmarks. However, it is not clear why children would fixate on distances from the appendages, specifically, and do so over and above distance information to the nearest points on each wall. After all, the appendages were both smaller than the walls and farther from the children, so one would expect them to be less salient. To compound matters, the resulting ratio of the relevant distances to the appendages would itself be quite small — approximately 8:7, a subtle difference by the standards of typical perceptual discrimination tasks. Admittedly, children have been known to navigate based on even subtler distance ratios (Lee, Winkler-Rhoades, & Spelke, 2012), so this, too, is possible. But it remains unclear why this not particularly salient information should have dominated their behavior. And the difficulty is at its sharpest when we turn to the square enclosures in which Yousif and Lourenco found distance information to be neglected. There, the ratio of the egocentric distances from the center of the room to the center of each wall was *greater* than the ratio of the distances to the appendages. The critic must therefore hold that the same children exploited a subtle distance cue in one condition while ignoring a more pronounced distance cue in another.

A second reason to reject this rival interpretation pushes in the opposite direction. Our first reason (just stated) challenged the critic to explain why children would rely on the

[6] We would like to thank Elizabeth Spelke for pressing us on this point.

specific distance relations they propose, while the second notes that the critic's reply threatens to complicate basic motivations for the two-system view. For with their rival interpretation on the table, our critic inadvertently draws attention to the fact that distance information *was* available to children in the very tasks that were designed to probe (and rule out) their ability to use length representations during reorientation (see the right scheme of Figure 1D). In those tasks, children could have reoriented based on distance information alone, if we allow that they might represent the variable distances from (e.g.) the corners of the walls used.[7] Indeed, this concern has fangs, since the rival interpretation already maintains that distance content is represented from specific points or surfaces on a singular wall or Spelke object. Our critic therefore faces a dilemma. To answer our first reason for doubt, they must explain why children relied on the (not particularly obvious or salient) distance cues that the rival interpretation posits in Yousif and Lourenco's study. But in doing so, they must simultaneously explain why children did *not* use comparable distance cues to reorient successfully — *as if they were drawing on length content* — in the very tasks that motivated thinking the place system encapsulated from representations of length to begin with. The more readily children are credited with computing distances to such points, the harder it becomes to explain their failures in the original studies; the less readily they are credited with this, the harder it becomes to explain their success with the appendages. To our minds, this is a tough needle to thread.

To reiterate why all of this matters vis-à-vis the broader claim about modularity: Fodorians appeal to the encapsulation of the visual system from the organism's explicit beliefs to explain why the lines of the Müller-Lyer illusion continue to look different in length even after we get out our tape measure, confirm that they are not, and reflect on this fact. By the same token, a system that is encapsulated from length information should be unable to access or make use of this information no matter how salient it becomes. The architecture of the system would preclude this. Yet if our recommended interpretation of Yousif and Lourenco is correct, salience is precisely what made the difference: A modest change to the environment — the addition of small appendages — was enough to bring length information to bear on reorientation. This is exactly what encapsulation forbids,

[7] In fact, this concern is not unique to the dissociability of length and distance: Lee, Sovrano, and Spelke (2012) also reported that children fail to use angle information, but manipulating angle involves manipulating either the length of the sides of the angle or the distance between their vertices. Hence, in many cases, angle information could be tracked via representations of distance alone.

and just what we would expect if cue use were governed by context-sensitive weightings rather than by fixed architectural constraints.

Different concerns arise regarding the form module's proposed encapsulation from distance and direction. This encapsulation is posited to explain why forms and mirrored forms often fail to be distinguished. Yet it has long been understood that sense invariance for objects may reflect less the mental systems that support object recognition than the objects themselves. Bornstein and colleagues (1978) note that "the confusion of mirror images is not a 'confusion' but an adaptive mode of processing visual information. In the natural world, the only mirror images that ever occur are aspects of the same thing and therefore need not be distinguished" (p. 32). In a paper beautifully (sub-)titled, "Reflections on mirror images", Walsh (1996) points out that "it is not every day that one is troubled by being required to remember the orientation of a painting" (p. 1081). Dilks and colleagues (2011), writing about these mirror confusions, note that they may arise simply "because many objects are vertically symmetric" (p. 11305).

This is much less often the case for navigated spaces, of course: Usually, turning left versus turning right is consequential. In practice, this means that if we *really* wanted to understand whether children (or adults, for that matter) are equally sensitive to sense information in objects and in scenes, we would have to create a special set of objects and scenes for which sense information was equally diagnostic. While we are confident that such a stimulus set could be made in principle, we are not aware that one has ever been tested. This is pressing, since evaluating sense information in form analysis has long been argued to rely on processes of mental rotation (Shepard & Metzler, 1971), which are both effortful and demanding of working memory (Hyun & Luck, 2007). The effortful and demanding nature of these processes might alone suffice to explain why sense information is neglected in form analysis (compare Westra, 2017, and Carruthers, 2015). In any case, what would need to be shown is not simply that children have a preference or tendency to neglect certain cues, but that the neglected cues *cannot* feature in their analysis of object forms, no matter how salient they become, and no matter how relevant they are to the system's computations. This is the same standard that, as we argued above, the place module fails to meet with respect to length. Thus, we doubt that there is sufficient evidence to justify the claim that children (or adults!) neglect sense information

in form analysis in ways that would motivate thinking such content strictly inaccessible to the mechanisms or systems involved.

Positive evidence for geometric cue combinations

There are many other independent pockets of evidence that cast doubt on how cleanly dissociable the geometric cues involved in form and place analysis prove to be. For example, it has been shown that adults represent locations in both small-scale spaces (Yousif & Keil, 2021; Yousif et al., 2024; see also Yousif, 2022; Garro-Rivero, forthcoming) and in large-scale spaces (Chen et al., 2025) using *polar coordinates* by default. Importantly, polar coordinates represent locations by composing angle and distance information — cues that are typically separated in the two-system view. On the two-system view, it is unclear why angle and distance information would become spontaneously integrated as part of a default mode of spatial representation, given that the dissociations that motivate two-system view are said to persist into adulthood (as is the case with sense invariance of objects, for instance).

Then there is the fact that both small-scale objects and large-scale navigable spaces are said to be represented with their topological structure first and foremost, with metric information encoded secondarily (Yousif & Brannon, 2024, 2025; Yousif et al., 2026). Indeed, when adults were asked to draw from memory both navigable spaces (Byrne, 1979; Moar & Bower, 1983) and simple 2D forms (Kittur et al., 2026), they showed the same systematic errors (e.g., distortions of drawn angles and line lengths), suggesting that common representations are employed. There is also reason to believe that this topological sensitivity is early developing and stable throughout the lifespan, with children as young as four years old matching objects with respect to their topology in a manner that is almost identical to the matching behavior of adults (Yousif et al., 2025). This is not to mention other work showing sensitivity to other aspects of topological representation that are also stable across development and across species (see Chen, 1982; Chen et al., 2003; Kibbe & Leslie, 2016).

Regardless of whether we take this evidence to meaningfully undermine the two-system view, it points to the fact that there are various spatial representations (e.g., coordinate representations, topological representations) that are largely missing from the framework in its current form: Topological representations concern coarse spatial representation,

abstracted away from metric information like length, distance, and angle. Indeed, the essential finding from Kittur and colleagues (2026) is that even when metric information like angle and distance is entirely washed away from 2D drawings across 'chains' of memory, the topological structure is nevertheless preserved. These findings thus pose a challenge to the two-system view on two fronts. First, they demand an explanation of where topological spatial knowledge resides. Second, they demand an explanation for why it is that behavior appears strikingly similar across scales, despite the supposed dissociation between these systems and their respective domains (large-scale places and small to medium-scale forms, respectively). In other words, they motivate an antecedent skepticism about the foundations of the two-system view, in its current incarnation.

A modularist reply

These may all seem like trifling objections, but we happen to think they are serious. One could respond to all these observations by maintaining that the form and place systems have a modular and encapsulated architecture but with some ability to access the other's proprietary information. After all, in Section 1, we saw that Fodor was at pains to allow that modular (and non-modular) systems might share resources (as he took to be true of the modular systems involved in speech analysis). Alternatively, one could maintain the original distinction between form and place modules, doubling down on their use of distance and direction versus length and angle, respectively, while rejecting Spelke's conjecture that language is needed to integrate information across modules (2003; 2022; cf., Duval, 2025). Hence, one might maintain the original division of modular labor but maintain that our alleged counterexamples to this picture stem from the fact that, under certain conditions, the contents of the form and place system get combined, even in pre-linguistic creatures. The point to note is that: while we are sympathetic to this latter suggestion, in principle, the *entire reason* for positing two systems in the first place was the assumed fact that young children and other animals selectively use length/angle *or* distance/direction in different tasks, but not both. If there are inconsistencies in this starting assumption, it undermines the reason we had for thinking that spatial cognition might comprise two distinct and informationally encapsulated modules to begin with.

A proponent of the two-system view might, instead, reply by reminding us that independent neural evidence supports the view. After all, we saw in Section 2 that the proposed dissociation between a place module that represents distance and direction

contents, and a form module that represents angle and length content, is supposedly reflected in the organization of the brain (Spelke, 2022). The trouble is: Even bracketing difficulties making reverse inferences from neural data to conjectures at the algorithmic level (see Poldrack, 2006), let alone claims about informational encapsulation[8], the neural evidence itself is not as clean cut as proponents of the two-system view suggest. For instance, only *some* scene regions of the brain are sensitive to distance and direction (see Dilks et al., 2011; Persichetti & Dilks, 2016), while others respond to length and angle (cues supposedly reserved for the object system; Dillon et al., 2018). Likewise, object regions respond to direction contents even though direction content is meant to be encapsulated from the form system (Dilks et al., 2011). While these exceptions might be accommodated by the two-system view, especially in the absence of complete developmental data, the conjunction of considerable behavioral counterevidence, coupled with neural inconsistencies, forms a basis for doubting that the two-system view is accurate. This raises the question: What might an alternative framework for theorizing about the architecture of early geometric knowledge look like?

4 | The diverging algorithms framework

While the two-system view enjoys prominence among advocates of the core knowledge theory, we are not the first to question its merits and motivations. Drawing on different evolutionary, behavioral, and neuroscientific evidence, Newcombe (2018) submits that there are indeed multiple spatial systems, one for navigation and another for object manipulation (plus a third for symbolic spatial thinking). Nevertheless, she distances herself from Spelke and other adherents of the core knowledge hypothesis on the question of these systems' modularity: In particular, she denies that the systems under consideration are encapsulated from orthogonal geometric cues or non-geometric contents, as Spelke and others submit. A virtue of the resulting story is that it allows for

[8] Neurophiles often miss this, perhaps because Fodor (1983) devoted *an entire page* of his book to arguing that informationally encapsulated modules typically reduce to fixed neural machinery. We're not sure if Fodor's claim on this point was correct — although empirical critiques of this suggestion often miss the mark, denying such a reduction chiefly amongst the cognitive functions that Fodorians would readily deem *non*-modular (see e.g., Anderson, 2016, p. 3). Regardless, by emphasizing informational encapsulation in his characterization of a module, Fodor's achievement was to demonstrate that a principled faculty psychology is *not* at the mercy of neuroscientific reduction and can be cast at an autonomous algorithmic/psychological level (see Fodor, 1974; 1997).

more flexibility; narrow exceptions to the patterns of information access posited by the two-system view can now be accommodated by Newcombe's view. At the same time, it is unclear what positive predictions fall out of this view regarding the architecture of the underlying systems. The theory's flexibility threatens to leave it less incisive in this regard.

To appreciate this, consider that — on all accounts — there is a robust pattern of developmental and comparative data that any adequate theory of spatial cognition must explicate. For instance, an adequate theory must explain why rats (Cheng, 1986), young children (Hermer & Spelke, 1994), and other creatures often disregard featural cues when reorienting and even seem to neglect to use certain geometric cues that are freely utilized in other spatial tasks (Lee, Sovrano, & Spelke, 2012). For reasons discussed, an appeal to encapsulation offers to explicate this, thereby motivating a strong hypothesis about the architectural arrangement of the systems. But while we side with Newcombe in holding that such full-blown encapsulation fails to withstand scrutiny, at least when it comes to the systems comprising core knowledge of space, rejecting the encapsulation of these systems leaves us without an obvious explanation for the results we have been evaluating. Simply put: Noting that the place system *can* access featural and/or length and angle content fails to explain why this content is routinely neglected in the contexts which first motivated positing a geometric and/or place module. Similar points hold for the form system: If the system is not encapsulated from sense information, we should still like to know why it often fails to make use of this. Indeed, merely rejecting their encapsulation leaves us without any clear account of the systems' architecture, individuation, or architectural relationship – all matters that the appeal to modularity has been said to settle.

How, then, might we proceed? One option would be to find ways of resurrecting the encapsulation of the place and/or form module, despite the concerns raised in Section 3. To this end, proponents of the two-system view might avail themselves of theoretical and empirical considerations that have been taken to insulate the encapsulation of other modular systems from purported counterevidence (Firestone & Scholl, 2016; Mandelbaum, 2018; Quilty-Dunn, 2020; Clarke, 2021). In flagging this, we wish to stress that we are not antithetical to claims about modularity and Fodorian encapsulation in general. On the contrary, we have often advocated for them (Clarke, 2021; Casser &

Clarke, 2023; Clarke, *forthcoming*). Our position is simply one of skepticism over the idea that these defensive moves can save the encapsulation of the modules posited by the two-system view. The crux issue – as we see it – is not so much that a committed modularist might not find ways to accommodate some or all of the counterevidence amassed in the previous section (although we are dubious); rather, our worry is that doing so seems likely to tie them in knots and to leave the two-system view without any clear motivation (see, for instance, our discussion of Shusterman and Spelke's [2005] proposal that the limitations of a place system can be bypassed by use of simple associative mechanisms).

A second option would be to abandon the dissociation between encapsulated place and form systems altogether. There are several pieces of evidence that, on their surface, appear inconsistent with a clear modular dissociation between these systems (and, for that matter, not so much evidence to support their strict dissociation in the first place). This option is therefore tempting. Strong claims of encapsulation require strong evidence to be taken seriously, and such evidence is lacking in the case at hand — especially in comparison to other cases of modular processing which seem to us to be incontrovertible (see, e.g., discussion about the light-from-above assumption in the following section).

To motivate this second option, it might be noted that rejecting encapsulation is not a novel strategy. Miller and Shettleworth (2007) propose an associative view, where the relative associative strength of cues at locations shapes how often the locations are chosen (see Miller, 2009, for an extension of the model to room-size effects, including in children). Another approach that (*prima facie*) suggests a rejection of encapsulation appeals to Bayesian models of cue combination (Cheng et al., 2007; Xu et al., 2017). Xu and colleagues (2017) apply a Bayesian framework to reorientation, arguing that geometric and non-geometric information are combined in a probabilistic fashion.

A virtue of the latter view is that it allows that the value of any one cue might vary in a probabilistic fashion, depending not only on the local context but also perhaps prior experience with similar environments. Such views thereby succeed in ways that Spelke and Newcombe's views cannot: They offer to explain why it might be that children *occasionally* use certain cues that they often fail to. At the same time, they are specific to particular forms of spatial behavior (e.g., reorientation) and leave open key questions that

the appeal to modularity sought to settle: namely, how (and in what sense) systems of form and place analysis might be individuated at the level of cognitive architecture.

To address these questions, we recommend a third option: Rather than abandoning the systems that two-system theorists posit altogether, we might instead posit a different *kind* of modular division between them. This is conceivable because Fodor's characterization, framed in terms of informational encapsulation, is not the only way one can make sense of a system's modularity or cognitive dissociability (Carruthers, 2006; Chomsky, 2017).

Our preferred alternative in this context turns on the fact that psychological systems might be individuated either by the *content* that the mechanisms have access to, *or* by the *algorithms* that govern their operations (Samuels, 1998). Roughly, an algorithm is a finite sequence of well-defined steps that transforms inputs into outputs. Consider, for instance, a computer program that searches for information located within a single list of items. Suppose that this search engine employs two distinct search algorithms over this list (in Fodor's parlance: over this single "proprietary database" of information): one algorithm returns results based purely on semantic similarity, whereas the other returns results based on the frequency with which they are visited. Both algorithms access and make use of the same list of information. It is clear, however, that they may nevertheless return diverging results on account of differences in the informational content that each algorithm prioritizes and emphasizes. Yet, at the same time, it need not be that these algorithms *always* return different results and we can imagine back up procedures baked into either algorithm which would compel the machine to access and utilize different cues when it detects an error or deems its default mode of processing unreliable. Imagine then that the place and form systems function in a similar manner: They have access to the same "proprietary database" of geometric and non-geometric content, but they run on different algorithms that will often (but not always!) return different results by virtue of prioritizing diverging cues and contents in their operations. On such a view, the systems are individuated not by the representations they manipulate but by the algorithms performed over those representations (this is consistent with recent views positing that each domain of core knowledge may have its own domain-specialized language(s) of thought; see Chandra et al., 2026; see also Yousif & Epstein, 2026). See Figure 2.

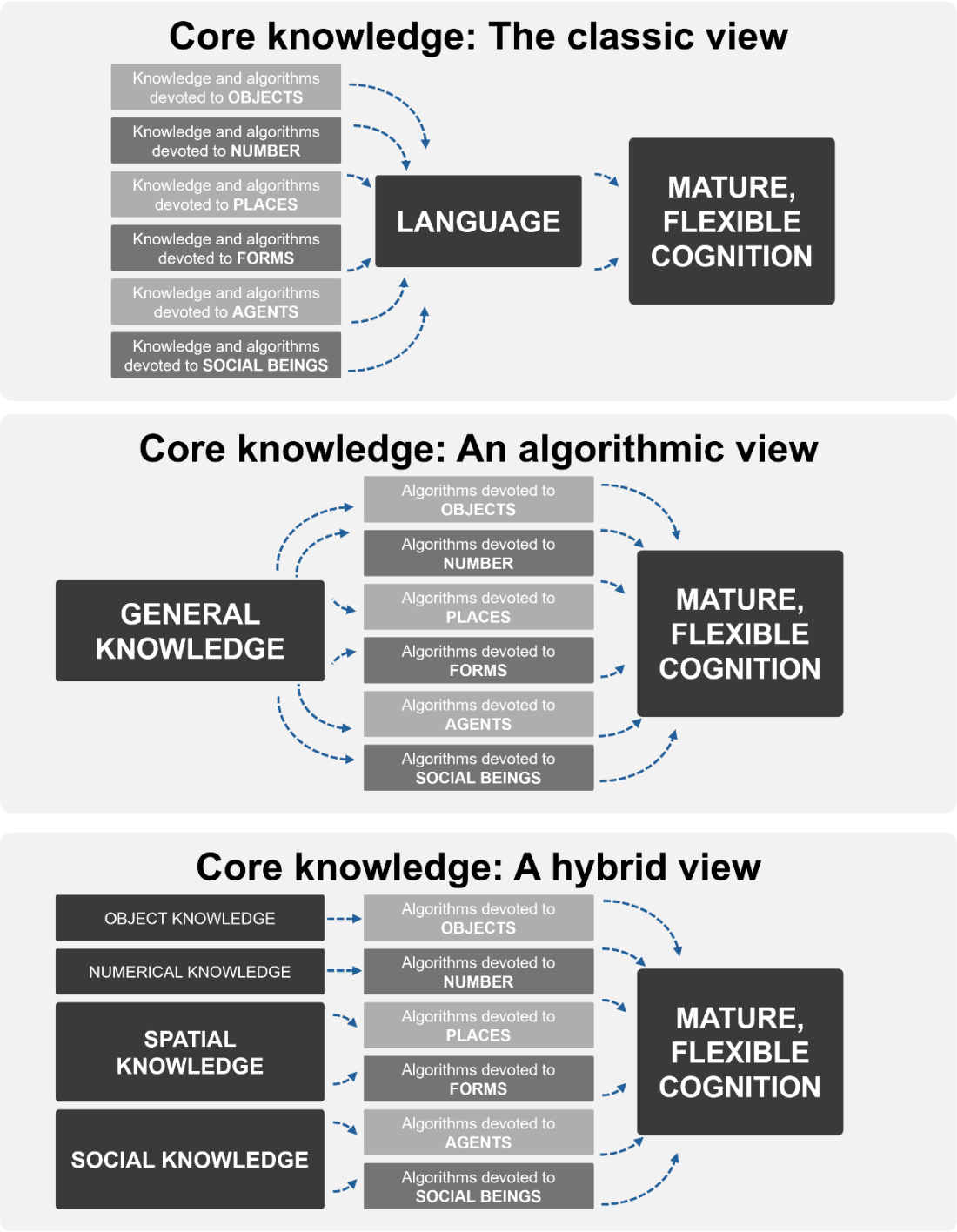


Figure 2. Different ways of thinking about the architecture of 'core knowledge'. The first view emphasizes distinct knowledge possessed by each module. The second emphasizes distinct algorithms. The third view is a combination of the two. We are not completely wedded to any one of these views.

Interestingly, this *diverging algorithms framework* is arguably closer to Cheng's initial formulation of his geometric module hypothesis than his allusions to Fodorian

modularity suggest. As Cheng put this, "It might be that all potentially useful information for spatial orientation is stored together in one record, but that different access rules make one kind of information, the geometric, more accessible for navigational purposes" (1986, p. 172).

Regardless of how Cheng intended this passage to be interpreted, our point here is that the appeal to diverging algorithms is an attractive suggestion that is importantly distinct from the postulation of Fodorian modules, and which nevertheless offers to explain the patterns of developmental and comparative data under consideration. On the one hand, positing distinct and autonomous algorithms for navigation and form analysis offers to explain why the systems at issue exhibit different signature limits. The place system's algorithms dictate preferential usage of distance and direction information, at least under normal conditions, while the form system's computations dictate preferential use of length and angle. On the other hand, and because the view allows that the systems perform different computations over the same representational resources, it allows that overlapping contents sometimes inform either system's operations — e.g., that sometimes the place system might use length content, and sometimes the form system might use direction content, to guide its computations.

Crucially, on this view, the form and place systems are no longer conceived of as encapsulated from the geometric and/or non-geometric information that gets accessed by the other, enabling the view to accommodate the counterexamples to Spelke's stricter Fodorian hypothesis we have described. For instance, it allows that non-geometric content might get made use of by the place system when the features in question are made particularly large and salient (cf., Shusterman & Spelke, 2005), that these features might occasionally guide flexible navigational inferences (e.g., enabling target locations to be encoded as those which are one left of the corner adjacent to the red wall; see Newcombe et al., 2010), and that they might sometimes be considered in tandem with geometric contents that are more readily made use of in visual form analysis (Yousif and Lourenco, 2017). This is because the dissociation of the systems does not turn on the dissociability of the information that either system has computational access to.

At the same time: The proposal still provides a framework within which to explain what an unqualified rejection of Fodorian encapsulation does not. For beyond accommodating

counterexamples to the strict encapsulation of these systems, it provides a framework within which to understand why children and other animals continue to selectively prioritize certain geometric content and neglect to consider others when (e.g.,) navigating and reorienting in small to middle-sized environments or why orthogonal cues are prioritized and neglected in form analysis. In much the same way that proponents of core knowledge conceive of the modules they posit as evolutionarily ancient adaptations that are common across species (Carey, 2009; Spelke, 2022; cf., Nieder, 2021), our proposal allows that the form and place systems (now demarcated by their diverging algorithms) might be products of ancient and/or convergent evolution that serve to cement the algorithms either system employs. As a result, the hypothesis offers a framework within which to understand why children and other creatures typically make use of certain geometric cues to navigate, in apparent abstraction from featural contents that strike us (adult humans) as transparently relevant to the task being performed; all the while, without requiring that these cues are always neglected.

To be clear, this proposal is not intended as a complete account of spatial cognition. It is proposed as a framework within which some such account might be developed. A complete theory would still need to identify the specific algorithms which actually dictate when information is and isn't employed by the place and form systems, and the parameters under which orthogonal cues become sufficiently salient that they get utilized in the tasks under consideration. It would also need to assess whether, and in what way(s), these algorithms are innate. Our crucial conjecture, however, is that some form of stable, system-specific algorithmic procedure underpins place and form analysis, since this offers to explain why cues that might otherwise seem salient or relevant to a young child (BRIGHT BLUE AND STRIPED WALLS!) *fail* to guide reorientation or form analysis in classic studies, while allowing that they can be accessed in other contexts.

This also clarifies how our framework relates to the associative and Bayesian accounts discussed above. We do not see these as competitors. Questions about how particular cues are weighted, and about when orthogonal cues become salient enough to be used, are precisely those that such accounts seek to answer, whether through the simulations of a Rescorla-Wagner model (Miller & Shettleworth, 2007) or through models of adaptive cue combination (Xu et al., 2017). These models are therefore natural candidates for specifying the algorithms that our framework leaves open. Nevertheless, it is important

to note that the diverging algorithms framework is broader than these proposals in two respects. First, it operates at a different level of psychological analysis: It characterizes how the systems in question are individuated within our cognitive architecture, rather than the processes they employ. Second, it is not specific to reorientation. It concerns the relationship between navigation and form analysis and might, potentially, be extended to other domains of core knowledge. This breadth gives the framework content of its own. What it adds is a claim about the structure of cue weightings: On our view, these differ systematically between the place and form systems, and they may or may not be the product of each cue's experienced reliability for the subject. This is why the same geometric property can be prioritized in one task and neglected in another, and why these priorities emerge early and similarly across species. A purely domain-general account of cue combination would need to posit system-specific weightings to capture this, at which point it would become one way of implementing the broader view we propose.

To illustrate how our framework might be developed: We submit that the algorithms which individuate the form and place systems are likely innate in a way that our tendency to neglect star sign content whilst hummus shopping is not. We say this because they are relatively uniform in early development and across species; they, hence, appear to be organized "in advance of experience" (Marcus, 2009, p. 147). For this reason, we were tempted to label our proposed framework *the innate algorithms hypothesis*. Nevertheless, we still consider it to be an open question whether these algorithms are, or can come to be, shaped and refashioned by learning. That they might be is suggested by the fact that children can come to integrate featural content into their spatial reasoning following prior exposure (Twyman et al., 2007; Lourenco & Cabrera, 2015) and that older humans freely integrate such information when reorienting (Hermer & Spelke, 1994). What we wish to note is that this is no foregone conclusion: In principle, such diverging algorithms might be fixed, much like certain tacit knowledge of grammar is on Chomskian accounts, yet later supplemented by the emergence or development of further cognitive resources, like natural language (Spelke, 2003) or working memory (e.g., Spencer, 2020), enabling a greater breadth of cues and contents to be considered simultaneously in spatial reasoning tasks. In any case, it is crucial to recognize that none of this turns on the respective systems' encapsulation from orthogonal cues and contents.

All of this is to say: What we are really advocating for is a new approach to the study of spatial knowledge, its origins, and its development. On our preferred framing, the "hard core" of this research program (Lakatos, 1970) pertains to a need for diverging algorithms that explain the uniformity in developmental and comparative studies of reorientation and form analysis, while simultaneously allowing that these algorithms might access diverse bodies of content and knowledge. It is a framework on which more precise theories of these abilities and systems can now be built.

5 | Ramifications for the core knowledge theory

Our discussion has focused on the origins of spatial knowledge. Contrary to the two-system view, as it has been formulated within the core knowledge literature, we have argued that the evidence for the encapsulation of form and place modules is weak (Section 3). Moreover, we have argued that the behavioral dissociations that motivate the view can be accommodated by our alternative diverging algorithms hypothesis, according to which the form and place systems are distinct on account of the algorithms governing their input-output functions, rather than information/content they have access to/are encapsulated from (Section 4). Given this, we advocate for a reconceptualization of the two-system view and its corresponding account of spatial knowledge in development. But how does this refinement bear on the core knowledge hypothesis more generally? We close by considering this question.

Core knowledge has been regarded as a distinctive psychological kind, sandwiched between perception and mature and linguistically mediated thought, on account of its architecture and relative abstractness. For instance, Carey (2009) conceives of core systems as akin to perceptual mechanisms in their modularity and in the iconicity of their representations, but unlike perceptual systems in that they trade in abstract contents, once thought to be the preserve of central cognition (but see Bai et al., 2025). Indeed, some of the content most relevant to the place system appears to be computed within perception itself: scene-selective visual cortex automatically encodes the navigational affordances of a scene, representing the paths available for movement across wide variation in visual features (Bonner & Epstein, 2017). Interestingly, Spelke (2022, p. 191) largely accepts this picture, but rejects Carey's suggestion that core knowledge is wholly iconic (Spelke, 1990; see also Quilty-Dunn, 2019; cf. Clarke, 2022). Regardless, the modularity of the systems involved is widely regarded as a defining feature of the

psychological kind these theorists posit (see, e.g., Spelke & Kinzler, 2007). Modularity itself — not just the specific knowledge that is posited to exist within those modules — is conceived of as a key feature of core systems. For this reason, it is worth considering how our rejection of Fodorian modularity in the case of spatial knowledge bears on the broader core knowledge hypothesis.

One possibility is that it offers a refinement that is wholly consistent with the architectural unity of core knowledge as a psychological kind. On this view, it might be conceded that the form and place systems are not encapsulated in the manner of a Fodorian module but individuated by their proprietary (and perhaps innate) algorithms (see Section 4). Nevertheless, it might be thought eminently plausible that this is also true of other core knowledge systems, such that all core knowledge systems should be individuated in this way. Perhaps then this path might lead to a refinement of the core knowledge hypothesis without threatening the unity of the psychological kind being picked out by its architectural profile.

Another possibility, however, is that the arguments here point to a more substantive reevaluation of core knowledge, raising a question about whether the broader umbrella of core knowledge can truly prove architecturally homogenous.

Why say this? Consider that one of the strongest motivations for the encapsulation of perceptual systems is that — while these mechanisms are inferential — they appear systematically incapable of integrating information that the subject knows and believes, no matter how salient or relevant its content. For instance, we noted in Section 1 that the visual system is widely seen to infer three-dimensional shape from patterns of shading, premised on the assumption that light comes from a single source *above*. This simplistic assumption serves us well in common environments that are lit by the sun or ceiling lights. However, it can also result in illusory percepts that systematically misrepresent reality. For instance, in the hollow mask illusion, a concave face is perceived as convex when it is lit from below, thereby inverting the typical correlations between shape and shading. What is crucial is that this illusion persists when known: Even when you reflect on your knowledge of the illusion, and/or attend to the lighting source below, your percept remains unchanged. So, while it is true that your visual system's priors about the source of lighting can eventually update, following long periods in atypically lit

environments, this seems to happen via mechanisms that are not directly, or rationally, sensitive to your knowledge of the situation. But if this is correct and such knowledge *does not* rationally inform the perceptual inference (Pylyshyn, 2003), we should like to know why this is; and it is, here, that an appeal to Fodorian modularity seems well-placed. It is at least plausible to suppose that the reason why no one has ever managed to identify an example in which learning something new straightforwardly and synchronically alters visual perception in clear or compelling ways is that the systems involved in visual inference are encapsulated from our beliefs and knowledge about the situation (Firestone & Scholl, 2016).

We emphasize these points because some systems of core knowledge produce recalcitrant illusions of much the same sort. For instance, core object knowledge is arguably responsible for vivid illusions like the tunnel effect (Scholl & Flombaum, 2010); core knowledge of agency operates according to increasingly well-understood principles (Scholl & Gao, 2013), and in ways that are insensitive to reflection on the fact that the agents in studies probing these are simple squares and triangles (Heider & Simmel, 1944). Meanwhile, the approximate number system that is associated with core knowledge of number is subject to numerous distortions, like the connectedness illusion (Franconeri et al., 2009), the coherence effect (DeWind et al., 2020), and the crowd size illusion (Waterhouse & Yousif, 2025) that lead to under/over estimations of numerical quantity. Often, these illusions persist throughout the lifespan, from early childhood onwards (Clarke et al., 2025).

What is most notable about these examples is not just that they result in illusions that are phenomenologically striking and readily appreciable, but that they *persist in spite of salient contradictory knowledge*. Recalcitrance indicates encapsulation; encapsulation indicates Fodorian modularity. While there may be some debate about the validity of these inferences (see, e.g., Prinz, 2006; Ogilvie & Carruthers, 2016), our point here can be stated modestly: In each of the above cases, core knowledge of objects, agency, and number still *appears* to be insensitive to certain known information and content, no matter how salient this becomes. Hence, something about the architecture or structure of the underlying systems must explain this. If we are right to deny that core knowledge of place and form exhibits similar recalcitrance from featural contents or orthogonal geometric cues, when

these become salient, the architecture of these systems must look quite different. This runs contrary to the architectural unity of core knowledge systems.

Here, however, a natural worry arises. In Section 4, we argued that stable, system-specific algorithms can lead a system to neglect information that it nonetheless has access to. Why, then, should the recalcitrant illusions just described not be explained in the same way, as the products of fixed algorithms operating over information that the relevant systems could, in principle, access? If they can, then the first possibility considered above is reinstated: All core knowledge systems might be individuated by their algorithms, and the architectural unity of core knowledge would be preserved. To address this worry, it helps to make explicit a diagnostic that distinguishes the two architectures. Algorithmic prioritization predicts graded neglect. Since the neglected information is accessible to the system, it should come to inform the system's operations once it is made sufficiently salient, reliable, or familiar. This is precisely the pattern documented in Section 3: Featural cues inform young children's reorientation in larger enclosures (Learmonth et al., 2001; 2002), when they are needed to structure an octagonal space (Newcombe et al., 2010), and following prior exposure (Twyman et al., 2007), while geometric cues that the place system ordinarily neglects can inform reorientation under the right conditions (Yousif & Lourenco, 2017). Encapsulation, by contrast, predicts neglect that does not yield to such manipulations, since the relevant information is simply unavailable to the system's computations. By this criterion, the illusions described above fall on the side of encapsulation. The connectedness illusion, for instance, persists when observers know that the connecting lines are irrelevant to the task (Franconeri et al., 2009), and the percepts elicited by Heider and Simmel's (1944) displays persist despite full knowledge of how those displays were constructed.

It must be said that we are not the first to question the boundaries between different core knowledge modules. In the domain of agency, it has, for instance, been argued that agent representations are computed on the basis of principles of object individuation utilized by other modules (van Buren et al., 2017), whether in sensory perception (Bai et al., 2025) or core cognition (Carey, 2009; Spelke, 1990), perhaps because these systems form a hierarchy such that the outputs of core object knowledge serve as inputs to core agency discrimination (see Clarke, 2021). This, presumably, requires modular integration that obtains independently of language (*pace* Spelke, 2003; 2022; see also Duval, 2025). In a

similar fashion, others have questioned the strict independence of modules for physical and social reasoning (Jara-Ettinger & Schachner, 2024; Liu et al., 2026).

What might seem more troubling for the broader theory of core knowledge is that some have argued for the wholesale rejection of other modular boundaries posited by the core knowledge theory. For instance, where proponents of the theory have typically argued for a dissociation between the discrimination of small sets, through parallel individuation (cf., Barner, 2017; Margolis, 2020) and large numbers, as facilitated by an approximate number system (Feigenson et al., 2004; Spelke, 2022), Cheyette and Piantadosi (2020) have recently argued that a single system, operating according to a singular algorithm, yields the divergent behaviors that have typically motivated positing a modular dissociation between these systems. But without taking a stand on the question of whether Cheyette and Piantadosi's denial of these divisions is tenable (see Clarke, *forthcoming* for a salient concern), it is important to note that, irrespective of whether there is one or two core modules for number, the remaining system or systems still produce recalcitrant illusions, like the connectedness illusion, noted above. As a result, the system or systems of core numeracy still appear to be encapsulated — or at least, architecturally distinct — from the systems of core spatial knowledge discussed here. Thus, core knowledge theorists still need to face up to the fact that there is less architectural unity amongst the systems being posited than these theorists would freely acknowledge.

These issues are not merely taxonomic. Consider the role that core knowledge theorists have assigned to natural language. On the two-system view, young children's failure to combine geometric and featural information when reorienting is explained by the encapsulation of the place system, and their eventual success is credited to language, which is thought to provide a combinatorial medium in which the outputs of otherwise isolated core systems can be conjoined (Hermer & Spelke, 1994; Hermer-Vazquez et al., 1999; Spelke, 2003; 2022). This proposal depends on the place system's encapsulation. If, as we have argued, featural content can inform reorientation without language — when features are made salient, when the environment demands it, or following prior exposure — then reorientation no longer provides clear evidence that language is needed to combine the contents of core systems. This does not show that language plays no role in the development of flexible spatial reasoning. But that role may lie elsewhere: for instance, in helping to reweight cues that are already accessible, or alongside other

resources such as working memory, in enabling more cues to be considered at once (see Section 4).

A defender of core knowledge might reply that none of this threatens the theory, since core knowledge was never defined by its architecture alone. On this view, what unites core systems is their early emergence, their continuity across species, and their characteristic signature limits, and these features survive whether a given system is encapsulated or individuated by its algorithms. We are happy to grant that a psychological kind could be picked out in this way. But the concession comes at a cost. Encapsulation was not an idle feature of core knowledge theory: It explained why core systems exhibit the signature limits they do, why their contents are not readily combined, and why something like language was thought necessary to combine them. A kind individuated by (the abovementioned) non-architectural features might describe these patterns but without explaining them. Put in terms of Figure 2: If we are right, different core domains occupy different positions in the space of architectures depicted there. Some may be distinguished by encapsulated bodies of knowledge, others by diverging algorithms, and others still by both. Core knowledge theorists must then decide whether the kind they posit is defined by its architecture, in which case it is not unified, or by something else, in which case its architecture must be explained domain by domain.

6 | Conclusion

Our aim in this paper has been a targeted one — to scrutinize a specific modular division posited by the core knowledge theory (i.e., the division between a system for representing places and a system for representing forms) and to examine the consequences that follow from that scrutiny. We have argued that the evidence for informational encapsulation between the place and form systems is less secure than it might initially appear, riddled with — complicated, but underappreciated — counterexamples. As a way forward, we have sketched an alternative framework on which the form and place systems are distinguished not by their encapsulated proprietary databases but by the distinct algorithms that govern how spatial information is prioritized and processed in each context. Much remains to be worked out, including the precise nature of these algorithms, the conditions under which different cues are accessed and prioritized by different systems, and whether any of this generalizes to other core knowledge domains. Yet this renewed skepticism promises to be productive. The proposed view, in a way, frees core

knowledge theory from commitments to strict encapsulation that the data cannot sustain (and that for other domains may prove similarly cumbersome). At the same time, our discussion raises timely questions about the nature of core knowledge systems — namely, whether they are architecturally homogeneous, or akin to perceptual processes in their modularity. If our hunches prove correct and these systems are not homogeneous, then core knowledge should be understood not as a unified psychological kind, but as a family of systems that share superficial features while differing in their fundamental architecture and in the nature and/or degree of their modularity.

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