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In defense of language-independent flexibility, or: What rodents and humans can do without language

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There are two main approaches within classical cognitive science to explaining how humans can entertain mental states that integrate contents across domains. *The language-based framework* states that this ability arises from higher cognitive domain-specific systems that combine their outputs through the language faculty, whereas *the language-independent framework* holds that it comes from non-language-involving connections between such systems. This article turns on its head the most influential empirical argument for the language-based framework, an argument that originates from research on spatial reorientation. I make the case that neuroscientific findings about spatial reorientation in rodents and humans bolster the language-independent framework instead.

KEYWORDS
animal thought, cognitive flexibility, computationalism, geometric module, language, spatial reorientation

1 | INTRODUCTION

A central issue in philosophy of mind and cognitive science is to explain the *flexibility* of human cognition. Moreover, one of the most important and puzzling aspects of human cognitive flexibility is our ability to entertain mental states that integrate contents across distinct domains

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(Carruthers, 2006; Fodor, 1983, 2000; Samuels, 2012). How is it possible for humans to have mental states that integrate information about, say, the size of objects and their monetary value? How is it possible to entertain the thought *that the smallest object in this room is the most expensive*?

Let us call the ability that allows for cross-domain content integration *content flexibility* (cf. Carruthers, 2006). In this article, I look at the issue of explaining content flexibility from the perspective of *classical cognitive science*, the view that mental processes are computational operations over mental representations.

Proponents of classical cognitive science have struggled for years with the issue of accounting for content flexibility, and it is widely seen as presenting it with one of its biggest challenges (Fodor, 1983, 2000). Within classical cognitive science, two broad explanatory frameworks have been proposed to deal with it. I call one *the language-independent framework*. It states that content flexibility arises from connections that put in contact multiple domain-specific systems in higher cognition and that do so independently of the language faculty (Pinker, 1997, 2005). I call the other *the language-based framework*. This framework is also committed to the existence of higher cognitive domain-specific systems. However, its central claim is that content flexibility comes from the way in which these domain-specific systems combine their outputs through the language faculty (Carruthers, 2002; Spelke, 2003).

Philosophers and cognitive scientists have put forward theoretical arguments both in favor and against these two frameworks over the years. Unfortunately, however, these theoretical arguments have not led to a consensus about which of the two frameworks we should adopt.[1] With this in mind, this article seeks to reassess the most influential *empirical* argument for the language-based framework. The argument originates from behavioral studies of spatial reorientation in psychology, and it was mainly developed by Peter Carruthers (2002) and Elizabeth Spelke (2003, 2011; see also Hermer-Vazquez et al., 1999; Shusterman & Spelke, 2005). It focuses on establishing two claims:

> **(G+F) *Geometric and featural systems* claim:** Many species, including humans, possess (at least) two distinct navigation systems, one dealing with geometric information and one with featural information.
>
> **(L) *Language* claim:** Language is what allows humans to integrate the outputs of these two systems to guide their goal-finding behavior following disorientation.

As it turns out, Carruthers (2012) has come to reject the argument. But it remains influential, and many people have cited it to justify adopting the language-based framework (e.g., Berwick & Chomsky, 2016; Pietroski, 2005).[2]

The main goal of this article is to turn this argument for the language-based framework on its head. I maintain that not only does empirical research on spatial reorientation *not* support the language-based framework, it in fact provides a powerful case to uphold the

[1]See Pinker (1997) for theoretical arguments for the language-independent framework, Fodor (2000) for theoretical objections against it, and Pinker (2005) and Fuller and Samuels (2014) for responses to Fodor's objections. See Carruthers (2002) and Spelke (2003) for theoretical arguments in favor of the language-based framework, and Machery (2008) and Rice (2011) for theoretical objections to it. See Carruthers (2002, 2008) for responses that address many of the issues raised by Machery (2008) and Rice (2011).

[2]See also Gleitman and Papafragou (2012), Tommasi et al. (2012), and Hohol (2020) for works that offer sympathetic, yet ultimately non-committal discussions of the argument.

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language-independent framework over the language-based framework. Here is how I proceed. In Section 2, I describe the two frameworks in more detail. In Section 3, I present Carruthers and Spelke's argument. In Section 4, I argue that various neuroscientific findings about reorientation put significant pressure on anyone who would want to endorse (G+F) and (L) together. In Section 5, I claim that we can appeal to the same findings to formulate a new argument for the language-independent framework.

2 | TWO FRAMEWORKS TO EXPLAIN CONTENT FLEXIBILITY

Classical cognitive science holds that human and non-human animal minds contain *mental representations* and that mental processes are *computational operations* over mental representations. From the perspective of classical cognitive science, we can distinguish two components of content flexibility: (1) the capacity to *generate* cross-domain mental representations; and (2) the capacity to *make use* of cross-domain mental representations to guide action planning and belief formation.

The reason why content flexibility has attracted the attention of classical cognitive scientists can be summarized succinctly. Many of them believe, on a variety of empirical and theoretical grounds, that higher cognition—the part of the mind that deals with action planning and belief formation—is largely constituted by *domain-specific* systems.[3] Domain-specific systems are cognitive systems that deal with questions about a restricted domain. Here are some examples of cognitive domains for which domain-specific systems have been posited: face recognition, social exchange of goods and services, attribution of mental states to others, sexual attraction, geometry of three-dimensional layouts, and visual properties of physical objects. However, the purported existence of domain-specific systems in higher cognition raises questions about the origins and role of representations that combine contents pertaining to distinct domain-specific systems. For instance, if there are separate systems for the geometry of three-dimensional layouts and for the visual properties of objects, how can someone produce a representation with the content *The shortest wall is red* and make use of that representation to guide action planning and belief formation? Questions like this are at the heart of research on content flexibility.

This is where our two frameworks come in. Both accept the premise that higher cognition is largely composed of domain-specific systems. They also both assume that humans possess a computational system whose function is to deal with language acquisition, production, and comprehension—what is commonly known as *the language faculty*. They differ significantly, however, in how they aim to explain capacities (1) and (2).

Let us start with the language-independent framework. Its core commitment is that content flexibility arises due to a large number of non-language-involving connections between higher cognitive domain-specific systems, perhaps along with a few domain-general executive mechanisms that control the flow of information processing. (By *non-language-involving* connections, I mean connections that do not involve the language faculty at any point, either as an intermediary or final node.) Oftentimes, when two domain-specific systems feed their own representations through non-language-involving connections to a further system, that further system will have the potential to generate an integrated cross-domain representation. The integrating system will then either make use itself of the cross-domain representation to

[3]See, e.g., Gallistel (1990), Pinker (1997), and Carruthers (2006) for reviews of many of the relevant grounds.

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guide action planning and belief formation or send it along to further downstream systems that will operate on it.[4]

On this framework, one could expect that a cross-domain representation with the content *The shortest wall is red* gets generated within an integrating system that receives feedforward, non-language-involving connections from the two domain-specific systems cited above. The integrating system would create this representation by combining representations with contents such as *X is the shortest wall* and *X is red* (where "*X*" refers to the same specific wall) fed respectively by the geometry system and the visual-property system.

The core commitment of the language-based framework, on the other hand, is that content flexibility originates with the language faculty.[5] It posits that the language faculty has direct feedforward and feedback connections to most, if not all, domain-specific systems in higher cognition. In normal language production, domain-specific systems feed their own proprietary representations to the language faculty whose role is to combine them to create, among other things, motor instructions to utter, write, or sign a specific sentence.

As a toy example, suppose that the geometry system and the visual-property system each produce a representation with the content *X is the shortest wall* and *X is red* respectively. In some cases, the language faculty would receive these two representations, and opt to create motor instructions to utter the sentence "The shortest wall is red".

Different models belonging to the language-based framework part ways at this point. For concreteness, I will present Carruthers' (2002) account—but nothing hangs on the details provided in the next paragraph.

Carruthers (2002) places an important role on *inner speech*. On his view, the generation of a cross-domain mental representation often occurs when someone decides to utter a sentence in inner speech that combines contents from two distinct domain-specific systems. When this happens, the language faculty's comprehension subsystem gets activated by the utterance, which leads it to create a representation of the uttered sentence in a specific format known as *logical form* (as understood by Chomsky, 1995). Importantly, this format is adequate for consumption by many higher cognitive systems. Since the uttered sentence combines contents from two domain-specific systems, that logical-form representation will do so as well. The comprehension subsystem then sends the logical-form representation to all higher cognitive systems to which it is connected. They in turn make use of the logical-form representation for action planning and belief formation.

[4]Pinker (1997, 2005) develops perhaps the most standard model pertaining to the language-independent framework. He maintains that cross-domain integration occurs due to crisscrossing, non-language-involving connections among a large number of domain-specific systems, *without there being any system or central arena where most of the information is conjoined*. However, other types of language-independent models have been proposed in the literature. For instance, some accounts give a central role to a specific non-linguistic system in integrating the outputs of other systems, such as the system in charge of mental-state attribution (Sperber, 1994). Some other accounts postulate a central arena, sometimes called a "blackboard", where domain-specific systems publish information that becomes accessible to all other connected systems (e.g., Shanahan & Baars, 2005). The differences between all these models will not matter for the purposes of this article.

[5]Besides the papers listed in Section 1, Mithen (1996) and Carruthers (2006) are often cited as endorsing the language-based framework. However, these two works maintain that content flexibility arises from the integrative role of the language faculty *as well as* from non-language-involving connections between domain-specific systems. So, there is an important sense in which they propose a *hybrid* model. Given this, I will not discuss them in the article. First, the argument presented in Section 3 has generally been understood as bolstering a pure language-*based* model of content flexibility. Second, the new argument that I develop in Section 5 supports a pure language-*independent* model.

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To get a better grasp of the language-based framework, it helps to say something about its main rationale. Proponents of the framework generally believe, based on various empirical and theoretical considerations, that non-human animals share many of the higher cognitive domain-specific systems possessed by humans (see, e.g., Spelke, 2003; Spelke & Kinzler, 2007). But this raises a puzzle about what happened in our evolutionary history that explains why humans alone gave rise to art, religion, advanced tool use, mathematics, and science. Language-based theorists maintain that we can solve this evolutionary puzzle by holding that the appearance of the language faculty in our lineage conferred on humans the ability to combine the outputs of higher cognitive domain-specific systems that are otherwise incapable of integrating their representations (see also Mithen, 1996).

Now, the main difficulty with determining which of the two frameworks we should favor is that little is currently known about the detailed architecture of higher cognition. For example, we are largely in the dark about the number of domain-specific systems humans might have, the operations these systems perform, their neural realization, and how they are connected to one another. Cognitive scientists have hypothesized a plethora of domain-specific systems as part of various local theories of specific phenomena, but very few of these theories specify in detail the operations performed by the postulated systems or the connections they bear to other systems. And none of these theories have gained universal acceptance. Given this state of affairs, it is generally unclear how to generate specific predictions from either framework, let alone *test* these predictions.

This context is a large part of why behavioral studies of spatial reorientation became a focal point of discussion in research about content flexibility. As we will see in the next section, these experiments seemed to provide strong evidence at once for the existence of distinct domain-specific systems involved in spatial navigation, for how they work, as well as for the role of language in integrating their outputs.

3 | THE REORIENTATION ARGUMENT

The empirical argument for the language-based framework that I want to discuss was mainly developed by Carruthers (2002) and Spelke (2003, 2011), and it draws on behavioral studies of spatial reorientation performed by psychologists.

The argument aims to support the language-based framework by establishing two claims:

> **(G+F)** ***Geometric and featural systems*** **claim:** Many species, including humans, possess (at least) two distinct navigation systems, one dealing with geometric information and one with featural information.
>
> **(L)** ***Language*** **claim:** Language is what allows humans to integrate the outputs of these two systems to guide their goal-finding behavior following disorientation.

In this section, I review the considerations put forward by Carruthers and Spelke to defend claim (G+F) (Section 3.1) and claim (L) (Section 3.2). (Note that, because Carruthers no longer endorses the argument, any use of "Carruthers" in this section should be understood to refer exclusively to Carruthers (2002).)

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3.1 | Distinct systems dealing with geometric and featural information

Suppose that a subject is exploring a known environment looking for a particular goal discovered on a previous visit, like a desired object or a food source. Then, she suddenly loses perceptual access to her surroundings, only to recover it a few seconds or minutes later. How is this going to affect her goal-finding behavior? This is what reorientation experiments investigate. Typical reorientation experiments occur in a rectangular environment that includes one distinctively colored wall (Figure 1) and a goal hidden in one of the corners. An experimenter begins by letting the subject discover the location of the goal, either by hiding the goal in plain view of the subject and/or by giving her the opportunity to find it on her own. This is followed by *a disorientation procedure*, which typically consists in rotating the subject while her vision is obstructed. Once that is done, the subject recovers visual access to her surroundings and attempts to retrieve or reach the goal.

What happens then? Well, that depends on the type of subjects involved. Human adults, for example, immediately look for the goal at the corner where it actually is—referred to as *the correct corner*—on nearly every trial (Hermer & Spelke, 1996). After all, the correct corner holds a unique relationship with the distinctively colored wall, a relationship that adults can easily rely on to distinguish the correct corner from the other three corners. Surprisingly, however, it turns out that in most conditions young children look for the goal at *two* locations significantly more often than anywhere else in the environment *without significantly favoring one over the other*: the correct corner and the diagonally opposite corner (Hermer & Spelke, 1996; Hermer-Vazquez et al., 2001). And so do a variety of non-human species when performing reorientation experiments that involve looking for food sources, conspecifics, or exit locations in known environments (Cheng et al., 2013; Tommasi et al., 2012).

Carruthers and Spelke take the behavior of young children and non-human animals in reorientation experiments as revealing something deep about the cognitive architecture of spatial navigation. Along with many other navigation researchers, they see the performance of these subjects as supporting the existence of a domain-specific, encapsulated system that guides search behavior following disorientation and that is commonly known as *the geometric module* (Cheng, 1986; Gallistel, 1990). It is domain-specific in that it represents the geometry of three-

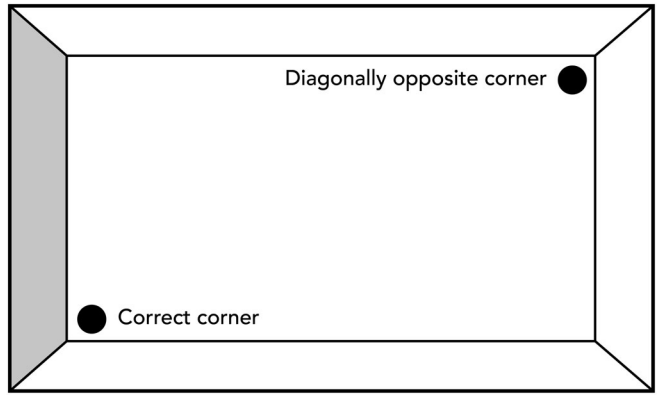

FIGURE 1 Experimental room used for a typical reorientation task as seen from above. It has three white walls and one distinctively colored wall (depicted here in light gray).

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dimensional layouts to guide search behavior in situations where subjects suddenly lose and recover perceptual access to their surroundings. It is encapsulated in that it makes use *only* of information about geometric cues once activated. As understood in the literature, *geometric cues* are cues that pertain to the metric properties (e.g., length, distance, height, angle) of three-dimensional surfaces and the left–right relations these surfaces bear to one another.

How does positing this system help explain the patterns observed with children and non-human animals? The explanation goes as follows. Since the correct corner has the same relationship as the diagonally opposite corner with regard to the overall layout of the three-dimensional surfaces in the experimental room (e.g., both corners have a long wall on the left and a short wall on the right in Figure 1), the geometric module guides subjects to search in one of these two corners at the beginning of a trial. And because it cannot distinguish between them in terms of their geometric properties, it chooses at random between them.

Carruthers and Spelke posit a further navigation mechanism, which I call here *the feature-processing system*. It guides subjects' behavior by using *featural cues*, namely cues such as colors and two-dimensional patterns on three-dimensional surfaces as well as isolated, self-standing objects (e.g., narrow trees, small rocks, telephone poles). Various strands of evidence support postulating such a mechanism as distinct from the geometric module, assuming the existence of the latter. For example, when rats perform a large number of reorientation trials in an unchanging experimental enclosure that has a stable goal location and a distinctively patterned panel in each of the four corners, they start choosing the correct corner more frequently over time (Cheng, 1986). Young children too can reliably find the goal if it is paired with a specific featural cue in some contexts (Hermer & Spelke, 1996; Lee & Spelke, 2010). One natural explanation for these results involves positing a system that helps subjects find the goal by tracking featural cues across visits.

In sum, by appeal to the type of findings just reviewed, Carruthers and Spelke maintain that human and non-human animals possess two systems—the geometric module and the feature-processing system—both of which can operate in reorientation experiments. This amounts to a defense of (G+F).

An important question remains, however: Why do human adults almost exclusively choose the correct corner in reorientation trials, in contrast to other types of subjects? Carruthers and Spelke's favored explanation is that human adults do so because *they routinely integrate the outputs of these two systems following disorientation* in opposition to young children and non-human animals, who never do so. This forms the basis of their defense of (L), to which we turn now.

3.2 | Language as content integrator for the two systems

If human adults can integrate the outputs of the geometric module and the feature-processing system, then there has to be something about them that explains why that is so—a capacity that they possess but that young children and non-human animals do not. A natural suggestion is: language. This gives rise to the claim that language is what allows humans to integrate the outputs of the geometric module and the feature-processing system to guide goal-finding behavior following disorientation. Carruthers and Spelke draw on two main further strands of evidence to defend (L).

First, human adults who engage in *verbal shadowing* (i.e., the process of repeating back recorded speech) while undergoing reorientation trials behave like young children and non-

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human subjects. That is, they choose both the correct corner and the diagonally opposite corner above chance, without distinguishing between them (Hermer-Vazquez et al., 1999). But, importantly, adult subjects choose the correct corner significantly above any other corner when they concurrently engage in *rhythmic shadowing* (i.e., the process of repeating back recorded rhythms devoid of linguistic meaning). These results support (L) because they suggest that tying up the resources of the language faculty through verbal shadowing causes human adults to fall back on the geometric module alone to guide their search behavior in ways that tying up general attentional resources through rhythmic shadowing does not.

The second strand of evidence comes from correlational data. It turns out that, among a variety of factors (like nonverbal intelligence, spatial working memory, vocabulary size), only the propensity to correctly apply the words "left" and "right" to describe spatial relationships between objects—which develops around 6 years old—is strongly correlated with children's success in reorientation trials (Hermer-Vazquez et al., 1999, 2001). This supports (L) since it "suggests a connection between linguistic ability and the conceptual underpinnings of successful navigation by [featural cues along with geometric cues]" (Shusterman & Spelke, 2005, p. 96).

Based on these findings, Carruthers and Spelke maintain that we should favor something like the following explanation of adult performance in *non*-verbal-shadowing conditions. Shortly after the beginning of a trial, the geometric module produces a representation with the content *The toy is in the corner left of the short wall and right of the long wall*. For its part, the feature-processing system produces a representation with the content *The toy is at the red wall*. Both representations are then fed to the language faculty, which outputs the sentence "The toy is in the corner left of the short *red* wall and right of the long wall". Or perhaps more simply "The toy is in the corner left of the *red* wall". Rehearsing this sentence in inner speech—a sentence that includes information from both systems—then allows the subject to distinguish the correct corner from the diagonally opposite corner.

4 | NEUROSCIENTIFIC EVIDENCE AGAINST THE REORIENTATION ARGUMENT

Let us call the set of considerations reviewed in the previous section *the reorientation argument*.

Some philosophers have been critical of the reorientation argument. They have objected to it largely on the grounds that there are plausible alternative explanations of the experiments discussed in Section 3.2. Samuels (2002) and Rice (2011) are cases in point. They each propose an explanation according to which human adults possess a yet unidentified non-linguistic cognitive system that typically integrates the outputs of the geometric module and the feature-processing system following disorientation. They further claim that we can account for the results from the verbal-shadowing condition by appealing to plausible assumptions about how this system interacts with the language faculty.

Unfortunately, however, all such alternative explanations have remained extremely underspecified. Moreover, their proponents provide few detailed reasons related to empirical research on reorientation for thinking that these explanations are *better overall* than the one proposed in Section 3.2. So, it seems that we have reached a sort of stalemate. Though the force of the reorientation argument is diminished by the existence of these alternative explanations, the explanations themselves do not appear inherently better than the account at the heart of the argument, and so the latter remains a live possibility.

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In this section, I remedy this situation. I develop a new reply which goes to the heart of the reorientation argument. I adduce specific neuroscientific findings to make the case that, on the assumption that (G+F) is true, then (L) is most likely false. (I will come back to the issue of whether (G+F) itself is true in Section 5.)

4.1 | Rodents can integrate the outputs of the two systems

I will start by arguing that, on the assumption that (G+F) is true about *rodents*, then it is extremely likely that *they* have a non-linguistic cognitive system that can directly integrate the outputs of the geometric module and the feature-processing system following disorientation. (I will argue that this conclusion carries over to humans in Section 4.3.)

The argument proceeds by defending the four following claims:

(i) In rodents, the activity of neurons known as *place cells* is generally sensitive to geometric cues following disorientation, and it can be responsive to featural cues following disorientation under specific circumstances.
(ii) The activity of place cells often guides the search behavior of rodents, both in oriented and disoriented conditions.
(iii) The geometric module and the feature-processing system feed representations directly to what I call *the location-tracking mechanism*—an additional system that I will describe shortly—to reset its internal value following disorientation.
(iv) The rodent location-tracking mechanism is a non-linguistic cognitive system that can *directly integrate* the representations sent by these two systems following disorientation.

This argument draws on single-cell recording studies. Such studies have revealed a large variety of spatially-tuned cells in the rodent hippocampal formation, notably including *place cells*. Place cells are neurons that fire when an animal represents itself as being in a specific location in an environment, independently of its heading (O'Keefe & Nadel, 1978). A given place cell might fire, for instance, whenever the animal is around 25 cm away from the north wall of an enclosure and 40 cm away from the west wall. The location where a given place cell preferentially fires is called its *place field*.

(i) *Sensitivity to geometric and featural cues following disorientation*

This claim is widely accepted among neuroscientists working on spatial navigation, and the main evidence for it can be summarized quickly. When it comes to geometric cues, note that place cells often maintain their place fields with respect to the shape of the environment following a disorientation procedure (Figure 2), as has been shown in rectangular (Jeffery et al., 1997; Keinath et al., 2017), square (Keinath et al., 2017) and triangular enclosures (Keinath et al., 2017).

Turn to featural cues. Experimenters often put saliently colored cardboard pieces, known as *cue cards*, on the walls of the experimental enclosures they use to study place cells. Such cue cards count as featural cues because they do not affect the geometric properties of the walls, only their color. And, crucially, it turns out that cue cards too affect place fields following a disorientation procedure—provided, that is, that the cue cards have previously been encountered for a certain amount of time under *oriented* conditions and they remained in a stable position

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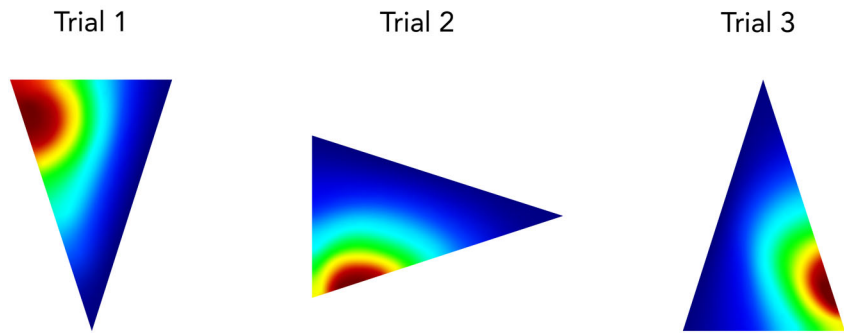

FIGURE 2 The influence of *geometric cues* on the firing field of a fixed place cell in an isosceles enclosure. Subjects undergo a disorientation procedure before every trial, as depicted by the rotation of the enclosure across trials. The colors inside the triangle represent the cell's level of activity (red, highest level—blue, lowest level) at that location. Schematic illustration based on Keinath et al. (2017), fig. 2. [Color figure can be viewed at wileyonlinelibrary.com]

during that time. If that obtains, place fields follow a cue card following a disorientation procedure (Figure 3) in circular (Dudchenko et al., 1997; Knierim et al., 1995) and square enclosures (Jeffery, 1998).[6]

It is worth addressing a contentious point of interpretation here. Though many neuroscientists have taken the analysis proposed in the previous paragraph for granted, Spelke (2022) has disputed it. She holds that rodents treat cue cards as geometric cues rather than as featural cues in the type of single-cell recording experiments just reported. Her reasoning for this relies on the idea that the brightness contrast provided by the cue cards, or their thickness, makes them look as if they are protruding from the enclosures' walls and therefore as if they have a three-dimensional structure of their own.

I believe, however, that there is a strong empirical reason for people who endorse (G+F) to *avoid* saying this. It has to do with a condition, hinted at above, that a given cue card needs to satisfy in order to affect place-cell activity: it only does so if it has been stable and subjects have explored the experimental enclosure for a certain amount of time in *oriented* conditions first. As it turns out, if subjects have frequently undergone a disorientation procedure before entering the enclosure in the past, then place fields will *not* follow the cue card (Knierim et al., 1995). Yet, it is hard to make sense of these findings if we accept (G+F) and the proposal that rodents treat cue cards as geometric cues. An implicit yet central assumption of models

[6]The experiment reported in Jeffery (1998) is not typically described as involving a disorientation procedure. However, as I use the expression here and for the rest the article, some subjects have undergone a *disorientation procedure* just in case they satisfy all the following conditions: (a) they lost visual access to their surroundings for a while (ideally, more than a minute); (b) they failed to remain immobile with their feet or paws planted on the ground during that time; (c) they, or salient cues in or around the experimental enclosure in which they found themselves, were rotated by the experimenter during that time. This construal is more permissive than some standard definitions in that it treats as disorientation procedures situations in which subjects' vestibular system fails to detect any angular movements caused by the experimenter and/or it is the experimental enclosure that is rotated rather than the subjects. Importantly, I think that we need something like this construal in order to avoid entailing that some key papers in the reorientation literature (e.g., Cheng, 1986; Pearce et al., 2006; Sovrano et al., 2003) do not really involve a disorientation procedure. Moreover, by that characterization, the subjects in Jeffery's (1998) *mismatch-rotation sessions* count as having undergone a disorientation procedure because, between every trial, they were confined to a platter in the center of the experimental enclosure which they explored for 4 min in the dark and, during that time, the cue card and the platter were rotated.

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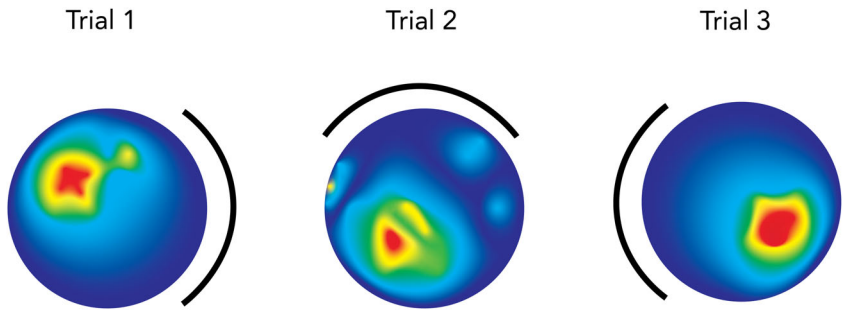

FIGURE 3 The influence of a *cue card* (thick black line) on the firing field of a fixed place cell in a circular enclosure. Subjects undergo a disorientation procedure before every trial, as depicted by the rotation of the cue card across trials. Schematic illustration based on Knierim et al. (1995), fig. 1. [Color figure can be viewed at wileyonlinelibrary.com]

that posit a geometric module is that subjects rely on geometric cues to guide their spatial behavior following disorientation *independently of any stability assessment*. This assumption helps geometric-module theorists explain why geometric cues guide corner choice on the first trial of behavioral reorientation experiments performed by psychologists and why subjects keep relying on geometric cues to find the goal in rectangular enclosures when doing so leads them astray in their search on about half of the trials.

(ii) *Involvement in guiding goal-finding behavior*

We need to begin by introducing a complication. There is a wide consensus among navigation researchers that mammals have *two* independent neural pathways that guide their search behavior when looking for known goals. One pathway is centered on the dorsolateral striatum, whereas the other pathway is centered on the hippocampal formation (which includes the hippocampus proper as well as regions surrounding it, like the entorhinal cortex and the subiculum) (Doeller et al., 2008; Nyberg et al., 2022).

The function of the dorsolateral-striatum pathway—or *the striatal pathway* as I will call it—is the execution of low-level motor responses in reaction to a history of reliably getting to a goal in an environment by performing those responses when confronted with specific cues. One clear example of rodents' reliance on the striatal pathway following disorientation is from Cheng (1986). In one of his experiments, rats performed a large number of reorientation trials in an unchanging rectangular enclosure that had a stable goal location in one of the corners and a distinctively patterned panel at each of the four corners. After a certain number of trials, they started choosing the correct corner significantly more often than the diagonally opposite one. However, when Cheng suddenly removed the panels in the correct corner and the diagonally opposite corner *while leaving the panels in the two other corners in place*, subjects fell back to chance between the correct corner and the diagonally opposite corner. This kind of performance breakdown suggests that, in the first part of the experiment, the rats were guided in their search behavior by the fact that the goal was always contiguous to a specific two-dimensional pattern. And physical-contiguity tracking is the hallmark of the striatal pathway.

Though there are many debates about the details, the function of *the hippocampal pathway* is to help the agent reach the location of a known goal by recording and retrieving the relationships between the goal and multiple surfaces and/or objects in an environment (as well as,

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sometimes, colors and two-dimensional patterns on these surfaces and objects). Moreover, there is strong evidence that rodents often call on this pathway to guide their movements *following disorientation*. Lesions to the hippocampus proper of a rodent completely disrupt its ability to use the overall shape of an enclosure to look for a known goal following disorientation in the same contexts in which non-lesioned rodents are exclusively influenced by environmental shape when disoriented (Jones et al., 2007; McGregor et al., 2004). The consensus is that rodents rely on the hippocampal pathway by default for behavior guidance following disorientation but that the striatal pathway can slowly start taking over when they have been repeatedly exposed to a specific stable goal-cue relationship, especially when that relationship is one of physical contiguity.

With that in mind, I will defend the following version of claim (ii): place cells guide the search behavior of rodents *when they rely on the hippocampal pathway* in both oriented and disoriented conditions.[7] The analysis for this claim relies on three findings:

- *In oriented conditions, place cells guide search behavior when a subject relies on the hippocampal pathway*. Robinson et al. (2020) trained mice to run on a virtual linear track and to stop when they reached a specific location close to the end where they could get a reward. Robinson et al. then set up a software protocol such that, when a subject moved passed a fixed "stimulation point" near the middle of the track, it underwent the optogenetic activation of those of its place cells whose normal firing fields were located near the beginning of the track. Mice exposed to this protocol began overshooting the reward zone significantly more often than before. Moreover, because the striatal pathway operates independently from the hippocampus proper where place cells are located, this strongly suggests that the animals were relying on the hippocampal pathway to guide their behavior.
- *Lesions to the hippocampus proper—the region where place cells reside—keep rodents from using overall environmental shape to guide their search behavior following disorientation in contexts where they would normally do so when relying on the hippocampal pathway* (Jones et al., 2007; McGregor et al., 2004; see last paragraph).
- *Following disorientation, the locations where place cells re-establish their firing fields predict the future location where a subject relying on the hippocampal pathway will search for a goal*. Keinath et al. (2017) observed that, in mice who had never been exposed in oriented conditions to a rectangular enclosure with a distinctive featural cue on one of the short walls, place cells generally re-initialized their firing fields either in their original location or in the diagonally equivalent location following a disorientation procedure, without favoring one location over the other. Keinath et al. also discovered the following predictive relationship: when place fields were re-established in their original location following disorientation, subjects generally looked for a known goal in the correct corner a few seconds later; when place fields were re-established in the diagonally equivalent location, subjects searched instead for the goal in the diagonally opposite corner on most trials. Furthermore, we have good reasons to believe that Keinath et al.'s mice were relying on the hippocampal pathway in doing so because they chose the diagonally opposite corner almost as often as the correct corner in the presence of a distinctive featural cue, thus displaying the type of almost exclusive reliance on environmental shape typical of the hippocampal pathway.

[7]Spelke (2022) seems to accept and defend this thesis as well (see pp. 121–125). Her defense proceeds in a different, but complimentary way to the argument offered here.

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I contend that we should endorse claim (ii) because it constitutes the best explanation of these three findings together. The best *alternative* explanation consists in saying that the hippocampal pathway guides behavior through two different classes of neurons—place cells in *oriented* conditions and a distinct type of cells in *disoriented* conditions—and that, whatever the exact nature of the second type of cells is, these cells guide behavior in disoriented conditions without themselves being causally influenced by place cells in doing so, even though lesions to the hippocampus proper disrupt their causal effect on search behavior and they in turn cause place cells to align their firing fields exclusively with the overall environmental shape following disorientation when subjects lack prior extended exposure to the environment in oriented conditions. Yet, this explanation is inferior to claim (ii). Along with the fact that it is far more complex than (ii), the main issue with it is that it does not seem that any known navigation-related cells could fit the description just provided for the second, hypothetical type of disoriented-condition-behavior-guiding cells:

- *Neurons typically involved in the striatal pathway*: These neurons do not seem to fit the description because lesions to the hippocampus proper do *not* disrupt subjects' ability to use the striatal pathway to guide search behavior following disorientation (McGregor et al., 2004).
- *Neurons that reside in the hippocampus proper but that are* not *place cells*: To my knowledge, there are two types of navigation-related cells in the hippocampus proper that can plausibly be argued to be functionally distinct from place cells: landmark-vector cells (Deshmukh & Knierim, 2013) and goal cells (Gauthier & Tank, 2018). Landmark-vector cells are neurons that fire when the agent occupies a location at a specific distance and direction from a self-standing object (such as a narrow, isolated cylinder in the middle of an experimental enclosure) and that remain otherwise unaffected by the location of three-dimensional surfaces (such as the enclosure's walls). Given their lack of sensitivity to three-dimensional surfaces, landmark-vector cells fail to fit the description for the hypothetical disoriented-condition-behavior-guiding cells since they could not cause place cells to align their firing fields exclusively with the overall environmental shape following disorientation. Goal cells, for their part, are neurons that become active when the agent is near the location of a known goal (e.g., a food source) and that remain otherwise unaffected by the location of three-dimensional surfaces. So, they fail to fit the bill for the same reason as landmark-vector cells: they could not cause place cells to align their place fields exclusively with the overall shape of an enclosure.
- *All other navigation-related neurons*: There are several categories of navigation-related cells outside the hippocampus proper that do not appear to be typically involved in the striatal pathway: for example, head-direction cells, grid cells, boundary-vector cells, border cells, conjunctive place-by-direction cells (see Grieves & Jeffery, 2017, for a more detailed list). Yet, it does not seem like any of them could fit the profile for the disoriented-condition-behavior-guiding cells. To see why, consider the fact that these hypothetical cells' causal influence on search behavior would need to be disrupted by lesions to the hippocampus even though that influence is *not* mediated by place cells themselves. The only way in which this could happen is if there are cells in the hippocampus *distinct from place cells* that provide a significant type of input to these hypothetical cells. But the problem is that the only navigation-related cells in the hippocampus that are arguably distinct from place cells (namely, landmark-vector cells and goal cells) do not have the right properties to account for the firing patterns of *any* of the extrahippocampal cells just cited. To give an example whose

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logic can be adapted to the other types of cells: head-direction cells' activity is often sensitive to the position of known three-dimensional surfaces around the subject (Clark et al., 2012), yet it is part of the profile of landmark-vector cells and goal cells that they do not react to the location of these surfaces.

(iii) *The geometric module and the feature-processing system feed representations to the location-tracking mechanism*

Place cells can fire in the same position for many days in an environment left unperturbed (Mankin et al., 2012). In fact, even some substantial modifications of the environment, like changes in lighting conditions or the removal of individual objects from the experimental room, often do not affect place fields (Muller & Kubie, 1987).

These empirical findings, along with many others, have led most neuroscientists working on spatial navigation to endorse two important theses: that the activity of place cells constitutes a *representation* of the subject's location; and that there is a specialized, place-cell-based higher cognitive system whose main function is to track the subject's location over time.[8] Neuroscientists use different names to refer to that specialized system, among the most popular being "locale system" and "hippocampal navigation system". However, I prefer to avoid these two expressions here. That is because they are sometimes interpreted in an alternative way as well—namely, as picking out a sort of overarching cognitive faculty that carries out *every* aspect of what the hippocampal pathway does (e.g., self-location tracking, advance path planning, online path following, near-goal approach, exploratory behavior) and that thus underpins multiple navigation processes housed in the hippocampal formation besides self-location tracking. Yet, I need an expression that only denotes the specialized cognitive system contained within the hippocampus proper that performs the process of maintaining dynamic representations of the subject's location through the activation of place cells. I have therefore coined a new name, *the location-tracking mechanism*, which I use exclusively in this way.

Empirical and theoretical work by neuroscientists has started producing a detailed picture of how the location-tracking mechanism operates (see O'Keefe & Krupic, 2021, for review): for example, whether and how different sense modalities can affect its location representations, how it adjudicates conflicts between distinct cues within and across modalities, how it reacts to the subject being introduced to new environments.

Where there is more controversy and uncertainty is the nature of the *cognitive systems* feeding it information about the cues to which it is sensitive. But, fortunately, in the context of the present discussion—in which we are assuming the truth of (G+F)—we can say something about this issue. Recall first that geometric cues help place cells to re-establish their regular place fields following disorientation and featural cues sometimes do so as well (claim (i) above). Assuming the existence of the location-tracking mechanism as just characterized, this entails that there are some system(s) that help it reset its internal location estimation following disorientation by feeding it information about geometric cues and featural cues re-identified from previous visits. Now, I maintain that we should take it that the system(s) playing that role are precisely the geometric module and the feature-processing system.

[8]See O'Keefe and Nadel (1978) for the *locus classicus* of the case for each thesis, and O'Keefe and Krupic (2021) for a complementary analysis.

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Why should we accept this? It has to do with the job description attributed to each system. The geometric module is theorized as a system whose role is to use information about geometric cues re-identified from previous visits to guide goal-finding behavior following disorientation. The feature-processing system, for its part, is conceived as a system whose function is to use information about featural cues re-identified from previous visits to guide goal-finding behavior following disorientation. Moreover, we have a strong justification for thinking that the location-tracking mechanism plays an important role in guiding goal-finding behavior following disorientation (see claim (ii)). So, it would be ill-motivated to posit some yet unidentified, additional navigation system(s) in charge of helping the location-tracking mechanism reset its internal value and eventually guide goal-finding behavior following disorientation. The geometric module and the feature-processing system fit the bill too well.[9]

(iv) *The rodent location-tracking mechanism is a non-linguistic cognitive system that can directly integrate the representations from these two systems*

To begin with, it should be obvious why the location-tracking mechanism is *non-linguistic*. Rodents do not have language in the relevant sense, so their location-tracking mechanism cannot be linguistic.

Turn to the claim that the location-tracking mechanism can *directly integrate* the outputs of the two systems. It gets support from the fact that, in the type of single-cell recording experiments where featural cues influence the activity of place cells (see claim (i)), featural cues could not have been used *alone* to reliably single out an accurate location estimate. Suppose for example that a rodent re-identifies a previously encountered cue card that now stands roughly 15 cm in front of its body. The cue card will look a certain size and shape in the subject's visual field. But it will have roughly the same size and shape in its visual field from many other locations in the environment. Even if the animal can adequately estimate its distance to the cue card, that would only narrow down its location estimate to a rough 15 cm-radius half-circle around the cue card (see top right corner of Figure 4). This strongly suggests that information about featural cues must be *integrated* with information about other types of cues to explain how the location-tracking mechanism manages to reliably recover an accurate location estimate in experiments like these. But what other types of cues? Since such single-cell studies control for everything else, it seems that we only have one choice: geometric cues.

[9]We should address a potential objection to this analysis. Navigation researchers sometimes assume that the striatal pathway and what I've called "the feature-processing system" are one and the same thing. This assumption could give rise to the objection that the feature-processing system cannot cooperate with the location-tracking mechanism, as proposed here, because the latter is part of the hippocampal pathway and the two pathways are largely independent. In response, let me note that there are good reasons for conceptualizing the feature-processing system as being *upstream* from the cognitive machinery implemented by the two neural pathways—or, if not upstream, then as a component of *both* pathways at once. First, the striatal pathway does not deal specifically with featural cues: rodents with hippocampal lesions can use a local geometric cue (e.g., the specific angle at which two corners meet) to guide their behavior, provided that the goal is contiguous to the cue (Jones et al., 2007). Second, the hippocampal pathway can handle featural information independently of the striatal pathway, as evidenced by the fact that place cells will, in some contexts, align their firing fields with a salient featural cue even when the cue has no stable relationship with any goal (Dudchenko et al., 1997; Jeffery, 1998; Knierim et al., 1995).

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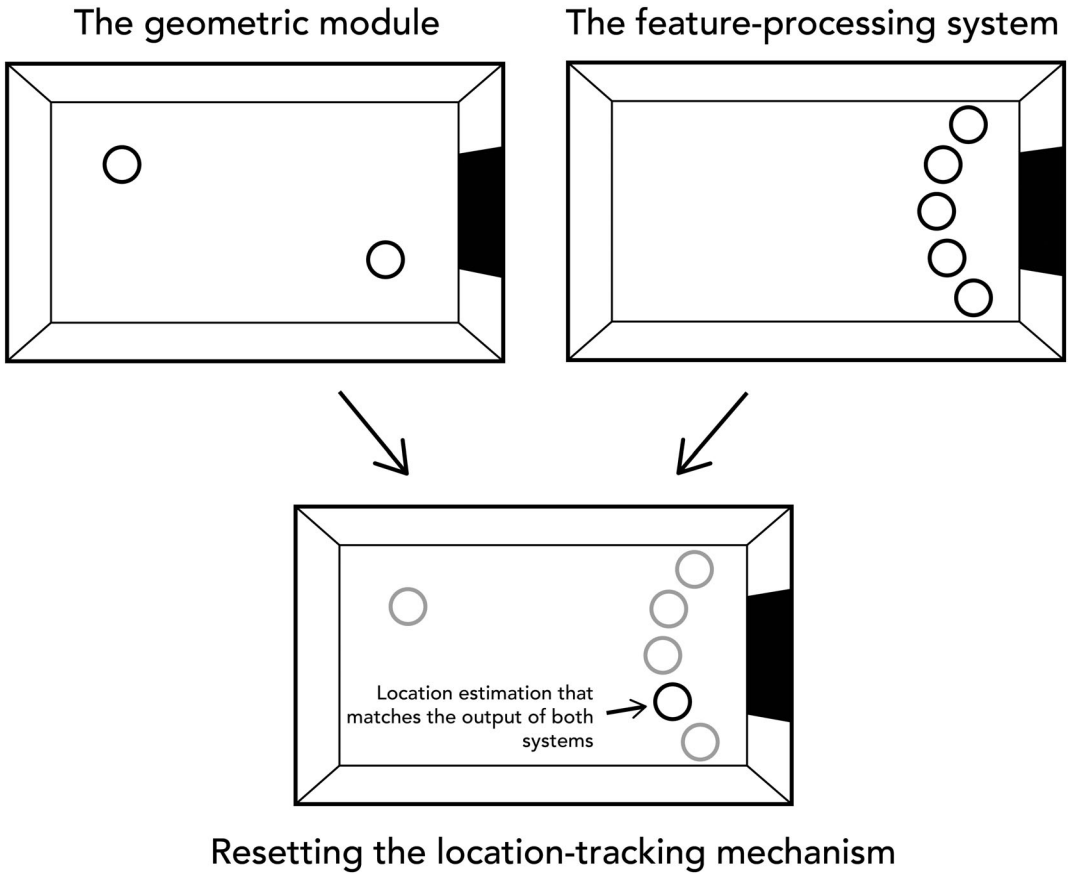

FIGURE 4 *Top*: Location estimations (open circles) sent out by the geometric module and the feature-processing system following disorientation. *Bottom*: Location estimation chosen by the location-tracking mechanism based on the *integration* of the two representations depicted at the top.

These considerations support the following account of experiments where featural cues influence the activity of place cells. Immediately following a disorientation event, the geometric module and the feature-processing system produce representations with the respective contents

According to geometric cues, subject is at (x_1,y_1); *or subject is at* (x_2,y_2); *or ...*

According to featural cues, subject is at (x_3,y_3); *or subject is at* (x_4,y_4); *or ...*

The task of the location-tracking mechanism then is to *integrate the content* of both representations so as to find a location estimation that matches the recommendation of both systems.

Admittedly, the type of content integration involved here could be relatively minimal. Whether it is or not depends on issues related to representational format that we cannot resolve here. On the one hand, suppose that the representations produced by the geometric module and the feature-processing system have a *map-like* format along the lines of the two images at

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the top of Figure 4. If so, the location-tracking mechanism would likely perform its resetting task by merging the two representations and then looking for a position in the compound representation's reference frame where the symbols for location estimates match (as in the bottom of Figure 4). In that case, it would integrate the two representations in a strong sense of *integration*. On the other hand, suppose that the two representations have a *discursive* format with a logical structure captured by something like the two italicized sentences in the previous paragraph. Then, the location-tracking mechanism would perform its resetting task by executing a one-by-one list comparison of the various locations recommended by the two representations and selecting the one location estimation that appears on both lists. This kind of content integration is more minimal than in the first scenario, but it still clearly counts as such. Unless the contents of *both* representations are accessed and compared to find a *matching* value, the mechanism simply would not be able to find an accurate location estimation in these experiments in the way we know it does.

Putting all the above together, it follows that, on the assumption that (G+F) is true about rodents, they have a non-linguistic system that can directly integrate the outputs of the geometric module and the feature-processing system following disorientation.

4.2 | Why do they go to the diagonally opposite corner then?

Suppose that we accept the argument just presented. An important question immediately arises: Why do rodents so often choose the diagonally opposite corner in the type of behavioral experiments performed by psychologists if they can integrate the outputs of the geometric module and the feature-processing system?

In principle, this question allows for multiple types of answers. My preferred answer, though, involves claiming that rodents possess representations of the *stability* of individual featural cues that they encounter. As I explained in my defense of claim (i) in Section 4.1, a cue card will play a role in aligning place fields following a disorientation procedure *only if the card has been observed as stable in the experimental enclosure for at least a few minutes in oriented conditions prior to the disorientation procedure*. Moreover, there does not seem to be any similar condition for the shape of an enclosure to get control over place fields. Such findings support two widely accepted ideas among neuroscientists working on spatial navigation: that rodents acquire and maintain stability representations for individual featural cues they notice; that the location-tracking mechanism only gets affected by a particular featural cue if that cue is represented as having a high enough stability value.[10]

These two ideas help us to answer the question raised above as follows. Subjects in typical reorientation experiments performed by psychologists undergo a disorientation procedure *whenever* they are about to enter the experimental enclosure. Hence, these systematic disorientation events should prevent subjects from increasing the represented stability value of the featural cues present in the enclosure. This should subsequently lead their location-tracking mechanism to rely on the location estimations from the geometric module, *but not* those from the feature-processing system, to reset its internal value following disorientation. Given the role of the location-tracking mechanism in guiding search behavior following

[10]See Knierim et al. (1995) and Jeffery (1998) for two of the first papers providing evidence in support of these ideas, as well as explicit discussion of them.

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disorientation, we should then expect subjects to choose the diagonally opposite corner about as often as the correct corner.[11,12]

Results from Keinath et al. (2017) bolster this explanation. As I mentioned in relation to claim (ii) in Section 4.1, they showed that, in mice who always undergo a disorientation procedure before entering a rectangular enclosure, place cells re-establish their firing fields by following the geometry of the enclosure—*but not* featural cues, even very salient ones. In this context, place cells *too* choose the diagonally opposite quadrant about half the time. Hence, it seems that there is at least one empirically well-motivated way of answering the question raised above.[13]

[11]One result from Batty et al. (2009) might seem to undermine this explanation. They trained a group of rats to find a goal location in a rectangular enclosure over a number of trials in *oriented* conditions when there was a distinctive and stable featural cue in the experimental room. They then exposed these subjects to a series of probe trials that started with a disorientation procedure, some of which involved the same featural cue. As it turns out, the subjects relied mainly on geometric cues to guide their search behavior in all the probe trials that involved the featural cue. This outcome appears to contradict the account in the main text because the subjects' extended exposure to the experimental enclosure in oriented conditions should have given them enough time to build up the represented stability value of the featural cue. However, I think it would be hasty to reject the account on that ground. Batty et al. had other groups of subjects, notably including a group whose training trials were identical to those described above except that they occurred in *disoriented* conditions. Subjects in this group had to choose the correct corner *on eight trials in a series of ten* to get out of the training phase and move on to the probe trials. Surprisingly, once they got out of the training phase, subjects in that group did not reliably use the featural cue to guide their behavior in any of the probe trials—even those probe trials that involved the exact same conditions as their own training trials (p. 333). This suggests that something about the way in which probe trials took place in Batty et al.'s experiment led the rats to treat them as importantly distinct from the training trials. Until we know more about what caused this, it is hard to draw any lessons regarding the account in the main text.

[12]Adopting the view set out in this paragraph has some important, and perhaps surprising, implications. For instance, it requires siding with prominent proponents of (G+F)—notably, Gallistel, Spelke, and Lee—on their claim that many extant experiments in which subjects reliably choose locations that are both geometrically and featurally adequate (e.g., Cheng, 1986; Twyman et al., 2009; see also Learmonth et al., 2008, in the case of human subjects) do *not* involve genuine integration of geometric and featural information into a single cognitive system in charge of behavior guidance. That is because subjects in these experiments also undergo a disorientation procedure whenever they enter the experimental enclosure. Moreover, as I see it, there are two main approaches to explaining the results of such studies without integration: (1) maintaining that subjects learn to execute a *sequence* of two independent operations, one involving the geometric module and the other involving the feature-processing system (cf. Gallistel, 1990; Lee & Spelke, 2010); (2) holding that subjects sometimes make use of representations that encode the *visual appearance* of the correct corner, and thus implicitly track the fact that the corner is, for example, left of a red wall to guide their behavior (cf. Wang & Spelke, 2002). Both approaches are compatible with the cognitive architecture developed in Section 4.1.

[13]The answer put forward in this section may seem to borrow in important ways from *the adaptive cue combination (ACC) theory* of reorientation (Xu et al., 2017). The central tenet of the ACC theory is that reorientation subjects decide where to look for a known goal following disorientation by doing a Bayesian inference about the probability that the sought-after reward will be found in a given corner given the represented *certainty* with which a particular type of cue indicates the position of the goal. However, appearances notwithstanding, the account proposed in this section yields a significantly different type of theory of reorientation. I will highlight one difference here, but there are others. It is that the account put forward predicts that what happens in an experimental enclosure prior to any rewarded trials can affect whether rodents will rely on featural cues to find a goal in the future. For example, it predicts that rodents extensively exposed in oriented conditions to a rectangular enclosure with a salient featural cue but without rewards will go to the correct corner significantly more often than naive subjects following disorientation once a reward is finally added. The ACC theory does not make any similar prediction because, as currently formulated, it only leaves *rewarded* exposures as a means of increasing the represented certainty associated with a given type of cue. (To my knowledge, no other theory of reorientation makes the prediction just highlighted. Moreover, I do not know of any published evidence that would allow us to confirm or infirm it, though Wang et al. (1999) report related findings about *human* subjects. I discuss Wang et al.'s results in fn. 15 below.)

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4.3 | Humans likely have a similar cognitive architecture for spatial reorientation

The argument of Section 4.1 puts significant pressure on the combination of (G+F) and (L). It does so by showing that language is not required to integrate the outputs of the geometric module and the feature-processing system following disorientation in *non-human animals*.[14] And this then undercuts the strategy of focusing on the purported role of language as content integrator to explain the difference in reorientation performance between human adults and non-human animals.

Here, I want to strengthen the case against the reorientation argument by providing two reasons for believing that, on the assumption that (G+F) is true, *humans* too likely have a non-linguistic location-tracking mechanism that can directly integrate the outputs of the geometric module and the feature-processing system following disorientation.

The first reason has to do with natural selection. Broad uniformity of behavioral (Tommasi et al., 2012) and neuroscientific findings (Las & Ulanovsky, 2014) about spatial navigation across mammalian species—including humans, monkeys, rats, mice, and bats—strongly suggests that the common ancestor of humans and rodents had the same cognitive architecture for spatial reorientation as present-day rodents do. Yet, there should have been substantive selection pressures *against* cutting the integrative component, the location-tracking mechanism, out of this architecture for any species that came after this common ancestor. Arguably, if something as intricate as the location-tracking mechanism was there in the first place, it is because it increased fitness by a significant amount. It seems unlikely that our ancestors in the *Homo* lineage evolved in an environment such that they would *not* have gotten punished for letting a previously selected-for integrative system be replaced by a new system, the language faculty, that takes up to 6 years to become effective at integrating the relevant representations to guide spatial behavior (Hermer-Vazquez et al., 2001) and that can be disrupted whenever we use our language-production abilities for other purposes (Hermer-Vazquez et al., 1999).

The second reason is that there is significant neuroscientific evidence that humans share the cognitive architecture described in Section 4.1. This evidence comes from studies where subjects use keyboards or joysticks to explore virtual environments while experimenters monitor their brain activity. First, single-cell recording studies with epileptic patients about to undergo brain surgery have uncovered cells in the human hippocampus that react to the subjects' location as they move around in such environments (Ekstrom et al., 2003). Second, the inactivation of the hippocampus of surgical patients through deep brain stimulation significantly interferes with the patients' ability to return to a goal location in virtual environments (Jacobs et al., 2016), showing that cells in the human hippocampus play a role in guiding their

[14]Some intriguing evidence points to the future possibility of formulating an argument about monkey and avian species that parallels the one presented in Section 4.1 about rodents. In particular, three considerations offer support for the view that monkeys and birds have a geometric module, a feature-processing system, and a non-linguistic location-tracking mechanism that integrates their outputs. First, all monkey and avian species tested in behavioral reorientation experiments—rhesus monkeys (Gouteux et al., 2001), chicks (Vallortigara et al., 1990), and pigeons (Kelly et al., 1998)—rely on geometric cues and/or featural cues to guide their search behavior in some contexts following disorientation. Second, a good case can be made that various species of monkeys (Las & Ulanovsky, 2014) and birds (Morandi-Raikova & Mayer, 2022) have place cells in their hippocampus. Third, these species arguably lack language in the relevant sense. However, what we are currently missing to formulate an argument equally strong as the one developed in Section 4.1 about rodents are studies with the kind of manipulations reported by, for example, Knierim et al. (1995), Keinath et al. (2017), and Robinson et al. (2020).

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goal-finding behavior. These first two findings, along with other considerations, have led to widespread agreement among neuroscientists that humans possess place cells and that these cells form the neural basis of a specialized cognitive system in higher cognition that tracks the agent's location for navigation purposes (see Epstein et al., 2017, for review). Third, functional imaging studies indicate that subjects display greater hippocampal activation with respect to control tasks when relying on *geometric* cues (Doeller et al., 2008), or *featural* cues (Sutton et al., 2012), to return to known goal locations following the functional equivalent of a disorientation procedure in virtual environments. Fourth, functional imaging studies have demonstrated that subjects exhibit even *greater* hippocampal activation when relying on featural cues *in the presence of geometric cues* to return to known goal locations following the equivalent of a disorientation procedure (Sutton et al., 2010). Once we assume that (G+F) is true, these last two findings support the view that the human location-tracking mechanism can directly integrate representations from the geometric module and the feature-processing system following disorientation.

In sum, these two reasons strongly suggest that, on the assumption that (G+F) is true, (L) is most likely false.

4.4 | Explaining the verbal-shadowing results and correlational data

The analysis presented so far leaves out an important issue. Recall the core findings of Section 3.2: (a) human adults choose the diagonally opposite corner more frequently when they engage in verbal shadowing than in other contexts; (b) children's production mastery of the words "left" and "right" is positively correlated with their success rate in reorientation trials. If humans possess a non-linguistic system that can directly integrate the output of the geometric module and the feature-processing system, then why do we observe these two patterns at all?

Again, this question allows in theory for various types of answers. Here, I will summarize my preferred answer, which involves two main observations.

First, human subjects do not spend much time in the experimental room before the first trial in typical reorientation experiments performed by psychologists. So, it is possible that featural cues do not have any impact on the internal value of their location-tracking mechanism in these experiments because the cues have not acquired a high enough represented stability value (cf. Section 4.2).[15] In that case, the location-tracking mechanism would reset its internal

[15]There is one experimental paper that seems to tell against the idea that human subjects maintain stability representations for featural cues: Wang et al. (1999). They reported that children aged 18–24 months searched at chance between the four corners of a square enclosure with one salient red wall after having been exposed to the enclosure in oriented conditions for a significant amount of time, sometimes over a few visits, prior to their first disorientation procedure. In theory, this should have provided subjects plenty of time to build up the represented stability value of the red wall. I would warn against drawing strong conclusions from this article alone, however. As Wang et al. themselves note, the hippocampus of 18–24-month-old children is far from fully developed. So, the mechanism in charge of managing stability representations and/or the part of the feature-processing system that interfaces with the location-tracking mechanism may not be completely operative at that age. Another issue is that the subjects visited other rooms between exposures to the experimental room, and these visits may have interfered with the memory encoding of geometric and featural representations created while in the experimental room. Newcombe et al. (2014) provide support for this sort of interference explanation. They reported that children younger than 21-month-old cannot display room-appropriate goal search behavior when exposed to two somewhat similar rooms in alternation in a search paradigm without a disorientation procedure, and that children younger than 26 months also fail to do so when they are not explicitly told what specific kind of object to look for.

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value based *only* on geometric cues. And, because we know that adults and older children often rely on featural cues to go back to the correct corner in *non*-verbal-shadowing conditions, it would mean that their search behavior in these conditions is driven by a distinct, language-based navigation process that bypasses the location-tracking mechanism.

Second, there is a plausible deflationary account of the role of language in reorientation experiments, put forward by Carruthers (2012), that posits just such a process:

> Adults and older children formulate a sentence like, "It is left of the red wall" and see that it encodes all of the information that they need to solve the task. They therefore rehearse that sentence to themselves (if they aren't shadowing speech) while undertaking the task. When they reach the search phase, they then treat the rehearsed sentence somewhat like an instruction for action ("Go to the corner that is left of the red wall"), the following of which enables them to by-pass or pre-empt what would otherwise have been their default inclination to look only at the geometry of the space [i.e., their inclination to look only at the geometry based on the output of the location-tracking mechanism]. (Carruthers, 2012, p. 394)

This process arguably accounts for finding (a). Carruthers then follows up with an explanation of finding (b):

> Younger children who lack the word "left," on the other hand, might try out for themselves the sentence, "It is *near* the red wall". But since this manifestly doesn't encode all of the information that they need—it doesn't tell them *which side* of the red wall to go to—they don't bother to rehearse it. (Carruthers, 2012, p. 394, his emphasis)

And so, they simply rely on the location-tracking mechanism to guide their search behavior.

Of course, more evidence would be needed to confirm the deflationary account presented in these two quotes. But, as such, it shows that the findings discussed in Section 3.2 are compatible with the view that humans possess a non-linguistic system that can directly integrate the output of the geometric module and the feature-processing system.

5 | TURNING THE REORIENTATION ARGUMENT ON ITS HEAD

In Section 4, I have claimed that various neuroscientific findings about spatial reorientation undermine the reorientation argument. In this section, I make the case that these findings also provide the basis of a new argument for the language-*independent* framework.

As noted in Section 2, the main problem with determining which of the language-independent or language-based framework we should favor is that we know little about the detailed architecture of higher cognition: about, for example, the number of domain-specific systems in higher cognition, what operations they perform, and their patterns of connectivity to one another. Arguably, the main reason why many researchers have focused on the reorientation argument is that they saw it as providing strong empirical reasons for positing two distinct domain-specific systems with detailed task descriptions and for thinking that language was directly involved in integrating their outputs. More generally, the argument became a focal

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point of attention because it seemed to provide support for the language-based framework by removing any question mark over the issue of whether there could be *any* two higher cognitive domain-specific systems that are unable to integrate their respective representations except through the language faculty. It appeared to give strong evidence that there could be such systems.

But we can now turn this reasoning on its head. The neuroscientific findings reviewed in Section 4 offer support for the three-system cognitive architecture presented there. The architecture, in turn, bolsters the case for the language-independent framework because it does the following: removing any question mark over whether there could be *any* two higher cognitive domain-specific systems that integrate their representations through non-language-involving connections. For instance, it rules out the possibility, sometimes hinted at by proponents of the language-based framework, that selection pressures in our evolutionary history would not have been of a type to allow for the development of non-language-involving connections between domain-specific systems in higher cognition.

This argument has two limitations that are worth delving into, however. The first limitation pertains to the fact that the three-system architecture presupposes the truth of claim (G+F). Yet, in the last 15 years, some researchers have proposed relatively well-specified theories of reorientation that reject (G+F) (e.g., Stürzl et al., 2008; Xu et al., 2017). A core commitment of these theories is that human and non-human animals possess a *single, unified*, higher cognitive system guiding spatial behavior following disorientation—not two systems, let alone three.

This is not the place to launch a full-on defense of (G+F), as there is a large literature in psychology dedicated to investigating it and theories that deny it (see Cheng et al., 2013; and Spelke, 2022, for reviews). But I want to offer a brief reply here. On the one hand, it is worth noting that many scientists researching spatial reorientation still take (G+F) as a viable hypothesis, and that a number of works (e.g., Duval, 2019; Gallistel & Matzel, 2013; Lee & Spelke, 2010; Spelke, 2022) have provided arguments and evidence against accounts of reorientation that reject (G+F). Importantly, what was said in Section 4 leaves these arguments and evidence untouched, as they bear on independent issues from those discussed in this article. On the other hand, it seems plausible to think that one of the hypotheses defended above buttresses (G+F). I argued in Section 4.2 that featural cues differ from geometric cues in that they must fulfill a stability requirement before being relied on to reset the activity of place cells following disorientation. On this view, featural cues cannot affect place fields unless the animal has observed the cues as stable first, as opposed to geometric cues whose impact on the cells is not so modulated. If it exists, this asymmetry suggests that there are two distinct cognitive systems—one relying on geometric cues, the other relying on featural cues—that help subjects re-establish the firing fields of place cells following disorientation, thus supporting (G+F).

The argument's second limitation is that, though it postulates direct content integration, the three-system architecture presented in Section 4 does not posit *cross-domain* content integration. After all, the representations sent to the location-tracking mechanism by the geometric module and the feature-processing system deal precisely with the same topic—the subject's location. So, the representation in the location-tracking mechanism that results from the direct integration of the output of the two systems is arguably not a *cross-domain* representation.

We should not read too much into this second limitation, however. To begin with, the three-system architecture still posits *indirect* content integration *across domains* through non-language-involving connections. According to the architecture, the location-tracking

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mechanism integrates information in a way that ensures that subjects can *simultaneously* rely on geometric cues and featural cues to guide their search behavior. Moreover, the architecture undercuts the standard evolutionary rationale for the language-based framework. The rationale holds that it is the acquisition of the language faculty that gave humans a cognitive edge over other species by allowing them to combine into a single representation the outputs of higher cognitive domain-specific systems (see Section 2). The rationale thus predicts that neither human nor non-human animals should possess non-linguistic systems that can integrate the outputs of higher cognitive domain-specific systems, *whether the integration would result in cross-domain mental representations or not*. Yet, the three-system architecture posits a non-linguistic system of that exact type in both rodents and humans.

We can even spin this evolutionary analysis around in favor of the language-independent framework. The architecture, if right, indicates that there were strong enough evolutionary pressures on species with less cognitive sophistication than humans and much smaller brains to develop non-language-involving connections between domain-specific systems. And this is in a case where the resulting integration would merely allow the animals to fine-tune decision-making related to spatial navigation in a narrow context. One could be forgiven for thinking that these pressures would ramp up as we move toward *Homo sapiens* in our phylogenetic tree, toward species that have bigger brains and possess more cognitive sophistication. Who is to say this has not happened with many other pairs of domain-specific systems in higher cognition, thus creating multiple cognitive loci for *direct* content integration *across domains* through non-language-involving connections?

6 | CONCLUSION

We can summarize the thrust of the article as follows. There are two broad frameworks for explaining content flexibility in philosophy of mind and cognitive science: the language-independent framework and the language-based framework. Moreover, some striking behavioral findings about spatial reorientation have led to the formulation of a highly influential empirical argument—the reorientation argument—that aims to support the language-based framework. It proceeds by defending the following claims: (G+F) Many species possess at least two separate navigation systems, one dealing with geometric information and one with featural information; (L) Language is what allows humans to integrate the outputs of these two systems following disorientation. In this article, I have pushed back against the reorientation argument in two ways. First, I have offered a direct reply to it by citing various neuroscientific findings that strongly suggest that, on the assumption that (G+F) is true, both rodents and humans have a non-linguistic cognitive system—the location-tracking mechanism—that can directly integrate the outputs of the two systems in question. This reply thus goes to the heart of the reorientation argument by undermining the combination of (G+F) and (L). Second, I have used these same neuroscientific findings to make the case that empirical work on reorientation in fact strongly supports the language-independent framework over the language-based framework.

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DATA AVAILABILITY STATEMENT

There is no data available.

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