Is there only one innate modular system for spatial navigation?

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It is a commentary on Elizabeth Spelke's target article "Précis of *What Babies Know*".

Abstract: Spelke convincingly argues that we should posit six innate modular systems beyond the periphery (i.e., beyond low-level perception and motor control). I focus on the case of spatial navigation (Chapter 3) to claim that there remain powerful considerations in favor of positing additional innate, non-peripheral modules. This opens the door to stronger forms of nativism and non-peripheral modularism than Spelke's.

A central thesis of *What Babies Know* (Spelke 2022) is that there are (at least) six innate modular cognitive systems beyond the periphery of the mind, one for each of the following domains: objects, places, numbers, forms, agents, and social beings. Moreover, it seems clear from previous works (e.g., Spelke & Kinzler 2007) and various discussions in the book that Spelke thinks that there are only a handful of systems that will turn out to be innate and/or non-peripheral modules — either exactly six or only slightly above six — and that research on core knowledge systems will therefore support *moderate* forms of both nativism and non-peripheral modularism.

My view on the book is that it does an excellent job of arguing for a *lower bound* on the number of such systems, but that it doesn't give strong reasons why we should stop at six and thus eschew stronger forms of nativism and non-peripheral modularism. It helps to distinguish two questions here: Are there additional innate modules operating *within* the six domains discussed in the book? Are there additional innate modules operating in *other* domains? I will make my case by focusing on the first question, and I will do so by taking spatial navigation (Chapter 3) as a case study. (Terminological note: In what follows, I count the properties of *domain-specificity* and *encapsulation* as jointly sufficient for modularity.)

Chapter 3 defends an influential idea in navigation research commonly known as *the geometric-module hypothesis*. On a standard construal, it says that humans and many non-human species (including all mammals) possess an innate, domain-specific, encapsulated cognitive system that guides search behavior following sudden disorientation. Moreover, the system is encapsulated by virtue of operating on geometric representations of the three-dimensional surface layout of environments, and nothing else. The chapter doesn't explicitly argue for the view that this is the *only* innate module involved in spatial navigation. However, it rejects two challenges to that view, which I discuss in turn.

The first challenge relates to the ability to do *path integration*, which is well-documented in humans and many other species (Etienne and Jeffery 2004). It is the process by which a subject keeps track of the distance and direction travelled from a certain origin point by relying on self-motion or *idiothetic* cues (i.e., proprioception, motor efference copy, vestibular signal related to head movements, and optic flow), perhaps along with other cues. Moreover, many researchers (e.g., Gallistel and King 2010) believe that path integration is underpinned by an innate, domain-specific, encapsulated, non-peripheral cognitive system on something like the following grounds:

> ***Innateness:*** Various species can perform path integration early in their life, with very little experience of the world (Newcombe et al. 1998; Bjerknes et al. 2018).
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> ***Domain-specificity:*** The system must use linear and angular velocity signals obtained from idiothetic cues to estimate the distance and direction travelled in recent bouts of spatial movements. To do so, it must perform the integration of velocity with respect to time, as well as other very specific mathematical operations suited to the task (Gallistel and King 2010).
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> ***Encapsulation:*** Given the complexity and specificity of the mathematical operations involved, the system can only make use of input representations that have a very specific format. This in turn suggests that it will use only rely on the inputs from a handful of systems, those that have evolved to cooperate with it — such as systems for dealing with idiothetic cues, as well as (possibly) systems encoding geometric or featural information about the environment (see below).
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> ***Non-peripherality:*** The system deals with abstract properties (location and heading of the subject), and it operates on information pertaining to multiple sense modalities (e.g., vestibular signal and optic flow). In addition, though it guides behavior in a variety of contexts (Etienne and Jeffery 2004), it is not a low-level motor system either.

Finally, given that this system is triggered in different conditions (oriented navigation) than the geometric module (disoriented navigation), it is often thought that it is distinct from the geometric module.

Spelke's response to this challenge (p. 123) is to deny the last step. She holds that the core place system, *a.k.a.* the geometric module, is what deals with path integration. On this view, the geometric module is at work in the context of both oriented and disoriented navigation. In support of this claim, she argues that a number of navigation-related neurons in the mammalian hippocampus that underpin path integration display similar signature limits as the geometric module.

This response strikes me as problematic due to various findings about one category of navigation-related neurons: *place cells*. (Place cells are neurons that become active when an animal represents itself as being in a specific location in an environment.) In particular, I believe that there are good reasons to adopt the two following claims: (1) the implementation of the process of path integration in mammals directly involves place cells; (2) place cells are sensitive to *featural cues* (e.g., odors, colors, textures, two-dimensional patterns on three-dimensional surfaces) in contexts where animals are performing path integration. Since it is a central commitment of the geometric-module hypothesis that the geometric module is completely insensitive to featural cues, (1) and (2) together entail that the geometric module can't be the system that implements path integration.

Why we should we believe (1) and (2)? I will start by citing two strands of evidence in favor of (1). First, multiple studies suggest that lesions to the hippocampus proper, where place cells are located, undermines rodents' ability to go back to their home base when they are in the dark and deprived of olfactory cues (e.g., Maaswinkel et al. 1999; Wallace & Whishaw, 2003). Second, Robinson et al. (2020) provide strong evidence that we can interfere with subjects' ability to perform path integration by intervening specifically on place cells. Robinson et al. began by training mice to move on a virtual-reality linear track and to perform licking behavior in a specific zone of the track, near the end, in order to receive a reward. Then, in one of the experimental conditions, when subjects reached a pre-determined location around the midway point on the track, they underwent optogenetic activation of place cells that typically fired near the *beginning* of the track. In this context, mice started overshooting the reward zone and running straight through to the end of linear track significantly more often than before. This strongly suggests that the optogenetic activation of those cells around the midway point often caused the resetting of path integration to a previous position on the track.

Moving on to (2). Because this claim seems widely accepted among neuroscientists working on place cells, I will focus on only one paper: Fischler-Ruiz et al. (2021) showed that adding odors at specific points on a virtual-reality linear track significantly increases the number of hippocampal cells that qualify as place cells (according to standard methods for identifying such cells based on imaging data) as well as significantly improving the ability of mice to reach a reward zone at the end of the track in the dark. This supports the view that odors, which count as featural cues, can affect place-cell activity in path-integration contexts.

In sum, these findings suggest that proponents of the geometric-module hypothesis must accept that there is an additional innate, non-peripheral module that implements path integration.

The second challenge pertains to a theoretical paper (Duval 2019) which argues, among other things, that extant versions of the geometric-module hypothesis are incomplete because they do not explain how subjects can reliably select the geometric representation of the current environment from memory following a sudden disorientation event.

Drawing on a variety of experiments that involve multiple enclosures, Duval further suggests that geometric-module theorists should posit a domain-specific and encapsulated cognitive mechanism that performs something like environment recognition by virtue of selecting a geometric representation of the current environment in memory. It operates according to the following principle: *Select the geometric representation in memory whose content best matches the current environment. If multiple representations match it about equally well, pick the one whose associated featural information best matches the featural cues in the current environment.* Assuming that the selection mechanism exists as characterized here, it has to be distinct from the geometric module because it is a central commitment of the geometric-module hypothesis that the latter is insensitive to featural cues. Furthermore, there are number of reasons to think that it would be innate and non-peripheral:

> ***Innateness*****:** By hypothesis, the selection mechanism feeds geometric representations to the geometric module that the latter needs to perform its behavior-guiding functions. So, if the latter is innate and operating early in life (as Spelke argues on pp. 134-135), the former would likely be as well.
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> ***Non-Peripherality***: The selection mechanism deals with abstract properties (geometry of the three-dimensional surface layout of environments). Moreover, though it guides behavior indirectly through the information it feeds to the geometric module, it is far from a low-level motor system.

Spelke's response to the challenge raised by Duval consists in holding that there would *not* have been strong evolutionary pressures for a specialized mechanism in charge environment recognition following a disorientation event. She writes: "Sudden, unknown, passive displacements to entirely new environments […] happened close to never in the lives of animals or people in preindustrial times. […] Although hurricanes or tidal waves may produce this situation, it is unlikely that we or other animals evolved specialized mechanisms for dealing with such rare events." (p. 93) She also points out that animals who actively navigate the world almost always change positions in a continuous fashion: e.g., "one step at a time" (p. 93) in the case of animals who stay on the ground. Thus, the process of path integration can help them maintain a sense of where they are in cases when they are *not* undergoing unexpected, passive displacements (which are very rare).

I want to push back on this analysis. I believe that, contrary to what Spelke claims, there are specific, recurrent situations in the wild where animals would benefit from a specialized mechanism for environment recognition. These are precisely situations where path integration is unreliable. One example comes from exploratory looping behavior. Many species perform looping paths in uncharted territories for purposes of exploration (Eilam 2014). Animals in this situation would benefit from a system in charge of environment recognition to determine whether they have come back to the environment where they started their exploration and have thus completed their loop. There is no way they can systematically rely on pure *idiothetic* path integration alone to determine whether have done so, as much work shows that idiothetic path integration quickly accumulates noise (see, e.g., Thrun 2002; Cheung et al. 2012). Another case pertains to animals who follow a familiar route in low-visibility conditions — due to fog, smoke, or the lack of sunlight at night — toward a known environment some distance away. For similar reasons about the unreliability of idiothetic path integration, such animals would benefit from a process of environment recognition to determine where they are on their route when there are sudden increases in visibility (e.g., a temporary clear-up in the fog, a better angle of the moon).

Hence, it seems that Spelke's response leaves intact the case, inspired by Duval (2019), for an evolved, innate, modular, and non-peripheral system in charge of environment recognition through geometric-representation selection. More generally, the foregoing discussion supports the view that there (are least) *two* innate, non-peripheral modules for spatial navigation in human and non-human mammals besides the geometric module brilliantly championed by Spelke.

Let me conclude by emphasizing that Spelke has done an enormous service to the cognitive science community with this book by providing a careful, detailed, and extremely important analysis of a very wide range of experimental findings in support of moderate forms of nativism and non-peripheral modularism. Although I don't think that Spelke has given strong reasons to stop at the six innate modular systems that she identifies, the value of *What Babies Know* cannot be overstated.

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