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Dimensions of Diversity in Spatial Cognition: Culture, Context, Age, and Ability

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Introduction

Throughout the lifespan and across cultures, all human behavior happens in space. By early childhood, people are capable of navigating complex 3D environments, executing sophisticated motor plans, and coordinating action with others. They also use their representations of space to structure a variety of non-spatial concepts, including time, number, similarity, and emotion. How do people perform these cognitive feats? One source of insight comes from studying the diversity of spatial cognition: Although the physical properties of space are invariant, the way people typically conceptualize space varies radically across groups, between individuals, and over development. By studying this variation in spatial cognition, we can better understand the universal set of cognitive and neural mechanisms that underlie it, with implications for the cognitive sciences, education, and design.

In that spirit, this symposium brings together researchers who work in disparate subfields (i.e. neuroscience, complexity science, cognitive psychology, developmental psychology) to discuss four different dimensions of diversity in spatial cognition, as it varies across cultures, contexts, ages, and abilities. **Marghetis, Holmes, Star-Lack, & Chacon** focus on cross-cultural diversity at a global scale. Taking a systems-level approach, this work leverages decades of published field work across dozens of cultures to clarify patterns and predictors of spatial cognition, and to identify blind spots and biases in the kinds of cultures that have been sampled. **Pitt, Carstensen, Boni, Piantadosi, & Gibson** zoom in on a single culture — the Tsimane' of Bolivia. By studying how spatial concepts (and spatial language) vary at the level of the *individual*, this work seeks to clarify the principles that govern such variation, at any level. **Huey, Jordan, Hart, & Dillon** focus on changes in spatial cognition over development. By comparing the geometrical intuitions of children and adults (within and across cultures), this work helps to clarify the universal and cultural origins of our visuospatial knowledge. Finally, **Bottini** investigates how blindness alters neural representations of space. Using fMRI techniques in congenitally-blind adults, this work clarifies the role of vision in cognitive maps, the foundation of spatial navigation. Together, these talks offer a multi-dimensional view of spatial cognitive diversity, and motivate interdisciplinary approaches to the study of the mind.

A Systematic Investigation of Spatial Cognition Around the Globe

Tyler Marghetis, Kevin J. Holmes,
Maya Star-Lack, & Sandra Chacon

Communities around the world vary in the way they conceive of space. While some communities favor an 'egocentric' frame of reference (FoR) (e.g, left, right), others rely primarily on an 'allocentric' FoR (e.g., north, uphill). Why? Proposed explanations have invoked a range of causes, including cross-linguistic variation, features of the environment, lexical competence, and subtle cues in the task context. Typically, these candidate causes are tested in isolation, using case studies of a single community or comparisons of two unrelated communities. But given that many dimensions of cross-cultural variation are correlated, these targeted tests are often unable to disentangle putative causes from the broader cultural ecosystem.

In this talk, we describe an effort to systematically document all published results on cross-cultural diversity in spatial FoRs in a single databank. Considering the full range of global variation in spatial cognition allows us to disentangle cultural dimensions that are highly confounded in targeted comparisons of only a few cultures. Moreover, the databank is designed to integrate with existing information on variation in language (Glottolog) and socio-environmental context (Database of Places, Language, Culture, and Environment; D-PLACE). This "bird's-eye" view of cross-cultural diversity thus allows us to identify — on a global scale — the factors that predict diversity in FoR-based spatial cognition. We also identify forms of cultural, linguistic, and environmental variation for which we currently lack data on cognitive variation — "black holes" of cross-cultural investigation. This project thus builds on the herculean efforts of field researchers to identify regularities in how people around the world use FoRs to think and reason about space.

Variation in spatial memory and language: Different reference frames on different axes

Benjamin Pitt, Alexandra Carstensen, Isabelle Boni,
Steven T. Piantadosi, & Edward Gibson

Spatial cognition is central to human behavior, but the way people conceptualize space varies within and across groups. Some people predominantly use *egocentric* space to describe spatial relations (e.g. the fork is *right* of the plate), while others use *allocentric* space (e.g. the fork is *upriver* of the plate). These spatial *frames of reference* (FoRs) characterize the way people talk about spatial relations and

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the way they tend to remember them, even in tasks that do not involve language. This cognitive and linguistic diversity has been observed across cultures, individuals, contexts, and age groups, but its causes remain unresolved.

We propose that variation in FoR use partly reflects people's ability to discriminate left-right space, which is known to vary within and across groups. Although literate adults readily distinguish symbols like 'b' and 'd,' children and many illiterate adults do not make such distinctions, conflating symbols, images, and shapes with their left-right reflections (but not with their up-down or front-back reflections). We reasoned that this cross-axis difference in spatial discrimination should produce a cross-axis difference in people's preferred FoR.

In an initial test of this proposal, we compared FoR use across axes in the Tsimane', an indigenous Amazonian group. In both verbal and nonverbal tests, Tsimane' adults spontaneously used different FoRs on different spatial axes as predicted by their discriminability: On the lateral axis, where egocentric (i.e. left-right) discrimination is difficult, their spatial behavior and language was predominantly allocentric; on the sagittal axis, where egocentric (i.e. front-back) discrimination is relatively easy, they were predominantly egocentric. These results (i) establish a correlation between spatial language and memory within a single culture, (ii) challenge the claim that each language group has a predominant spatial reference frame on a given scale, and (iii) support the proposal that differences in FoR use may partly reflect differences in spatial discrimination, not only across axes, but also across cultures, between individuals, and over development.

Children's and adults' intuitions about spherical geometry

Holly Huey, Matthew Jordan, Yuval Hart, & Moira Dillon

Formal geometry underlies much of human achievement, from science and technology to art and architecture. Previous cross-cultural research found striking similarities in the reasoning about planar and spherical geometry between French and American children and adults and Amazonian children and adults, who receive no formal education in geometry. The present work looks beyond shared geometric intuitions to ask how geometric principles common to planar and spherical geometry might relate to one another. In particular, while different systems of formal geometry may describe different kinds of surfaces (e.g., Euclidean/planar, Riemannian/spherical, etc.), they nevertheless adopt the same foundational definition of a line as the shortest, most efficient path between two points. What are the contexts in which spherical linearity is intuitive and how do planar and spherical linearity intuitions relate to one another?

We presented groups of American 6- to 8-year-old children and adults paths between two points on pictures of spheres and asked them to judge which path was the most efficient for an actor to get from her starting point to a goal object. In one kind of trial, the two paths were curved in the pictures, but one of the paths depicted the correct shortest trajectory between the two given points. In another kind of trial, the same, correct curved path was paired with an incorrect, straight path, pitting spherical and planar linearity against one another. Although children often chose the incorrect straight path, children and adults were surprisingly successful at identifying the efficient paths when comparing two curves. Children's and adults' intuitions about the shortest path between two points may thus generalize to spherical surfaces, at least when judgments are couched in judgments about the efficient actions of others and there is no competing planar linearity. While participants in this experiment receive formal education in geometry, they are likely to receive little to no formal education in spherical geometry. These studies therefore set the stage for future cross-cultural work aiming to characterize the principles that underlie our natural geometric intuitions.

Cognitive Maps in the Blind

Roberto Bottini

Humans' ability to move and orient in their everyday environments is grounded on the construction of cognitive maps through the coordinated activity of place cells and grid cells in the hippocampal formation. Place cells in the hippocampus fire when an animal traverses a specific location in an environment. Grid cells, discovered in the entorhinal cortex, fire instead at multiple locations arranged in a regular hexagonal grid that tiles the local environment in a map-like fashion. Grid-coding can be detected with human fMRI (via 60˚ periodic modulation of the BOLD signal) during wayfinding in large virtual environments. However, it is still unknown whether grid cells are involved in mapping small-scale environments in the absence of vision, and whether congenital visual deprivation significantly alters the 60˚ periodicity of grid-like coding in the medial temporal lobe.

To answer these questions, we designed an experiment in which participants navigate a clock-like environment while undergoing fMRI. Participants describe directions from one number to the other in the clock, guided by auditory instructions, sampling the whole trajectory space with a periodicity of 15˚. Preliminary results in a group of blindfolded sighted participants showed a sixfold rotationally symmetric signal in the entorhinal cortex, supporting the involvement of grid-cells in mapping the environment even in the absence of visual cues.

Here we present data from congenitally blind people and matched blindfolded sighted controls in the same task. Our results shed light on the role of vision in the construction of cognitive maps and, more specifically, whether congenital blindness alters the geometry of allocentric spatial maps encoded in the entorhinal cortex.