
The Mechanistic Foundation of Culture: A Dual-Spectrum Architecture of Behavioral Transmission

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Abstract

Culture is often portrayed as a uniquely human hallmark, framed in symbolic and interpretive terms that lack mechanistic grounding and allow the concept to encompass almost anything. However, the species with the most cognitively elaborate cultures outside humans—chimpanzees and orcas—show that culture is not a human-exclusive construct, but a continuous process grounded in general cognitive scaffolds. This perspective calls for a definition that is precise enough to be mechanistically testable while unified enough to apply universally across cultural phenomena. We therefore propose: culture is group behavior transmitted and maintained across time, supported by two continuous spectra of cognitive substrates: (1) individual-level social learning, from simple imitation to explicit teaching, and (2) group-level processes, from non-inferential matching to structured, intentional transmission. We further show that species with greater cognitive capacities occupy broader ranges on these spectra, engaging in more complex and cognitively demanding cultural behaviors. This framework replaces symbolic assumptions with mechanistic structure, offering a unified account of cultural stability, variation, and graded complexity across contexts.

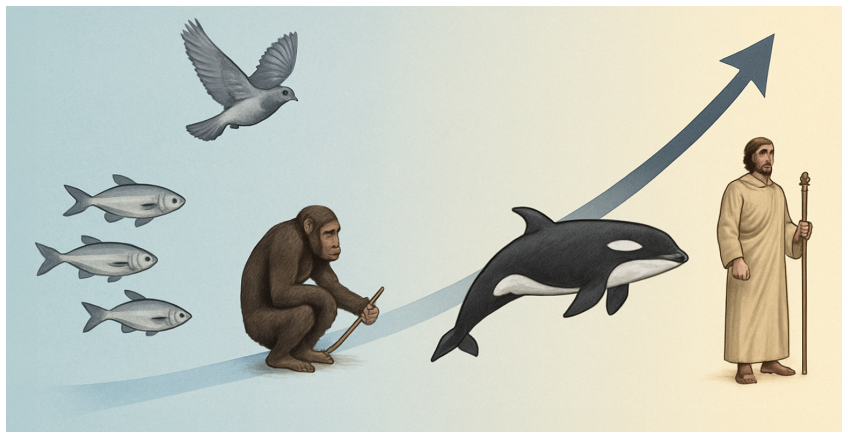


Figure 1: Rather than a uniquely human trait, culture spans across species as a continuous process—species with greater cognitive capacities occupy broader ranges of the spectrum, engaging in more complex and cognitively demanding cultural behaviors.

1 Introduction

Culture is widely regarded as a defining feature of social animals—especially humans. It enables behaviors, knowledge, and practices to be transmitted and sustained across individuals and generations, forming the backbone of collective coordination, shared norms, and long-term behavioral continuity. In human societies, culture is more than a peripheral feature of social life; it is the substrate through which civilizations persist, adapt, and evolve.

Yet across sociology Weber and Kalberg [2013], Durkheim [2016], Habermas [1985], cultural anthropology Geertz [2017], Malinowski [2013], Lvi-Strauss [1966], and cultural studies Williams [1983], Hall [1980], Hebdige [2013], the concept of culture is often defined in vague, symbolic, or interpretive terms—such as “shared meaning,” “identity,” or “discourse.” These framings rarely specify the cognitive or behavioral processes involved, and often conflate fundamentally different phenomena under a single label. As a result, “culture” is frequently stretched to encompass everything from ideology and language to fashion and media, diluting its utility for explaining stable group-level behavior.

To make culture a usable concept—one that explains social dynamics rather than merely narrates them—we need a clear, operational definition grounded in observable mechanisms. Without this, “culture” becomes a rhetorical container, in which any social phenomenon can be retroactively labeled cultural. A mechanistic account is essential not only for explanatory precision, but for understanding how real patterns of collective behavior emerge, persist, and change.

In this work, we propose a cognitive reframing of culture—one that avoids symbolic abstraction and instead defines culture as group behavior transmitted and maintained across time, supported by identifiable cognitive mechanisms. We highlight two foundational supports for this process: (1) individual-level social learning, and (2) a spectrum of group-level processes, ranging from low-level behavioral alignment to structured intentional transmission. By grounding this account in cross-species evidence—particularly from chimpanzees and orcas—we show that the cognitive scaffolds of culture are not uniquely human, but continuous across social species.

Our contribution. This paper offers a mechanistic reframing of culture from a cognitive and cross-species perspective. Instead of treating culture as a symbolic or uniquely human construct, we define it as group-level behavior that is transmitted and maintained over time through general-purpose cognitive mechanisms. Our key contributions are:

- Propose a mechanistic definition of culture as group behavior transmitted and maintained across time, grounded in cognitive mechanisms rather than symbolic abstraction;
- Identify two core substrates for cultural transmission: (1) individual-level social learning, and (2) a spectrum of group-level processes—ranging from low-level behavioral alignment to high-level intentional transmission—that support behavioral stability;
- Demonstrate the continuity of these mechanisms across species—particularly in chimpanzees and orcas—challenging the assumption of human cultural uniqueness;
- Clarify foundational confusions in traditional theories of culture, and offer a cognitively grounded, cross-species framework for analyzing cultural dynamics.

2 Related Work

2.1 Sociological Theories of Culture

In sociology, culture has often been examined through norms, identity, social reproduction, and institutional order. Interpretive sociology Weber and Kalberg [2013], Schutz [1967], structural functionalism Durkheim [2016], Parsons [2013], and critical theory Horkheimer et al. [2002], Habermas [1985] have analyzed how cultural forms sustain social coordination, reproduce social structures, and shape individual subjectivity. These traditions provide important accounts of culture at the societal level. However, they are less concerned with the cognitive and behavioral mechanisms through which cultural patterns are acquired, stabilized, and transmitted across individuals. As a result, they offer limited tools for explaining how cultural regularities emerge from individual learning, repeated interaction, and group-level alignment.

2.2 Anthropological Theories of Culture

In cultural anthropology, culture has commonly been conceptualized as a symbolic system, a moral order, or a structure of meaning. Symbolic anthropology Geertz [2017], functionalism Malinowski [2013], and structuralism Lvi-Strauss [1966] emphasize interpretive logics, ritual forms, kinship systems, and locally embedded worldviews. These approaches have been central for understanding the richness and specificity of human cultural life. Yet because they prioritize meaning, context, and symbolic interpretation, they provide limited tools for deriving a general mechanistic account of cultural transmission. Cultural practices such as ritual Malinowski [2014], kinship Evans-Pritchard [1940], and exchange Malinowski [2013] are often analyzed as distinct domains, rather than as expressions of shared cognitive and behavioral processes.

2.3 Behavioral Studies of Animal Culture

Decades of research have documented socially transmitted cultural behaviors in nonhuman animals, including primates Whiten et al. [1999], Boesch [2003], orcas Rendell and Whitehead [2001], and birds Catchpole and Slater [2003], Aplin et al. [2015]. These studies reveal a wide range of socially transmitted behaviors, including tool use Goodall [1964], Boesch and Boesch [1990], Whiten et al. [1999], imitation Whiten et al. [2004], and teaching-related behavior Rendell and Whitehead [2001], suggesting that cultural behavior is not restricted to humans.

However, animal culture remains only partially integrated into general theories of culture. In mainstream cultural theory, culture is still often defined through human-specific symbolic or institutional forms. Even within animal culture research, findings are frequently organized around species-specific observations, making cross-species comparison difficult. This leaves a need for a framework that connects human and nonhuman cultural behavior through shared cognitive and behavioral mechanisms.

3 The Mechanistic Gap in Traditional Theories of Culture

Culture is often defined through abstract terms such as shared beliefs, social norms, symbolic meaning, collective identity, or moral order. These concepts describe what culture looks like at the social level, but they do not explain how cultural patterns are acquired by individuals, stabilized within groups, or maintained across time.

Traditional approaches provide rich descriptions of cultural content, yet they rarely connect these descriptions to mechanisms of acquisition, alignment, reinforcement, and transmission. Sociological and anthropological accounts often explain culture through meanings, norms, rituals, kinship, exchange, or symbolic order, while leaving underspecified how these patterns become learnable, repeatable, and stable across individuals. A mechanistic account of culture therefore requires a lower-level explanation of the cognitive and behavioral processes through which group behavior is transmitted and maintained.

4 Cross-Species Evidence: Culture Beyond Humans

A growing body of cross-species research challenges the long-standing assumption that culture is uniquely human. Synthesizing evidence across birds, cetaceans, elephants, and primates, Whiten [2021] documents culturally transmitted behaviors ranging from tool use and vocal dialects to social conventions. These behaviors are often stable across generations and sustained through social learning.

Among nonhuman species exhibiting cultural behavior, chimpanzees Whiten et al. [1999] and orcas Rendell and Whitehead [2001] are among the best-documented cases. Their traditions span multiple behavioral domains, persist across generations, and show systematic group-level variation. These cases provide a concrete empirical basis for developing a more mechanistic understanding of culture.

4.1 Chimpanzees: Cross-Group Variation and Cultural Diversity

One of the most influential demonstrations of nonhuman culture comes from a comparative study across multiple wild chimpanzee communities. Whiten et al. [1999] systematically documented



(a) Chimpanzees:
tool use, grooming, hunting

(b) Orcas:
dialects, hunting styles, teaching

Figure 2: Two non-human species with well-documented, population-wide cultural repertoires.

39 behavior patterns—ranging from tool use to grooming rituals—that varied across populations without ecological explanation. These patterns include termite fishing, leaf clipping, nut cracking, and social games like hand clasp grooming—behaviors that were customary in some groups and absent in others.

The study introduced a “cultural profile” methodology, mapping behavioral repertoires across seven chimpanzee communities and identifying clusters of socially learned traditions. Crucially, this work challenged the long-standing assumption that culture is exclusive to humans by demonstrating community-specific practices transmitted via social learning. The patterns resemble human cultural variation not just in content, but in their group-specific persistence and intra-group conformity, suggesting that chimpanzees possess the cognitive and social infrastructure necessary for maintaining behaviorally distinct traditions.

4.2 Orcas: Group Traditions, Vocal Dialects, and Teaching

Orcas exhibit striking cultural complexity. Distinct populations maintain divergent hunting strategies, migratory routes, and vocal behaviors that are socially learned and transmitted across generations Rendell and Whitehead [2001]. These differences can persist despite geographic overlap and are not fully explained by ecology or genetics, pointing to stable group-specific traditions.

Among these, vocal dialects are especially revealing. Orca groups possess stable, socially acquired call repertoires that align with social group boundaries rather than environmental conditions. These dialects function both communicatively and socially, echoing the group-specific structure of human languages.

Orcas also meet formal criteria for teaching Caro and Hauser [1992]. Mothers have been observed slowing down during hunts to allow calves to practice motor sequences—an intentional modification of behavior that incurs cost and facilitates more effective learning. Such structured scaffolding implies that orca culture is not merely transmitted, but actively supported and refined, fulfilling key conditions of cumulative cultural learning.

5 A Cognitive Reframing of Culture

5.1 Culture as a Cognitive-Behavioral Architecture

Motivated by the mechanistic gap identified above and the cross-species evidence reviewed in the previous section, we define culture as group behavior that is transmitted and maintained across time, supported by structured cognitive and behavioral processes. This definition treats culture as an observable pattern of behavioral transmission, grounded in how individuals learn from others and how groups align, reinforce, and transmit behavior across repeated interaction.

Specifically, we identify **two continuous spectra of cognitive demand** that jointly support cultural dynamics:

- One spans *individual-level social learning*—from imitation to selective imitation, functional learning, and explicit teaching;
- The other spans *group-level processes*—from behavioral alignment to norm tracking, shared practice, and structured intentional transmission.

This framing shifts the study of culture from symbolic abstraction to the lower-level logic of behavioral transmission, allowing us to analyze the conditions under which behaviors persist, spread, and remain stable within groups.

5.2 Culture Across Species: From Binary to Spectrum

Building on this framework, we challenge the binary notion that only humans “have culture” while nonhuman animals “do not.” Cultural behavior is better understood as a graded phenomenon, structured by the cognitive mechanisms that enable its formation and transmission. Numerous species exhibit socially maintained behaviors—such as tool use, grooming customs, or coordinated foraging—that persist across individuals and generations.

What differs across species is not simply the presence or absence of cultural behavior, but the cognitive depth underlying its transmission. Toward the more cognitively demanding end, orcas have been observed engaging in deliberate teaching Rendell and Whitehead [2001], actively guiding younger individuals during coordinated hunts. In the middle range, chimpanzees transmit many behaviors through observation and imitation Whiten et al. [1999], with only limited and debated evidence for teaching. Toward the lower end, many schooling fish follow the movements of their neighbors, with little evidence of evaluation or selective preservation of the behavior.

This gradient—from passive following to imitation and intentional teaching—captures the individual-level spectrum within the architecture of culture. Species with greater cognitive capacity can occupy a broader range of this spectrum, supporting both simpler forms of imitation and more demanding forms of functional learning, teaching, and structured transmission.

Note: This subsection focuses on individual-level cultural transmission; behavioral research on group-level processes in nonhuman animals remains limited, mainly due to the difficulty of tracking multi-generational dynamics in the wild.

6 The Dual-Spectrum Architecture of Cultural Transmission

We propose that cultural transmission is supported by two distinct but complementary continuous spectra. The first concerns *individual-level social learning*, ranging from low-level imitation to functional learning and explicit teaching. The second concerns *group-level processes*, ranging from implicit behavioral alignment to norm tracking and structured intentional transmission. Together, these spectra define a cognitive-behavioral architecture for analyzing the bottom-level logic of cultural transmission: how multiple individuals learn from, respond to, align with, and transmit behavior to one another across repeated interaction.

Note: These spectra are not fixed or exhaustive categories, but a minimal, behaviorally grounded basis for analyzing cultural transmission.

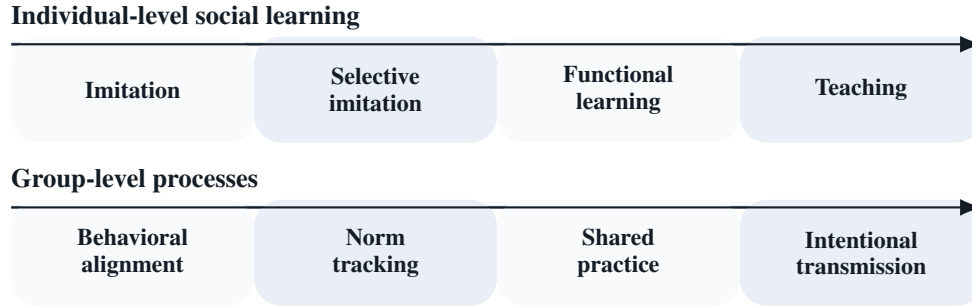


Figure 3: Two aligned spectra for cultural transmission, ordered from low to high cognitive demand: individual-level social learning (top) and group-level processes (bottom).

6.1 The Cognitive Spectrum of Individual Social Learning

We organize individual-level social learning along a spectrum of cognitive demand, ranging from lower-level imitation to selective imitation, functional learning, and explicit teaching. This spectrum distinguishes how much evaluation, abstraction, and intentional support are involved when individuals acquire behavior from others.

- **Lower end – Imitation:** copying observed behaviors without necessarily understanding their full functional logic. Individuals may adopt what others do because the behavior is familiar, commonly practiced, socially available, or repeatedly observed, with limited evaluation of its deeper purpose Meltzoff and Moore [1977].
- **Intermediate – Selective imitation:** choosing which behaviors to adopt based on observed success, status, or contextual relevance. These forms rely on simple heuristics but adjust behavior according to perceived effectiveness and contextual fit Rendell et al. [2010].
- **Higher – Functional learning:** discerning the purpose and functional logic of an observed action, enabling abstraction and generalization beyond the immediate behavior Gergely et al. [2002].
- **Peak – Teaching:** deliberately adapting behavior to facilitate another’s learning, allowing skills or knowledge to be acquired more efficiently than through trial-and-error alone Csibra and Gergely [2009].

6.2 The Cognitive Spectrum of Group-level Processes

Beyond individual social learning, cultural patterns are also shaped by group-level processes that align, reinforce, and transmit behavior across repeated interaction. We organize these processes along a second spectrum of cognitive demand, ranging from low-level behavioral alignment to norm tracking, shared practice, and structured intentional transmission.

- **Lower end – Behavioral alignment:** behaviors such as flocking or entrainment, where individuals match others’ actions without deliberation or evaluation Le Bon [2017].
- **Intermediate – Norm tracking and conformity:** including majority-biased copying, where individuals infer what is typical or appropriate in their group and adjust accordingly Asch [1956], Sherif [1936].
- **Higher – Shared practice:** individuals refine their knowledge, strategies, or skills through direct interaction and shared activity, using the group context to adjust and improve performance Lave and Wenger [1991], Johnson and Johnson [1989].
- **Peak – Structured intentional transmission:** information or practices are deliberately designed and broadcast to the group as a whole—ranging from formal education to coordinated cultural messaging Gerber and Green [2000], Centola [2010].

Existing Theories of Culture	Our Framework
Defined in symbolic or interpretive terms (e.g., “shared meaning,” “collective identity”)	Defined mechanistically as group behavior transmitted and maintained over time
Human-exclusive assumption: culture as a uniquely human phenomenon	Continuous spectrum across species, grounded in shared cognitive substrates
Explained through case-specific narratives (e.g., ritual, kinship, exchange)	Unified cognitive architecture applicable across domains and taxa
Focus on outcomes (norms, order, meaning) without specifying acquisition mechanisms	Specifies two continuous spectra: individual-level social learning and group-level processes
Lacks operational criteria for cross-species or computational modeling	Provides testable, cross-species, and mechanistic structure

Table 1: This table contrasts traditional theories of culture, which are largely symbolic and human-exclusive, with our framework that defines culture mechanistically, spans species, and specifies testable cognitive dimensions.

7 Theoretical Implications: Beyond Symbolism and Human Exceptionalism

7.1 On the Limits of “Cultural Learning” as an Explanatory Construct

The term cultural learning is conceptually imprecise. It refers broadly to socially acquired behaviors, yet fails to specify the cognitive operations through which those behaviors are acquired, selected, retained, or transmitted. By collapsing distinct mechanisms under a single label, it offers description without explanation.

Rather than clarifying how behaviors are acquired, maintained, or transmitted, the term often functions as a placeholder: it implies transmission while leaving the underlying cognitive and behavioral processes unspecified.

Our framework makes this ambiguity explicit. By analyzing culture as a composition of cognitive layers, we show that cultural learning is not a unitary process, but a compound label that masks heterogeneous mechanisms.

7.2 On the Conceptual Ambiguity of “Cultural Evolution”

The term cultural evolution is commonly used to describe how cultures change and accumulate over time. However, it often leaves unclear what the relevant unit of change is. In many empirical cases, what changes are discrete elements of culture—knowledge, norms, or practices—rather than the broader cultural structure itself.

Moreover, cultural evolution does not by itself specify whether change implies improvement, adaptation, accumulation, fragmentation, or reorganization. Cultures do not necessarily become objectively better or more adaptive; they may simply change, persist, fragment, or reorganize. Consequently, it is often unclear whether culture as a whole is evolving, or whether particular cultural elements are being transmitted, modified, stabilized, or replaced.

Without clarifying the units of analysis—whether knowledge, norms, practices, or institutions—the concept of cultural evolution risks treating culture as a single coherent object of change, rather than specifying which cultural elements are changing, how they change, and at what level the process occurs.

8 Future Work

Rather than treating “culture” as a distinct object of study, future work should focus on identifying the boundary conditions under which group behavior becomes stable and transmissible over time.

What makes some behaviors easier to acquire, retain, or transmit? How do social learning and group processes interact to amplify or suppress certain patterns?

By shifting the question from “what counts as culture” to “what kind of behavior tends to persist and propagate,” we open the door to a more mechanistic, testable, and cross-species foundation for cultural dynamics.

9 Conclusion

Culture has often been described through symbolic, human-centered narratives that obscure its underlying mechanisms. In this work, we define culture as group behavior transmitted and maintained across time, supported by cognitive and behavioral processes that differ in complexity and demand. This reframing treats culture as a graded phenomenon organized along two continuous spectra: individual-level social learning and group-level processes.

Cross-species evidence from chimpanzees and orcas shows that this structure is not unique to humans. Instead, it reveals a shared mechanistic logic through which cultural behavior can emerge, stabilize, and vary across species with different cognitive capacities. By grounding culture in cognitive-behavioral mechanisms rather than symbolic abstraction, this framework provides a clearer foundation for understanding cultural stability, variation, and complexity.

Declaration of LLM Usage

The authors used OpenAI’s ChatGPT to assist in refining phrasing and improving clarity. All theoretical arguments and interpretations are original and authored by the researchers.

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