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Structural diversity, functional plasticity: the role of de-generacy in Human Evolution

Paul Howard Mason

School of Natural Sciences Macquarie University NSW 2109 Australia
https://orcid.org/0000-0002-5488-1056

Summary - *This review article explores the concept of de-generacy as a fundamental yet underutilised principle in evolutionary anthropology. De-generacy, defined as structurally distinct elements performing overlapping functions, is widely recognised in genetics, neurobiology, and immunology but remains overlooked in cultural evolution. Distinguishing de-generacy from redundancy—where identical structures fulfill the same role—is crucial for understanding adaptability, resilience, and innovation in both biological and cultural systems. Despite its explanatory potential, de-generacy has been largely absent from anthropological discourse due to historical baggage and terminological confusion. The misuse of "degeneracy" in colonial and eugenic narratives has hindered its application, even as contemporary evolutionary theory—particularly the Extended Evolutionary Synthesis—highlights structural variation as a driver of adaptive complexity. Consequently, an opportunity to refine methodologies in anthropological research, particularly in modelling cultural transmission, has been overlooked. De-generacy is a distributed property of complex adaptive systems that, in many circles of science, has been hidden in plain sight, overlooked because of a reductionist bias, and ignored because the term itself is misleading. This article clarifies the distinction between de-generacy and redundancy and demonstrates its significance in biological anthropology. Empirical examples illustrate de-generacy across multiple domains, including linguistic variation, kinship terminologies, and ritual practices. A comparative case study of Indonesian* Silek *and Brazilian* Capoeira *provides a snapshot of how structurally distinct yet functionally similar cultural formations emerge across diverse contexts. These examples reinforce de-generacy as a key explanatory principle in cultural resilience and transformation. By integrating de-generacy into evolutionary anthropology, this article advances a more nuanced understanding of cultural transmission and transformation. Recognising structurally diverse yet functionally coherent practices enhances models of cultural evolution, moving beyond strictly adaptationist explanations. Ultimately, de-generacy provides a robust conceptual tool for analysing variation, complexity, and persistence in human evolutionary systems, warranting greater attention in interdisciplinary research.*

Keywords - *Degeneracy, De-generacy, Redundancy, Cultural recipe, Cultural evolution, Complex systems, Equifinality, Multifinality.*

Introduction

This article introduces the concept of *de-generacy*—a foundational principle in complex systems theory—as an essential yet overlooked component of evolutionary theory. In biological anthropology, *de-generacy* offers a valuable framework for analysing socio-cultural formations and transformations. A system exhibits *de-generacy* when structurally different components perform similar functions depending on context, resulting in a many-to-one structure-to-function ratio. This principle is well-established in the biological sciences, where *de-generacy* has come to be recognised as a key characteristic of genetics and epigenetics (Maleszka et al. 2013; Pasipoularides 2015; Paredes et al. 2019; Crick 1955; Frank 2003), immune systems (Cohn 2005; Sercarz and Maverakis 2004; Tieri et al. 2007; Cohen et al. 2004), neurobiology (Merchant et al. 2013; Seifert et al. 2014; Komar et al. 2015; Man et al. 2016; Seifert et al. 2016; Turgeon et al. 2016; Zerilli 2019; Noppeney et al. 2004), bodily movement (Downey 2012a; Davids et al. 2013; Guignard et al. 2017; Orth et al. 2018), as well as human and animal communication systems (Winter 2014; Mason et al. 2015; Winter and Wedel 2015; Hebets et al. 2016; Gomes et al. 2016; Stange et al. 2017; Patricelli and Hebets 2016; Ronald et al. 2017; Palagi et al. 2019). However, its implications for human cultural evolution remain underexplored. This article argues that de-generacy is a crucial yet neglected concept in biological anthropology, one that enhances our understanding of variation, adaptation, and the persistence of cultural traits over time.

Despite its relevance, *de-generacy* has been largely absent from anthropological discourse due to historical baggage, terminological confusion, and disciplinary silos. The term has often been conflated with redundancy, which refers to the presence of identical structures performing the same function, whereas *de-generacy* describes structurally distinct elements with overlapping functions (Whitacre 2010; Whitacre and Bender 2010). This distinction is critical: redundancy contributes to system stability, while *de-generacy* enables adaptability, robustness, and innovation. The frequent misinterpretation of *de-generacy* as redundancy has led to its theoretical significance being overlooked in discussions of cultural and biological evolution.

The neglect of *de-generacy* in biological anthropology also stems from the historical misuse of the term 'degeneration.' During the 18th and 19th centuries, colonial narratives co-opted the notion of degeneracy to justify racial hierarchies and eugenic ideologies, associating the term with decline, pathology, and social deviance (Dugatkin 2019). This legacy has rendered the term politically sensitive, leading anthropologists to avoid its application despite its conceptual utility. Furthermore, the reductionist tendencies of early evolutionary thought—favouring singular causality over complex, multilevel explanations—have contributed to the oversight of *de-generacy* as a fundamental evolutionary mechanism (Atamas 2005; Mason 2015).

Developments in evolutionary theory, particularly through the Extended Evolutionary Synthesis (EES), offer a more dynamic and integrative framework for explaining complexity in both biological and cultural evolution (Pigliucci and Müller 2010; Müller 2007; Laland et al. 2015). The EES expands upon the Modern Synthesis by incorporating developmental processes, phenotypic plasticity, niche construction, and multiple inheritance systems—including genetic, epigenetic, behavioural, and cultural pathways—as key drivers of evolutionary change. Central to this enriched perspective is the role of structural variation in enabling adaptability and innovation. Both Müller (2007) and Laland et al. (2015) emphasise the evolutionary value of maintaining system functionality through non-identical components or pathways, particularly in response to perturbation—a crucial mechanism for robustness, flexibility, and evolvability. The capacity of structurally distinct elements to perform overlapping or convergent functions has been widely recognised in systems biology, yet this phenomenon remains underarticulated in the EES literature. This article argues that naming heteromorphic isomorphism brings an underacknowledged but essential mechanism to the foreground. Labeling such patterns as degenerate not only facilitates recognition but also provides a conceptual tool for identifying sources of variation and selection that might otherwise be obscured. By integrating insights from genetics, neurobiology, and cultural evolution, this article demonstrates how de-generacy offers a powerful lens for understanding the emergence, persistence, and transformation of complex traits in both biological and cultural domains.

To substantiate this claim, the article explores examples of *de-generacy* across biological and cultural domains. In genetics, the redundancy of the genetic code coexists with *de-generacy* in codon assignments, allowing for greater functional plasticity (Crick 1955; Frank 2003). In neurobiology, synaptic variability and neural reorganisation exemplify *de-generacy* in cognitive processing (Merchant et al. 2013; Seifert et al. 2014). In cultural evolution, *de-generacy* can be observed in diverse domains such as linguistic variation, where multiple dialects or registers serve similar communicative functions within a single speech community (Labov 1972), or in kinship terminologies, where structurally distinct naming systems convey equivalent social relationships across different cultures (Lévi-Strauss 1967). Additionally, variations in mortuary practices—such as different forms of ancestor veneration across societies—illustrate how structurally different rituals can fulfill similar functions of social cohesion and intergenerational continuity (Hertz 1907). These cases illustrate how *de-generacy* facilitates adaptability and resilience in both biological and cultural systems, making it an essential concept for evolutionary anthropology.

By reclaiming and clarifying the concept of *de-generacy*, this article contributes to the ongoing refinement of evolutionary theory. Understanding *de-generacy* not only resolves theoretical ambiguities surrounding functional plasticity but also enriches our perspective on cultural diversity and adaptation. Given its explanatory power in both biological and cultural contexts, *de-generacy* should be recognised as a fundamental component of the evolutionary process, warranting greater attention in anthropological research.

'Degeneration' vs. 'De-generacy'

The historical misuse of the term 'degeneration' has contributed to its avoidance in contemporary discourse. Georges-Louis Leclerc, Count of Buffon, first introduced the theory of degeneration in the 18th century, describing Native Americans as a degenerate variety of humans and New World animals as biologically inferior (Buffon 1749-1788). Later, in the 19th century, the French psychiatrist Bénédict Augustin Morel defined degeneracy as "a morbid deviation from an original type" (Morel 1857). Max Nordau further popularised the concept in *Entartung* (1892), arguing that degeneracy was a mental and social disease indicative of social collapse (Nordau 1895). These ideas influenced racial hierarchies and eugenic policies, ultimately leading to their rejection by modern science (Greenslade 1994). Recognising this historical baggage is essential for ensuring outdated biases do not creep back in reclaiming *de-generacy* as a neutral and scientifically useful concept.

The historical misuse of the term "degeneration" as a synonym for decline or pathology necessitates careful redefinition to prevent conflation with discredited racial ideologies and other misapplications. Following Turgeon et al. (2016), Mason et al. (2017), Dinçer 2019), and Pastor et al. (2020), this article adopts the hyphenated term *de-generacy* to distinguish the outdated theory of New World Degeneration (Dugatkin 2019)—which falsely linked biological and cultural diversity to decline and pathology—from a key concept that enables researchers to systematically analyse the variable, intersecting factors that shape complex living systems. In contemporary science, *de-generacy* describes a fundamental property of complex adaptive systems, fostering robustness, functional plasticity, and innovation. The term was redefined in the mid-20th century by George Gamow, who described the genetic code as "degenerate" to explain how multiple codons encode single amino acids (Mulder et al. 2006). Since then, the concept has been expanded into neurobiology, immunology, and cultural evolution (Edelman and Gally 2001). In anthropology, recognising *de-generacy* allows for a more nuanced understanding of cultural transmission and transformation, addressing persistent challenges in modelling cultural evolution. By incorporating *de-generacy* into evolutionary frameworks, scholars can better account for the complexity of socio-cultural change, moving beyond overly simplistic models that overlook structural diversity and functional plasticity. This article adopts the hyphenated term *de-generacy* to emphasise its precise technical meaning in complex systems theory: the presence of structurally distinct elements capable of performing overlapping functions. This distinction not only differentiates *de-generacy* from redundancy but also further distances it from the discredited racial ideologies historically associated with "degeneration."

Redundancy, de-generacy, and pluripotentiality: differentiating concepts in biological and cultural evolution

Redundancy, de-generacy, and pluripotentiality are crucial concepts for understanding variation and adaptability. Distinguishing clearly between them—and understanding how they interrelate—is essential for getting into the nuts and bolts of complex systems. Redundancy refers to the presence of identical structures performing the same function, contributing to system stability. For example, identical copies of a gene in an organism's genome can serve as a backup mechanism, ensuring that essential functions are maintained if one copy becomes nonfunctional (Nowak et al. 1997). However, redundancy can also be counter-adaptive; when an identical structure persists without functional differentiation, it may lead to inefficiencies, increased metabolic costs, or maladaptive overexpression (Wagner 2005). Furthermore, vulnerabilities in one redundant component will be shared by all redundant copies potentially compromising system function under adverse conditions.

By contrast, de-generacy describes non-identical or structurally distinct elements that perform similar or overlapping functions depending on context; his many-to-one relationship between structure and function promotes flexibility, innovation, and robustness (Edelman and Tononi 2000; Whitacre 2010). In biological systems, de-generacy plays a crucial role in enhancing adaptability, resilience, and evolutionary potential.

Unlike redundancy, which maintains system stability through identical backup components, de-generacy enables flexibility by utilising structurally distinct elements that perform similar functions. This principle is particularly evident in genetics and neurobiology, where multiple pathways ensure robustness in the face of perturbations. For instance, in genetics, multiple codons encode the same amino acid, offering resilience against mutation (Woese 2001). This genetic de-generacy provides an evolutionary advantage by allowing variation to accumulate without immediate detrimental effects, thereby fostering innovation and adaptability.

In the brain, different neural circuits can generate the same behavioural outcome, allowing for compensation in the event of injury or damage (Edelman and Tononi 2000). De-generacy in neural networks also underlies learning plasticity, enabling skill acquisition and refinement over time (Noppeney et al. 2004). This phenomenon is evident in motor control, where different neural pathways can achieve the same movement pattern (Seifert et al. 2016). The existence of de-generacy in cognitive processing contributes to learning, problem-solving, and adaptability. These examples reinforce de-generacy's central role in human flexibility and resilience.

Human communication provides another rich example of multiple structures encoding the same meaning. In the Korean language, for instance, politeness distinctions are encoded not only through honorific nouns, verbs, and grammatical markers (Sohn 1999; Brown 2011; Yeon and Brown 2011) but also via speech acoustics such as pitch, speech rate, and loudness (Brown et al. 2014; Winter and Grawunder 2012). Additionally, politeness is conveyed through bodily gestures, such as bowing and adjusting interpersonal distance (Hall 1966; Mehrabian 1969). These diverse but functionally overlapping cues illustrate de-generacy in communication, ensuring robustness and adaptability in social interactions (Winter 2014; Mason et al. 2015).

The neuroanthropological work of Downey (2012a,b) provides a concrete demonstration of how structurally distinct neural pathways can support comparable high-performance skills across cultural contexts. His research on vestibular recalibration in capoeira practitioners and on elite rugby training environments illustrates how cultural *enskilment*—the embodied acquisition of skills through guided practice and sensory attunement—can exploit neurological de-generacy, wherein different neural configurations support similar cognitive or motor outcomes. These findings reinforce the value of integrating biological, cultural, and developmental perspectives to understand how variation in embodied experience reshapes neural architecture through overlapping but non-identical pathways.

Across domains, de-generacy equips biological systems with the capacity to respond dynamically to environmental pressures. It fosters resilience by ensuring that critical functions are not dependent on a single structural pathway. In immunology, for example, de-generacy is well established as a mechanism for broad antigen recognition, allowing structurally diverse lymphocytes to respond to a wide array of pathogens (Van den Elzen et al. 2004; Cohn 2005; Mason et al. 2015). This structural flexibility enhances both system robustness and adaptive breadth, ensuring functional continuity despite antigenic variation. Conversely, de-generacy has also been implicated in the complexity and treatment resistance of certain pathological conditions: in the robustness and evolvability of cancer cell networks (Tian et al. 2011), in compensatory changes to primary afferent excitability following nerve injury that contribute to neuropathic pain (Ratté et al. 2014), and in the structural redundancy and disordered connectivity observed in psychiatric disorders (Paunova et al. 2023). Whether shaping brain circuitry, motor learning, immune responses, language systems, or disease progression, these examples demonstrate how de-generacy underpins both immediate adaptability and long-term evolutionary potential.

Distinguishing redundancy from de-generacy is vital for understanding evolvability. The capacity to draw upon structurally distinct yet functionally overlapping elements enhances a system's resilience, supports innovation, and ensures continuity under changing conditions. Yet adaptability is not solely a matter of many-to-one mappings. Sometimes, a single structure gives rise to multiple functions depending on context—what is known as pluripotentiality. For instance, the same dance movement or musical instrument may serve ritual, recreational, or competitive purposes depending on its cultural embedding. While distinct from de-generacy, pluripotentiality similarly relies on context-sensitive functionality and contributes to the flexibility of complex systems. If de-generacy highlights the diversity of structures that converge on a shared function, pluripotentiality reveals how a single structure can yield divergent outcomes across situations. These two principles—one emphasising functional convergence, the other functional divergence—offer a complementary framework for understanding how systems adapt, evolve, and persist (see Table 1). Together, they enrich our analytic toolkit for tracing resilience, transformation, and innovation across biological and cultural domains.

While the concepts of de-generacy and pluripotentiality have been well established in evolutionary biology and complex systems science (Edelman and Gally 2001; Whitacre 2010), closely related ideas have also developed independently in other disciplines. In developmental psychology, for instance, John Richters (2021) has drawn explicit connections between de-generacy and the terms *equifinality* and *multifinality*, originally introduced by Cicchetti and Rogosch (1996) and grounded in general systems theory (von Bertalanffy 1968). *Equifinality* refers to the phenomenon whereby different structural configurations or developmental pathways can produce the same outcome—a clear parallel to the concept of de-generacy. *Multifinality*, by contrast, captures the idea that a single structure or process may yield different outcomes depending on contextual influences, closely aligning with what I have termed *pluripotentiality*. Like de-generacy and pluripotentiality, these terms clarify the significance of functional plasticity and contextual responsiveness in complex systems.

Although equifinality and multifinality are useful and increasingly accepted across disciplines, this article retains de-generacy as its central analytic term. First, de-generacy is more deeply embedded in the literature on evolutionary systems, theoretical biology and neurosciences—fields directly informing this paper's interdisciplinary scope. Second, despite its unfortunate semantic baggage, de-generacy captures the structural variation underpinning functional convergence more precisely than the term equifinality, which can misleadingly imply goal-directedness or fixed endpoints due to its "finality"

Tab. 1 **- Redundancy** ***refers to the presence of identical elements that provide backup to ensure system reliability (e.g., multiple copies of the same audio CD).*** **De-generacy** ***describes the ability of structurally different elements to perform the same function (e.g., different instruments producing the same rhythm).*** **Pluripotentiality** ***refers to a single structure performing different functions depending on context (e.g., the same instrument producing different melodies or rhythms in different settings).***

CONCEPT	DEFINITION	STRUCTURE	FUNCTION	CONTEXT-DEPENDENCE	CONTEXT-SENSITIVITY	EXAMPLE
Redundancy	Structural insurance	Identical	Fixed and duplicated	High – requires specific resources	Low – performs same function regardless of context	A CD of capoeira music: plays the same songs if a CD player is available, regardless of setting.
De-generacy (Equifinality)	Functional versatility via structural diversity	Non-identical but overlapping	Similar or equivalent	Low – interchangeable resources	High – function adapts to context	Berimbau and tambourine: different instruments can both produce capoeira rhythms; choice varies by setting.
Pluripotentiality (Multifinality)	Functional versatility via contextual shifts	Structurally similar	Variable, context-specific	Low – few constraints on use	High – changes function with context	A tambourine: used in capoeira, samba, or devotional music depending on the cultural, ritual or performance context.

suffix. The term equifinality risks invoking a teleological bias, suggesting that biological and cultural processes move toward a predetermined endpoint, when in reality, the moments we analyse are merely synchronic snapshots of the ever-unfolding, heterogeneous construction of living systems. These forms are not destinations but dynamic articulations of structural variation and functional convergence, shaped by contingent histories, shifting environments, and iterative adaptation. For consistency with the scientific literature from which this article draws, and to preserve clarity in conveying that we are talking about a dynamic system property supporting resilience, innovation, and adaptability across changing contexts, I therefore use de-generacy as the primary term, while fully acknowledging the conceptual value of equifinality and multifinality in related fields.

Without *de-generacy*, selection would function as a purely eliminative process, where traits are either retained or discarded wholesale. Such a rigid framework would lead to an inevitable collapse of diversity, as any environmental or functional shift could wipe out all identical copies of a trait. *De-generacy* is therefore essential for selection, because while the least fit variants might be removed from a population, a diverse pool of alternative solutions are preserved, enabling continual adaptation. In the absence of *de-generacy*, selection would not refine complexity—it would ultimately extinguish it.

An ecological system contains many different structures with variable functions that can adapt to a range of contexts. A system exhibiting only redundancy would consist of identical structures with identical functions. It would display low context-sensitivity but high context-dependency—in other words, as long as the necessary resources are present, it will perform its task regardless of changes in its environment. A CD of capoeira music, for example, will play the same songs repeatedly (if a CD player and speakers are available), whether it is played in a capoeira training hall or at a funeral—awkwardly insensitive to context.

A system exhibiting de-generacy, by contrast, has the capacity to recruit different structures to perform similar functions, and to vary its outputs in response to context. It might use different instruments to produce music, or select songs suited to particular occasions—songs of celebration at a festival, or music of mourning at a funeral. In this way, de-generacy coexists with pluripotentiality: as contexts shift, the system can draw upon its internal variety to generate divergent, meaningful responses. Classical music may be enriched by a full orchestra, but it can still be enjoyed with a single instrument—what we might call parcellation, a subtype of de-generacy in which complexity is reducible without loss of function. This flexibility allows systems to adapt to variable environments (low context-dependency) and remain attuned to situational demands (high context-sensitivity).

As we will explore later in this article, the punches, kicks, and grapples of *silek* performed at *Tabuik* are choreographed to re-enact the deaths of Hasan and Hussein, connecting bodily movement to religious mourning. In contrast, the circular sweeps and arcing kicks of *capoeira* performed at the *Festa de Iemanjá* are accompanied by reverential songs honouring the Queen of the Sea. Through strategic rearrangements of their musical and movement repertoires, *silek* and *capoeira* demonstrate how cultural systems exhibit de-generacy, responding sensitively to context to serve as powerful vehicles of commemoration, celebration, and community identity.

De-generacy functions as a mechanism of adaptive potential in complex systems by providing multiple, structurally distinct pathways to perform similar functions**.** This structured variation increases the resilience of systems to perturbation (by ensuring backup capacities), but also enables innovation by allowing elements to be recombined, repurposed, or expressed differently in response to new selective pressures. In biological evolution, de-generacy facilitates phenotypic plasticity and robustness (Edelman and Gally 2001), while in cultural systems, it supports the recontextualization of practices and ideas across generations and settings. For instance, the capacity of fight-dance traditions like Capoeira and Silek to shift between pedagogical, performative, or commemorative functions illustrates how a single set of embodied skills can be redeployed in culturally meaningful ways. Rather than relying on a single optimal form, de-generacy expands the space of viable cultural expressions and transmission pathways, thereby enhancing the evolutionary adaptability of socio-cultural systems.

Cultural perspectives

De-generacy in cultural practices

Research suggests that human culture exhibits both classic selection-like processes and mechanisms distinct from traditional paradigms of biological evolution (Rogers and Ehrlich 2008a). In their comparative study of Polynesian oceanic canoe design, Rogers and Ehrlich hypothesised that traits influencing survival and reproduction evolve at different rates than those without such effects. Their findings showed that functional design traits—those affecting seaworthiness and stability—evolved more slowly than aesthetic traits, supporting the idea that cultural change can be analysed through an evolutionary framework. However, their research did not establish that natural selection actively operates within cultural systems (Rogers and Ehrlich 2008b), as it measured selection solely in terms of trait persistence or disappearance, without accounting for structurally different solutions to similar functional challenges. This limitation underscores the necessity of incorporating *de-generacy* into discussions of cultural evolution. Selection alone cannot explain how cultural traits persist and adapt across generations—*de-generacy* provides the raw material for selection to act upon.

Without structurally distinct variations of a cultural trait, selection would have nothing to act upon beyond presence or absence. *De-generacy* enables cultural systems to retain adaptability even when external pressures shift. It prevents the stagnation and eventual extinction of cultural forms by ensuring that alternative solutions remain available within a population. Without *de-generacy*, selection would not refine complexity but ultimately erode it, making evolutionary theory incomplete unless it fully accounts for the interplay between variation and selection. In cultural systems, as in biological evolution, long-term adaptive potential depends not only on what survives but on the diversity of ways survival can be achieved.

While *de-generacy* has been widely acknowledged in biological sciences, its application to cultural evolution remains under-recognised. If cultural systems are evolutionary systems, then different cultural formations—cooperatively constructed and dynamically shifting patterns of human behaviour—would exhibit *de-generacy*. Given that *de-generacy* contributes robustness, evolvability, and complexity to living systems, identifying *de-generacy* at the cultural level would help explain how cultural behaviours adapt to changing social or environmental conditions while maintaining the capacity for both resilience and transformation. At a simple level, cultural tools often exhibit *de-generacy* by manifesting in diverse forms while serving equivalent functions. For example, different calendar systems—such as the Gregorian, Lunar, and Islamic calendars—demonstrate how distinct cultural frameworks structure timekeeping in functionally similar ways. These tools operate at the level of material and symbolic artifacts, while cultural formations encompass broader traditions, practices, and modes of social organisation that persist across generations. Recognising *de-generacy* at multiple levels helps clarify the ways cultural elements are preserved, modified, or recombined in response to shifting environmental and historical pressures. Cultural systems exhibit *de-generacy* when structurally distinct practices or beliefs fulfill similar social roles. The ability to adapt cultural behaviours to changing social or environmental conditions highlights the importance of *de-generacy* in cultural resilience and transformation. *De-generacy* may indeed facilitate cultural diversity while maintaining functional coherence.

The relevance of de-generacy and pluripotentiality to biological anthropology and cultural evolution becomes especially clear when viewed through an open-systems framework (Mayr 1964, 1988). Like biological systems, human cognitive and cultural systems are shaped by nonlinear epigenesis, stochastic processes, and historical contingencies. These conditions mean that functionally similar cultural traits can emerge from structurally different origins (de-generacy or equifinality), while similar cultural forms may lead to divergent social and cognitive outcomes depending on context (pluripotentiality or multifinality). In human neuroanatomy, de-generacy may be the fundamental morphophysiological property enabling cultural emergence, flexibility and persistence. Cultural representations are not localised to a single neural structure or function; instead, they are supported by distributed, degenerate neural architectures wherein structurally distinct circuits can give rise to equivalent cognitive outcomes. This neural de-generacy ensures that socially shared meanings and conceptual schemas do not require the identical neural substrate across individuals—only that sensory input can be processed, and perception and cognition organised, in functionally comparable ways. Within cognitive and neural systems, functionally overlapping but structurally distinct processes ensure learning, problem-solving, and resilience in response to new challenges. Prost (1994) suggested that if a universal morphophysiological basis for human thought could be identified, it would provide a foundation for socially shared concepts and meanings. De-generacy offers precisely such a foundation, supporting the neural plasticity required for cultural learning, communication, and adaptation. By allowing multiple neural pathways to encode and reproduce shared representations, de-generacy facilitates the emergence of socially distributed cognition, ensuring that culture is both resilient and dynamic across individuals and generations. The study of the co-evolution of de-generate mental and cultural representations may be a step toward what Shore (1996, p.13) describes as "…both an ethnographic theory of mind and a cognitive theory of culture."

Case study of de-generacy in cultural formations

De-generacy in cultural formations can be observed by comparing structurally distinct yet functionally equivalent practices across societies or analysing how a single cultural community manifests different structures over time (Lewis 1989). While "function" in cultural settings is often more plural, shifting, or ambiguous than in many biological systems, certain embodied practices lend themselves more readily to structure-function-context analysis. The function of aesthetic traditions such as jazz music or ballet can be difficult to pin down, but martial arts traditions such as *Silek* (from Indonesia) and *Capoeira* (from Brazil) provide tangible, purpose-driven movement vocabularies—blocks, kicks, and evasions—whose immediate physical function (to simulate or sublimate combat) can be clearly distinguished, even as these movements are elaborated into choreographic and ceremonial expressions (Mason 2016, 2017). Though shaped by distinct histories and cultural logics, both Silek and Capoeira combine stylised combat movements with music and ritual performance, and are embedded in coastal festivals that engage collective memory, identity, and resilience. The musical accompaniment is not arbitrary or purely aesthetic, but is modulated in relation to the unfolding fight-dance, affecting timing, mood, and symbolic meaning. These fight-dancing practices provide a compelling example of structurally different yet functionally similar cultural formations. Developed independently in geographically distinct regions, they exhibit structural differences while serving analogous social, ritualistic, and physical training functions. A brief examination of these genres embedded within coastal religious festivals provides insight into how structurally diverse cultural practices can fulfill similar social roles, highlighting de-generacy as a key process in cultural evolution.

Performances of Silek during the Muharram ceremonies in Pariaman, West Sumatra, and Capoeira during the Iemanjá festival in Salvador da Bahia, Brazil (Mason 2016), provide an illustrative comparison of how *de-generacy* manifests in cultural formations. Both festivals occur near coastal environments and involve ritualistic processions in which symbolic objects are taken to the beach. In Bahia, practitioners of Capoeira perform before carrying offerings into the ocean to honour Iemanjá, the goddess of the sea, in a tradition rooted in West African spiritual influences. In Pariaman, Silek is performed as part of a larger Islamic commemoration of Imam Hussein, culminating in the ceremonial launching of cenotaphs into the ocean. Although these festivals have developed independently, their parallel histories of cultural adaptation and syncretism exemplify how cultural practices evolve within new contexts while maintaining functional coherence (Korom 2003).

Capoeira during the festival of Iemanjá - Capoeira originated in the wharf cities of Brazil and evolved as both a martial art and a means of cultural resistance. It incorporates acrobatics, music, and call-and-response singing, creating an expressive and dynamic performance. Capoeira performances are characterised by circular, flowing movements, punctuated by evasive dodges and sweeping kicks (Downey 2005) and have been incorporated into many regional events including the iconic festival of Iemanjá. The music accompanying Capoeira is integral to the practice, featuring berimbaus (musical bows), pandeiros (tambourines), atabaques (drums), agogôs (cowbells), and reco-recos (rasps). Practitioners engage in ritualistic play-fighting within a circle (roda), using deception and agility rather than direct strikes. During the festival of Iemanjá, many of the Capoeira songs performed reference Iemanjá, reinforcing the cultural and spiritual ties between the embodied art and the religious event. After the festival performance, the community often joins in samba de roda, a traditional Afro-Brazilian dance, before participating in a procession to the shore to complete the offering ritual.

Silek during Muharram - Silek, a Minangkabau martial art, is deeply intertwined with cultural identity and spiritual practice in West Sumatra. It is traditionally performed without musical accompaniment during training, but in the context of Muharram ceremonies, it is adapted into a choreographed performance set to music. The movements of Silek emphasise grounded stances, deception, and fluid transitions between attack and defense. Unlike Capoeira, Silek includes direct linear strikes, grappling, and knife techniques. During the Muharram festival, Silek practitioners perform in pairs, enacting choreographed combat sequences while accompanied by traditional wind instruments and double-sided barrel drums. The performance often includes theatrical elements that reference the story of Imam Hussein, aligning the martial art with the festival's broader commemorative themes. Following the performance, the Silek practitioners participate in the ritual procession, contributing to the collective enactment of the ceremony's spiritual and social significance.

Structural differences, functional overlap - Capoeira and Silek are structurally distinct traditions shaped by their respective historical and cultural trajectories. Capoeira integrates acrobatic movements, rhythmic footwork, and deceptive attacks in circular motions, traditionally practiced and performed in tandem with call-and-response singing and percussion instruments. Silek emphasises grounded stances, rapid strikes, and fluid evasions in linear motions, traditionally practiced without music but accompanied by percussion and woodwind during performances. Structurally, the training methods, movement vocabularies, and performative elements between Capoeira and Silek differ significantly.

Despite these structural differences, Capoeira and Silek exhibit tangible functional parallels. Both are forms of dance and combat that blend martial efficacy with ritualised performance, serving as embodied repositories of cultural knowledge. Both function as pedagogical systems, training practitioners in agility, strength, stamina, coordination, adaptability, mental control, discipline and resilience while reinforcing communal identity. Furthermore, both arts operate as symbolic expressions of local and national identity, reinforcing group solidarity while attracting tourism and external recognition as well as contributing to ethnic representation, regional patrimony, and cultural heritage.

The comparable cultural contexts in which these traditions find themselves embedded, namely the festivals of Iemanjá and Muharram share thematic, geographical, and processional similarities. The festival of Iemanjá, a syncretic Afro-Brazilian ritual devoted to the ocean deity, where performances reinforce connections between spirituality, ancestry, and communal solidarity shares many surface-level similarities with the Muharram ceremonies, a Shi'a-influenced Minangkabau ritual commemorating the martyrdom of Hussein, wherein martial displays become acts of embodied devotion, historical remembrance, and communal participation. The integration of Capoeira and Silek into each respective festival ensures their intergenerational transmission and continued sociocultural relevance.

This cross-cultural comparison of Capoeira and Silek as practiced within regional festivals illustrates how structurally distinct cultural traditions—shaped by different historical, religious, and geographic contexts—can perform overlapping social and symbolic functions (see Table 2). Both serve as embodied forms of remembrance, reverence, and identity-making in ritualised public events. In this sense, they exhibit de-generacy: different cultural structures (e.g. martial arts with distinct origins, movement styles, and musical accompaniments) converging on similar functions (e.g. ritual performance, cultural transmission, community cohesion).

Importantly, this structured variation is not merely symbolic or aesthetic—it plays an instrumental role in how cultural knowledge is transmitted, adapted, and sustained across generations. Unlike vertical transmission models that assume the replication of a fixed set of traditions from parent to child, de-generacy supports transmission through multiple overlapping channels—oral instruction, mimicry, apprenticeship, ritual performance, and sensory immersion in

***Tab. 2** - This table compares the structural and functional elements of two martial-arts-based performance traditions—Capoeira (Brazil) and Silek Minang (Indonesia)—as practiced in similar but not identical coastal religious festivals. This comparison illustrates de-generacy in cultural expression: multiple structurally distinct systems (music, movement, integration) converging on similar social and symbolic functions.*

CASE EXAMPLE	CONTEXT	FUNCTION	STRUCTURE		
			MUSIC	MOVEMENT	MUSIC–MOVEMENT
Capoeira	Religious festival off the coast of Bahia, Brazil	1. Embodied expression of physical skill 2. Symbolic expression of local and national identity 3. Cultural representation of regional patrimony and heritage	Vocal and percussive; includes *berimbau,* tambourine, drums, etc.	**Improvised circular** movements with kicks, sweeps, and evasions (*ginga*)	Movement is **subordinate** to the music
Silek Minang	Religious festival off the coast of West Sumatra, Indonesia		Woodwind and percussive; includes *sarunai* and double-barrel drums	**Choreographed** movements with **direct** strikes, grapples, and linear footwork	Music is **symbolically related** to the movement but not synchronized

festivals. This means that even if one transmission route fails or is disrupted (e.g. colonisation, migration, or marginalisation), the tradition may persist or re-emerge through alternate pathways that preserve core functions while modifying form. This perspective aligns with the Extended Evolutionary Synthesis by recognising the distributed, iterative, and co-constructed nature of cultural evolution—where environmental pressures, social networks, and cognitive processes shape the retention and transformation of practices over time.

Just as de-generacy in the genome allows for different phenotypes to emerge in response to environmental conditions, de-generacy in cultural systems ensures the persistence and diversification of traditions by enabling multiple, context-sensitive pathways for cultural expression and transmission. This functional plasticity supports cultural continuity through distributed forms of learning and enactment, innovation through structural variation and recombination, and resilience through the adaptive flexibility to reorganise or reassemble cultural elements under conditions of disruption or change. It enables cultural systems like Capoeira and Silek to evolve and endure even in the face of social dislocation, political pressure, or environmental transformation. By recognising de-generacy as a foundational property of cultural systems, anthropologists gain a more nuanced understanding of how cultures are not merely preserved, but continually re-enacted, recontextualised, and reimagined through dynamic, plural processes of transmission and expression.

De-generacy and cultural recipes

Recent developments in evolutionary anthropology and cultural evolution, particularly in niche construction theory (Laland et al. 2000), gene-culture coevolution (Boyd and Richerson 2005; Waring and Wood, 2021), and extended inheritance models (Jablonka and Lamb 2005, 2007), have increasingly recognised that structural variation coupled with functional plasticity is fundamental to explaining how human cultures persist, adapt, and transform over time (Henrich 2016; Mesoudi 2017; Sterelny 2012). Models of cultural transmission increasingly recognise that structurally diverse yet functionally equivalent cultural traits enhance adaptability and resilience. The work of Richerson and Boyd (2005) on cultural evolution, for instance, emphasises the multiple pathways through which cultural traits are transmitted. Sperber and Claidière's (2006) cultural attraction theory shows how transmission is shaped not by perfect replication but by recurring transformations constrained by both cognitive biases and environmental affordances. This aligns with de-generacy in that structurally distinct representations can converge on similar functions due to shared processing tendencies across individuals. Likewise, researchers in computational anthropology have shown how variation in transmission pathways and learning biases supports the durability of functionally equivalent practices across time and place (Mesoudi 2017; Acerbi and Mesoudi 2015). Empirical research is similarly providing examples of de-generacy with studies on kinship systems, linguistic diversity, and ritual behaviours also revealing that distinct terminological systems or ceremonial structures often fulfil comparable social roles (Evans and Levinson 2009; Jordan 2003; Levinson 2022). More recently, Henrich et al. (2022) have demonstrated that cumulative culture and innovation depend on the interplay of diverse learning strategies that support both stability and novelty. While many of these studies have not used the term de-generacy, they implicitly reflect its central insight: that structural diversity enables functional robustness. Making the concept explicit allows scholars to better theorise the conditions under which cultures evolve adaptively and exaptively through distributed, non-identical solutions to shared problems.

While explicitly labelling *de-generacy* offers clarity and focus to patterns already observed in various studies, its application becomes even more tangible when paired with the concept of cultural recipes (Krause 1985, p. 30-31; Schiffer and Skibo 1987, p. 597; Neff 1992, p.160). A cultural recipe encompasses the process and components—whether conceptual, material, or social—used to construct cultural phenomena. This framing recognises both the variability and context-dependence of cultural expressions (Lyman and O'Brien 2003). Recipes are inherently flexible, allowing adaptation to new environments or circumstances while maintaining their overarching function, mirroring the structural variation and functional overlap central to *de-generacy*.

Lyman and O'Brien (2003) find the recipe concept useful because it recognises that what is being transmitted is both a process with malleable instructions and a product with variable results. A recipe requires a time, place, and duration for execution. Furthermore, a recipe is contingent upon ingredients, tools, and agents. The term recipe in its fullest sense captures the heterogeneous construction of activities, events, and artefacts, and recognises that cultural traits need not be prescriptive, immutable, or segregated. Lyman and O'Brien add that recipes can be dissected into smaller parts or put together with other recipes "to form a metaphorical menu" (2003, p.245). The recipe concept fits well with an example used by Sperber and Hirschfeld (2007) in a discussion of the causal chains of culture. Sperber and Hirschfeld describe the cultural transmission of preparing mayonnaise. Learning how to cook does not entail the replication of knowledge but the conversion of that knowledge into behaviour. Furthermore, knowledge of cooking comes from having been able to follow several recipes. Any particular recipe is a path to knowledge that can be converted into behaviour only if the instructions are situated within a familiar field of activity. To cook is not to replicate a pre-existing recipe, but to interpret instructions according to available resources and present circumstances. The notion of cultural recipe is helpful because it reminds theorists that both processes and products are subject to transformation.

Cultural production involves not only the final artifact but the process, tools, and contingent circumstances shaping it. Knowledge is transformed into behaviour depending on available resources and broader contexts. Recipes highlight that cultural formations—dynamic, orchestrated patterns of behaviour—are not fixed but continually constructed and reconstructed over time. O'Brien, Lyman, Mesoudi, and Van Pool (2010) adopt the recipe notion as an encompassing term that can be defined at different scales, recipes are large, nested ideational units "with any given product being a more or less imperfect empirical manifestation of a recipe as a result of variation in raw materials, manufacturing skills, and so on" (2010, p.3802). The notion of recipe applies equally well to music and dance, which are both cultural activities that are decomposable into perceptually discrete units and potentially additive into entire repertoires. Whether making ceramics, playing with musical instruments, or improvising bodily movement, rules and ingredients can be reconfigured to form novel recipes and innovative products (that may or may not leave a material trace).

Integrating *de-generacy* with the cultural recipe model provides a practical framework for anthropologists to analyse how structurally diverse yet functionally coherent practices persist and transform. Consider musical traditions as an example: jazz manifests in myriad forms globally, influenced by regional instruments, cultural norms, and individual interpretations, yet retains its distinctive core identity. Similarly, Capoeira and Silek represent cultural recipes in action—complex assemblages of martial techniques, musical accompaniment, and ritualistic performance, reconfigured to suit specific social contexts.

By linking de-generacy with cultural recipes, biological anthropologists can bridge the abstract theoretical principles of evolutionary systems with tangible, observable practices. While it is true that cultural "functions" are often more plural, symbolic, or contested than their biological counterparts, this does not preclude functional analysis altogether. In fact, the ambiguity of function in cultural systems makes de-generacy all the more useful, as it allows us to identify patterned relationships between diverse structures and overlapping roles across contexts—whether social, emotional, pedagogical, or ritual. By teasing out the dynamic interplay between structure and function—even when those functions are multiple or shifting—this alignment not only refines the analytical tools available for studying cultural evolution but also deepens our understanding of cultural resilience, transformation, and complexity.

Integrating *De-generacy* into the conceptual toolkit

The concept of de-generacy holds transformative potential for biological anthropology, offering a refined framework for understanding variation, adaptation, and cultural change. Defined as the capacity for structurally different elements to perform similar functions depending on context, de-generacy underpins the flexibility and robustness of complex adaptive systems. In biological systems, this allows organisms to respond to environmental challenges through multiple genetic, neural, or behavioural pathways. In cultural systems, de-generacy manifests through diverse practices, networks, and symbolic activity that fulfills overlapping social, pedagogical, or ritual roles, allowing traditions to adapt without rigid replication.

The integration of de-generacy into anthropology's conceptual toolkit helps address longstanding theoretical gaps—particularly the tendency of earlier models to privilege linear inheritance and singular adaptive functions. Recognising de-generacy as a core feature of evolutionary systems allows anthropologists to model cultural change not as a single-track process, but as a multidimensional, plural, and resilient interplay between structure, function, and context.

Biological anthropologists have long grappled with explaining how human behaviours and cultural practices evolve, persist, and transform across generations. Yet, the absence of a robust, discipline-wide framework for conceptualising cultural traits has led some scholars outside anthropology to resurrect outdated and problematic models—such as the meme—applying them in reductionist and misleading ways. While evolutionary theory has provided strong models for genetic and ecological adaptation, cultural evolution remains resistant to the same explanatory tools due to its non-linear, multi-level nature. The principle of de-generacy, which emphasises structural diversity coupled with functional plasticity, fills this gap by providing an explanatory framework that accounts for cultural continuity and innovation in dynamic environments.

Unlike redundancy, which ensures system stability through identical backups, de-generacy promotes flexibility and adaptability by allowing structurally distinct elements to perform overlapping functions. This distinction is crucial because redundancy preserves stability without fostering change, whereas de-generacy enables systems to dynamically respond to environmental and social perturbations. De-generacy thus enhances evolutionary theory by addressing how cultural systems maintain resilience while facilitating novelty, a question that existing models, such as exaptation (Gould and Vrba 1982) and spandrels (Gould and Lewontin 1979), accommodate but fail to fully resolve. While exaptation explains how traits originally evolved for one function are co-opted for another, it does not account for the simultaneous persistence of structurally diverse solutions to the same problem. Spandrels, on the other hand, emphasise evolutionary byproducts rather than the generative potential of overlapping structural variants. In contrast, de-generacy highlights how multiple, coexisting solutions allow for system-wide adaptability in both biological and cultural domains.

A major advantage of applying de-generacy to cultural evolution is its ability to explain how non-adaptive and maladaptive traits—which impose fitness costs—persist alongside adaptive ones, a problem identified by Mesoudi and O'Brien (2008, p.23). Rather than assuming that all cultural traits are subject to selective pressures favouring fitness optimisation, de-generacy allows for the coexistence of traits with varying adaptive value, enabling cultural systems to experiment with novel configurations while maintaining overall functionality. This perspective aligns with Deacon's (2010) hypothesis that human language and other complex traits emerged under relaxed selection pressures, where de-generacy facilitated innovation by buffering against intense selective constraints.

Furthermore, de-generacy offers a structure-function-context analytical lens to explain cultural transformations. Just as genetic systems use multiple codons to encode the same amino acid (Woese 2001) and neural networks employ diverse circuits to achieve similar behavioural outcomes (Edelman and Tononi 2000), cultural practices exhibit de-generacy when structurally distinct traditions perform equivalent social functions. For example, kinship terminologies, linguistic systems, and ritual performances vary widely in form yet serve common purposes such as group cohesion, knowledge transmission, and identity reinforcement. This recognition broadens the analytical scope of cultural evolutionary models, ensuring that anthropologists can account for cultural resilience, transformation, and adaptability.

The integration of de-generacy into biological anthropology also encourages interdisciplinary collaboration. Insights from genetics, neuroscience, and computational modelling can enrich anthropological approaches to cultural evolution, while ethnographic and archaeological perspectives can inform models of complex evolutionary systems. De-generacy, operating across multiple levels of organisation, serves as a conceptual bridge between traditionally separate fields, fostering a more integrative understanding of human evolution.

Perhaps most critically, de-generacy frees cultural evolutionary theory from strict adaptationist biases and offers a dynamic framework that accounts for developmental processes, social structures, political and economic contingencies, and environmental constraints. Traditional Darwinian approaches to cultural evolution often fall into functionalist traps, collapsing acquisition and inheritance into overly rigid frameworks (Gabora 2013; Schroeder and Ackermann 2023; Szocik 2019). Multilevel approaches that integrate evolutionary theory with complex systems thinking are proving more fruitful in capturing the contingent factors shaping human evolution (Andersson et al. 2014; Foley 2016; Fuentes 2016; Parravicini and Pievani 2016; Whiten et al. 2017).

De-generacy operates at multiple levels of complexity, enabling insights from genetics, neuroscience, and fieldwork to inform studies of cultural evolution. For instance, examining de-generacy in technological innovation, social learning, or environmental adaptation could generate new perspectives on co-evolutionary dynamics. Moreover, de-generacy has practical applications beyond anthropology: in public health, understanding de-generacy in traditional medical practices can inform culturally sensitive health interventions; in environmental anthropology, recognising de-generacy in indigenous land-use strategies could enhance sustainability models. These applications reinforce de-generacy's theoretical depth and real-world relevance, demonstrating its explanatory power in both academic and applied research.

By highlighting the adaptability and resilience inherent in structurally diverse systems, de-generacy offers an evolutionary framework that better reflects the dynamism of human cultural complexity. Its integration into biological anthropology strengthens the study of cultural evolution, ensuring that future research moves beyond simplistic selectionist narratives toward a more comprehensive understanding of how human societies innovate, adapt, and endure.

Conclusion

This article has advanced de-generacy as a transformative concept in evolutionary theory, bridging biological and cultural domains to elucidate the dynamics of variation, adaptation, and resilience. By integrating de-generacy into evolutionary anthropology, I have demonstrated how structural diversity and functional plasticity interact to shape the stability, transformation, and adaptive potential of biological and cultural systems. Reclaiming the term from its problematic historical associations and firmly situating it within complex systems theory, I have clarified its conceptual utility for addressing gaps in traditional models of cultural and biological evolution.

At its core, de-generacy provides a powerful framework for understanding the interplay between structure and function across evolutionary scales. In biological systems, it underpins genetic robustness, neural flexibility, and immune adaptability, safeguarding organisms against perturbations while fostering innovative pathways for adaptation. In cultural systems, it manifests in the diverse forms of cultural recipes—rituals, tools, and practices—that serve analogous functions across varied contexts, ensuring resilience and continuity amidst environmental and social change. This many-to-one structure-function relationship, observed across human cultural formations, transcends redundancy by revealing how variation within systems fosters innovation while maintaining dynamic equilibrium. The presence of de-generacy in both biological and cultural domains suggests a deep evolutionary logic of resilience, where diversity is not merely tolerated but actively maintained as a resource for adaptation.

One of the major contributions of this article is to provide a clear, operational definition of de-generacy that distinguishes it from related concepts such as redundancy, exaptation, and spandrels. Unlike redundancy, which involves functionally identical backups, de-generacy involves structurally distinct elements capable of performing overlapping functions, thereby promoting greater adaptability. Unlike exaptation (Gould and Vrba 1982), which describes the co-option of existing traits for novel functions, de-generacy captures how structurally different solutions emerge, coexist, and are selectively maintained within a system to achieve comparable outcomes. In cultural evolution, this means that different symbolic, ritual, or institutional forms may serve analogous social roles—such as mediating conflict, marking transition, or reinforcing group identity—even if their structures differ significantly. These overlapping functions can allow cultural systems to remain resilient under change, since alternative structures may step in when others are lost, suppressed, or recontextualised. By precisely articulating its definition and analytical scope, this article argues for the potential of de-generacy to advance cultural evolutionary theory, offering new ways to conceptualise the persistence, diversification, and recombination of cultural traits across contexts.

Future research will benefit from extending the application of de-generacy across evolutionary anthropology, cultural evolution, and the biological sciences, particularly by integrating it into computational and mathematical models of culture-gene coevolution. By formalising these principles of functional convergence and divergence within cultural transmission models and evolutionary simulations, scholars can gain deeper insights into the interactions between biological and cultural adaptations across multiple levels of complexity. However, to fully operationalise de-generacy within empirical research, methodological challenges—such as defining functional equivalence among structurally distinct traits—must be explicitly addressed. A more refined approach will allow researchers to move beyond static models of cultural inheritance, revealing how de-generacy fosters adaptive flexibility, creative recombination, and evolutionary innovation in cultural systems.

In co-evolutionary models of brains and culture, de-generacy is key to understanding the iterative feedback loops that shape human behaviour, knowledge systems, and social organisation. Humans both adapt through culture and to culture (Lende and Downey 2012, p.119), while cultural formations, in turn, evolve in response to human learning and interpretation (Deacon 1998). De-generacy provides a structural framework for conceptualising this dynamic, demonstrating how multiple, contextually contingent pathways for cultural expression—such as oral traditions, written texts, and digital media—enable knowledge to persist, transform, and diversify across generations. By embedding de-generacy within co-evolutionary models, researchers can move beyond rigid adaptationist frameworks, instead capturing the complex interplay of biological constraints, environmental affordances, and cultural transmission. This perspective offers a more dynamic account of how human cognitive flexibility and cultural plasticity interact over time.

A promising direction for future research in biological anthropology could involve interdisciplinary studies that combine brain imaging, ethnographic fieldwork, and choreomusicological or ethnomusicological analysis to investigate cultural enskilment. A neuroanthropological approach grounded in the study of music and dance—such as Capoeira or Silek—avoids the semantic confounds common in linguistic tasks and offers more targeted models for studying the complex systems dynamics of embodied learning. These humanly organised expressive systems culturally specific forms of sensorimotor coordination and attunement, acquired through immersive apprenticeship and refined through performance. They involve highly structured yet culturally diverse forms of embodied expression that allow researchers to design experiments using non-verbal stimuli and non-verbal responses. This would enable more direct investigation of how structurally distinct neural pathways can support overlapping functions across individuals and populations, offering new insights into neural plasticity, embodied cognition, and the adaptive potential of encultured brains.

Ultimately, the study of de-generacy is the study of diversity—of the ways in which complex systems thrive by fostering variation, maintaining adaptability, and generating novel solutions to recurrent challenges. It is also the study of diversifying diversity, as systems evolve through iterative processes of transformation and recombination. By embracing de-generacy as a foundational principle of cultural and biological evolution, biological anthropology is poised to provide a richer understanding of human adaptability, a more precise framework for studying cultural change, and new insights into the resilience of living systems. In doing so, de-generacy not only refines evolutionary theory but also offers new tools for navigating the complexities of the past, present, and future.

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