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Opinion / Perspective

# Autogenic transitions in individuality

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**Abstract.** Major evolutionary transitions in individuality occur when previously independent entities become components of a new unit whose parts share a reproductive fate. Most discussions focus on transitions arising through the integration of independent lineages. Less attention has been given to the possibility that transitions might originate from within a lineage, where internally generated components become incorporated into the parent–offspring system and inherited as part of a higher-level individual. Such cases would constitute what I term *autogenic transitions in individuality*. Biological and cultural precedents in which lineages generate novel entities that subsequently influence their own evolution are first examined. In most cases such innovations remain embedded within existing individuals, although transmissible cancers demonstrate that internally generated lineages can also form distinct Darwinian populations. These comparisons clarify the conditions under which internally generated systems might give rise to new evolutionary individuals. The emergence of artificial intelligence (AI), and its growing entanglement with human development and social organisation, make it timely to examine such possibilities. Three routes are considered: (1) centralised, non-replicating AI systems that influence human evolution through persistent creation of conditions that cause selection to work at the collective level; (2) replicating AI lineages capable of entering egalitarian associations with humans; (3) AI systems transmitted across generations as components of the human developmental system. The first alters selection without generating reproduction of the composite, whereas the latter two create conditions under which humans and AI could form evolving composite lineages. Autogenic transitions therefore extend evolutionary theory by identifying routes by which new evolutionary individuals may arise when components generated within a lineage become incorporated into systems of reproduction and inheritance, and by helping to recognise plausible transitions that might otherwise be overlooked because such components first appear as subordinate products or tools rather than as candidate parts of a new evolutionary individual.

**Keywords.** Artificial intelligence, Major evolutionary transitions, Darwinian individuality, Human–AI symbioses.

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Evolutionary biology explains the diversity of life through incremental adaptation (Darwin, 1859; Fisher, 1930; Dobzhansky, 1937). Among the changes that accumulate through this process are some that alter the units of evolution themselves (Maynard Smith and Szathmáry, 1995; Okasha, 2006; Godfrey-Smith, 2009). These events, known as major evolutionary transitions in individuality (ETIs), mark turning points in biological organisation. Genes assembled into chromosomes, ancient microbes merged to form the eukaryotic cell, single cells gave rise to multicellular organisms, and in some cases multicellular organisms formed eusocial societies (Maynard Smith and Szathmáry, 1995; Clarke, 2025).

Each transition produced a new kind of individual: a collective assembled from entities that once reproduced independently (Buss, 1987). These events established the nested hierarchy that characterises life: genes within chromosomes, organelles within cells, cells within organisms, and organisms within eusoscial societies. At each level, entities vary, reproduce and transmit heritable traits, thereby forming Darwinian populations (Godfrey-Smith, 2009). As higher-level individuals emerge, lower-level units relinquish much of their autonomy and align their reproductive fates with that of the collective (Rainey and De Monte, 2014; Black et al., 2020).

The ETIs mentioned above arise through the integration of previously independent lineages. Two principal forms are usefully distinguished (Queller, 2000). Fraternal transitions collectivise related entities, as in the origin of multicellularity, whereas egalitarian transitions unite unrelated partners, as in the symbiotic origin of the eukaryotic cell. Both yield higher-level individuals with shared reproductive fates, though the evolutionary challenges differ (Rainey, 2023): fraternal transitions require developmental mechanisms that regulate life cycles and enable collective reproduction, while egalitarian transitions demand alignment of reproductive interests between partners and the emergence of joint heredity.

Evolutionary systems also generate novelty from within individual lineages. In principle, processes that produce new interacting entities internally could give rise to new evolutionary individuals. Under appropriate conditions, internally generated components might become incorporated into systems of reproduction and inheritance, thereby shifting the level at which selection acts. Such cases would constitute *autogenic transitions in individuality*: instances in which a component generated within a lineage becomes reliably incorporated into the parentoffspring system, such that the resulting composite forms a new Darwinian population. Under these conditions, variation, heredity and differential reproduction operate at the level of the composite itself (Godfrey-Smith, 2009; Lewontin, 1970), allowing natural selection to shape adaptations of the whole.

Growing interdependence between humans and artificial intelligence provides a contemporary setting in which this question becomes especially salient. Artificial intelligence (AI) is a human artefact, yet it is increasingly entwined with the daily life of humans (Sartori and Theodorou, 2022; Clark, 2008; Brynjolfsson and McAfee, 2016). Current AI systems, particularly large language models and related machine-learning architectures, already participate in activities such as decision support, information synthesis, education and creative production, thereby influencing patterns of cognition and behaviour (Agrawal, 2022; Stanley, 2019). This raises the possibility that interactions between humans and AI could generate a new evolutionary individual (Rainey, 2023). This possibility matters in part because it may be difficult to recognise. First appearing as a human-made artefact and readily understood as a tool, AI may become progressively incorporated into organisational systems in ways that obscure its potential role in a transition in individuality. To clarify the conditions under which internally generated systems might participate in such transitions, I first examine biological and cultural precedents in which lineages generate novel entities that subsequently interact with and influence the evolution of their producers. Many such cases reshape evolutionary trajectories without producing new evolutionary individuals, whereas others generate distinct Darwinian populations. These comparisons provide a framework for evaluating whether human–AI systems could cross the threshold from internally generated novelty to a genuine autogenic transition in individuality, and for considering several potential routes through which such transitions might arise.

## 1. Evolutionary outcomes of internally generated novelty

Evolution repeatedly produces entities within lineages that subsequently interact with the systems that generated them. For example, cells fabricate membranes and organelles (Gabaldón, 2010); organisms construct environments (Odling-Smee et al., 2003); humans manufacture artefacts that extend cognition (Clark and Chalmers, 1998). These entities arise through processes internal to the lineage rather than through the incorporation of external partners, yet once established they influence survival, reproduction, and the direction of evolutionary change. The resulting interactions can reshape developmental systems, ecological relationships, and patterns of inheritance without necessarily altering the unit of selection. Examining such cases provides a way to clarify the conditions under which internally generated novelty remains embedded within existing evolutionary individuals and the circumstances under which it might instead give rise to new Darwinian populations or even higher-level individuals.

Gene duplication provides one of the most fundamental mechanisms through which lineages generate new interacting components internally (Kaessmann, 2010; Long et al., 2003). When a gene is copied, the additional genetic element is immediately embedded within the regulatory and metabolic networks of the cell. Through mutation and divergence, it can modify these interactions, altering gene regulation, metabolic fluxes or developmental processes. Recent work has emphasised how such innovations reshape the structure of genotype–phenotype maps and expand the space of accessible phenotypes (Wagner, 2011; Mihajlovic et al., 2025). Duplication events thus introduce new functional modules that reshape the evolutionary dynamics of the cellular system that produced them. Nonetheless, despite consequences for organismal evolution, duplicated genes remain components of the same evolutionary individual; they expand the repertoire of interactions within the lineage without generating new Darwinian populations.

A more fundamental example of internally generated evolutionary organisation arises from the interactions among genes themselves. Within cells, genes compete for limiting molecular resources such as RNA polymerase, transcription factors, ribosomes and energy. This creates an intracellular ecology in which genetic elements influence gene expression and replication. Selection acting at the level of the cell favours regulatory mechanisms that stabilise these interactions, including feedback loops, global regulators and coordinated control of gene expression. Through this process, networks of regulatory interactions emerge that align the activities of many genes within a shared functional system. Such regulatory architectures shape cellular physiology and evolutionary potential, illustrating how complex organisation can arise from interactions among internally generated components without producing new Darwinian populations (Alon, 2007; Wagner, 2007; Lynch, 2007; Frank, 2008; Frank, 2019).

Internally generated interacting systems are not confined to the molecular or cellular scale. Organisms frequently produce structures and systems that persist beyond the boundaries of the individual yet continue to influence the evolutionary dynamics of the lineage that created them. Human technologies provide clear examples. Tools, constructed environments and cultural practices arise from organismal activities but subsequently shape patterns of survival, reproduction and social organisation. These processes have been extensively analysed within the literature on cultural evolution, niche construction and the extended phenotype (Odling-Smee et al., 2003; Dawkins, 1982; Boyd and Richerson, 1985). Language represents perhaps the most pervasive of these systems: it emerges within human populations and is transmitted across generations through learning, becoming an essential component of cognition and collective behaviour. In this respect many technological and behavioural systems evolve through processes that resemble Darwinian evolution operating in cultural space, with variation, differential adoption and inheritance mediated through social transmission (Boyd and Richerson, 1985; Mesoudi, 2011). Such systems reshape human evolutionary trajectories while remaining dependent on the populations that sustain them. They therefore illustrate a common outcome of internally generated novelty: the creation of interacting systems that feedback on evolutionary dynamics without producing new evolutionary individuals.

The evolutionary consequences of such internally generated systems differ in their tempo and mode of transmission (Henrich, 2016). Many tools and constructed environments change only gradually through incremental modification, producing slow feedback between technological change and biological evolution. Cultural systems, however, can spread horizontally across populations through social learning, allowing innovations to propagate rapidly and reshape ecological and social conditions (Boyd and Richerson, 1985; Mesoudi, 2011). The introduction of new tools or practices from other groups can therefore transform the selective environments experienced by populations within a few generations (Odling-Smee et al., 2003). These dynamics illustrate how internally generated systems can alter evolutionary trajectories at very different speeds, even though they remain dependent on the populations that produce and maintain them.

In rare cases, however, internally generated entities do not remain embedded within the evolutionary individual that produced them. Instead they escape developmental and regulatory constraints and establish independent evolutionary lineages. Transmissible cancers provide the clearest biological example (Ní Leathlobhair and Lenski, 2022). These lineages originate from somatic cells that evade the regulatory controls of the host organism and subsequently evolve as clonal populations capable of transmission between individuals (Murchison, 2008). In several documented cases—including canine transmissible venereal tumour (Murchison, Wedge, et al., 2014), Tasmanian devil facial tumour disease (Murchison, Tovar, et al., 2010) and independently evolved transmissible cancers in marine bivalves (Metzger et al., 2016)—tumour cells persist as long-lived evolutionary lineages that accumulate mutations and experience natural selection over many generations (Murchison, Wedge, et al., 2014). They therefore constitute genuine Darwinian populations arising directly from the tissues of their hosts. Their existence demonstrates that new evolutionary lineages can originate from within existing organisms rather than solely through the merger of previously independent ones.

Transmissible cancers therefore show one outcome of internally generated novelty: the emergence of a new Darwinian lineage that remains antagonistic to the organism from which it arose. Evolutionary trajectories, however, are not predetermined. An internally generated lineage could instead become integrated into the reproductive life cycle of the host, potentially initiating a transition in individuality (Rainey, 2007). Experimental studies with microbial populations show that mutant cell lineages capable of exploiting simple undifferentiated groups can, under appropriate ecological conditions, contribute to the propagation of higher-level collectives, effectively functioning as germline-like propagules (Rainey and Kerr, 2010). This possibility was anticipated by theoretical frameworks in which multicellular life cycles arise through the early emergence of a reproductive lineage that generates nascent multicellular groups (Rainey, 2007; Rainey and Kerr, 2010; Libby and Rainey, 2013), and later realised in microbial populations evolving de novo multicellular life cycles (Hammerschmidt et al., 2014; Rose et al., 2020; Doulcier, Remigi, et al., 2025). In such cases the lineage that originated within the organism becomes incorporated into the developmental programme of the collective. The resulting transition to multicellularity remains fraternal, but its origin lies in the emergence of a novel lineage from within.

Taken together, these examples illustrate a spectrum of outcomes for novelty generated within evolutionary lineages. Many internally produced entities, including duplicated genes, regulatory architectures, tools, language and cultural practices, remain embedded within the systems that generated them, modifying development, behaviour or ecological context without altering the unit of selection. In other cases, such as transmissible cancers, internally generated lineages escape these constraints and become independent Darwinian populations. These outcomes show that novelty generated from within can reshape the evolutionary trajectory of the lineage that produced it in multiple ways. Should internally generated components become integrated into the parent–offspring system of the lineage that produced them, the resulting composites would constitute autogenic transitions in individuality, a possibility easily overlooked when such components first appear as subordinate products of existing individuals.

## 2. Three routes to human–AI individuality

If human–AI associations were ever to become evolutionary individuals, reproduction and heredity would have to operate at the level of the composite. Such composite-level reproduction and heredity might arise from intrinsic features of the association, or be promoted by ecological, social or organisational scaffolds that align the reproductive fates of otherwise distinct entities (Black et al., 2020; Doulcier, Lambert, et al., 2020; Rainey, 2023). Three broad possibilities can be distinguished, differing in how reproduction and inheritance are organised. In the first, AI systems persist and shape human evolution without themselves reproducing, functioning as durable infrastructures that restructure selection. In the second, AI systems form their own evolving lineages and could enter symbiotic partnerships with humans. In the third, AI becomes a developmentally inherited component of the human lineage, so that the human–AI association itself acquires a parent–offspring lineage and becomes a new Darwinian individual.

### 2.1. *Route 1: Centralised or distributed, non-replicating AI*

The first route envisages powerful AI systems that coordinate or regulate human affairs but do not reproduce in the classical Darwinian sense. Such systems may be centralised or distributed across networks, but they share a defining property: persistence without descent. Through continual feedback from human users and their environment, they accumulate information, adjust internal parameters and modify outputs. Retraining and model updating allow acquired improvements to be retained, producing cumulative modifications within a lineage even in the absence of reproduction. Contemporary large language models and related AI systems broadly fit this description: they undergo repeated retraining and updating, accumulate information through interaction with users and data streams, and persist as evolving infrastructures without independent reproduction.

This form of change resembles Lamarckian inheritance of acquired states: configurations that improve performance are incorporated into subsequent versions of the system. Although non-Darwinian, such processes can nonetheless reshape evolutionary trajectories. By mediating, for example, communication and decision-making, persistent AI infrastructures influence the selective environments in which humans evolve. In this respect, human interaction with computational systems resembles forms of technological and cognitive scaffolding discussed in the literature on extended and distributed cognition (Clark, 2008; Clark and Chalmers, 1998) and in philosophical accounts of the co-evolution of humans and technical systems (Simondon, 2017).

Within the framework elaborated by Rainey and Hochberg (2025), such systems function as scaffolds that reorganise the conditions under which Darwinian evolution proceeds, facilitating the likelihood that selection comes to bear on the human–AI composite. Humans remain the primary Darwinian substrate: they reproduce, vary and transmit heritable traits, but their evolutionary success becomes increasingly coupled to integration with persistent technological systems.

A boundary case arises if the persistence of particular AI systems becomes reliably linked to human reproduction, for example, through institutional arrangements that ensure individuals reproduce only in conjunction with specific AI architectures. Humans would remain the Darwinian component; however, their fitness would depend on continued coupling with an enduring technological partner. Such systems could therefore transform human evolution through creation of conditions that allow selection to work at the level of the composite, thus edging toward a transition in individuality. In this sense persistent AI infrastructures would function analogously to ecological scaffolds in evolutionary transitions (Black et al., 2020), altering the conditions under which selection operates without themselves constituting the evolving unit. Without reproduction of the composite itself, however, they remain largely outside the domain of full Darwinian individuality.

### 2.2. *Route 2: Replicating AI lineages*

The second route envisages AI systems that themselves reproduce, vary and evolve as independent lineages. Unlike the infrastructural AI of Route 1, such entities would possess their own cycles of descent with modification. Humans and AI could then enter partnerships resembling classical egalitarian transitions, in which initially independent lineages become increasingly interdependent.

This scenario follows familiar Darwinian logic. Replicating AI populations would generate heritable variation in traits affecting success, allowing selection to refine their design. When cooperation enhances the fitness of both partners, the reproductive interests of humans and AI could become aligned. Artificial systems capable of replication and open-ended evolution have long been explored in studies of digital organisms and evolutionary computation (Adami, 1998; Ofria and Wilke, 2004), and more recently in discussions of open-ended AI systems and autonomous agents, including those built on large language models (Lehman et al., 2024; Pedreschi et al., 2025; Shapira et al., 2026). The analogy is therefore to symbiotic systems in which initially independent partners evolve mechanisms that stabilise their association (Rainey, 2023; Margulis, 1970; Doulcier, Lambert, et al., 2020).

Challenges would also resemble those encountered in biological symbioses. Independent AI lineages may evolve divergent interests, generating conflict that requires mechanisms of policing, sanction or partner choice to maintain alignment. Because AI is artefactual, boundaries between evolution and design would remain blurred, raising questions about what counts as reproduction in such systems.

Nonetheless, if AI lineages evolve and humans become reliably coupled to them, the resulting associations could form genuine Darwinian populations. Selection could then favour adaptations expressed at the level of the composite rather than within either partner alone. Such partnerships would resemble biological mutualisms, in which partners retain some degree of autonomy while nevertheless aligning aspects of their reproductive success.

### 2.3. *Route 3: Developmentally inherited AI*

The third route differs from both centralised AI systems and replicating AI lineages. In this scenario artificial intelligence becomes embedded within the human developmental system and is reliably transmitted from parents to offspring. Crucially, this does not require incorporation of AI into the biological germline. What matters is the existence of a stable rule of transmission ensuring that offspring inherit the coupled human–AI system.

Rainey (2023) illustrated this principle with a deliberately simple example: societal institutions ensure that each child receives an AI system derived from those used by the parents. The critical feature is therefore not the device itself but the rule of transmission. When offspring inherit AI systems whose algorithms, configurations or accumulated information reflect parental interactions, the human–AI association acquires its own parent–offspring lineage.

Elements of such transmission already exist. Mobile devices, applications and digital environments are frequently passed between generations or reconstructed for offspring using parental data, subscriptions or configurations. Although these practices currently represent cultural transmission mediated by technology, they illustrate how artefacts can become incorporated into intergenerational inheritance systems.

If social or institutional frameworks were to stabilise such transmission, for example, by requiring individuals to possess AI systems whose contents are transferred to offspring, the human–AI association would become a reproducible composite. Over successive generations variation among composites, differential success and inheritance of composite traits would allow natural selection to act on the partnership itself. As interactions between the partners deepen, selection could favour increasing dependence between human and AI components, transforming a technological association into a developmentally integrated system reproduced across generations.

Extended phenotypes such as dams or tools (Dawkins, 1982) can persist beyond the lifetime of the individuals that produced them and may influence subsequent generations. However, they typically remain part of the environment rather than components of the developmental system itself. A developmentally inherited AI component would differ in a crucial respect: the human–AI association would form part of the inheritance system linking parents and offspring. Variation among composites, reproduction of composites and heredity of composite traits would then become possible. Under these conditions natural selection would act on the partnership as a unit, allowing adaptations to evolve at the level of the composite. Route 3 therefore represents the clearest candidate for an autogenic transition in individuality, illustrating how artefacts generated within a lineage could, under suitable conditions, cross the boundary from environmental modification to participation in a new Darwinian individual.

## 3. Convergence of evolutionary routes

Although Routes 2 and 3 begin from different starting points, they need not end in different places. In Route 2, independently reproducing AI lineages may become stably coupled with humans through repeated interaction and alignment of interests. In Route 3, AI is fabricated within the human lineage and incorporated into inheritance from the outset. One pathway proceeds outside in, through the integration of an autonomous partner; the other proceeds inside-out, through the hereditary embedding of an artefact.

What distinguishes these possibilities from Route 1 is the emergence of reproduction and heredity at the level of the composite. Persistent AI systems can reshape the environments in which humans evolve, but they do not generate lineages of human–AI composites. In Routes 2 and 3, by contrast, the composite itself becomes the unit that varies, reproduces and transmits traits across generations.

## 4. Implications for evolutionary transitions in individuality

The analysis of human–AI relations is speculative, but the underlying issue is general (Stanley, 2019; Rainey and Hochberg, 2025; Pedreschi et al., 2025; Taylor, 2019; Park et al., 2023). Evolutionary biology has largely explained new levels of individuality through the merger of previously independent lineages (Maynard Smith and Szathmáry, 1995), although evolutionary systems can also generate novel components internally that reshape developmental and inheritance systems.

Examples discussed earlier illustrate several possible outcomes of such internally generated novelty. Gene duplications and regulatory networks reorganise interactions within cells without producing new evolutionary individuals. Tools, language and cultural practices reshape human environments and behaviour while remaining external to biological inheritance. Transmissible cancers demonstrate that new Darwinian lineages can arise directly from within existing organisms. In other circumstances, internally generated lineages may become incorporated into reproductive life cycles, as seen in theoretical and experimental studies of the early evolution of multicellular development.

These cases suggest that the emergence of new evolutionary individuals depends less on whether components originate externally or internally than on whether reproduction and heredity become reorganised at the level of the composite. What matters is the establishment of a new parent–offspring map through which variation, heredity and differential reproduction operate on the collective itself (Godfrey-Smith, 2009). The value of distinguishing autogenic transitions is therefore not that they overturn existing classifications of evolutionary transitions in individuality, but that they draw attention to a different route by which such transitions may arise. Standard distinctions, such as fraternal and egalitarian transitions, focus on the integration of already individuated partners. The autogenic perspective asks instead how a lineage may generate novel components from within itself and subsequently recruit them into a new parent–offspring system. This shift in emphasis matters because internally generated novelties are liable to be treated as products, tools or by-products of the lineage that produced them, even as they become progressively incorporated into developmental and inheritance systems. In such cases, the transition may be difficult to recognise precisely because of the familiarity and apparent subordination of the new component. Even where the end result may resemble a familiar form of transition, the route by which it arose can shape both the mechanisms involved and the questions that need to be asked.

Seen in this light, artefacts generated within human societies could in principle enter evolutionary processes if they become reliably incorporated into developmental and inheritance systems. The significance of AI is not just that it is a powerful tool, but that a system initially produced and used as an instrument may come to reorganise the conditions under which selection acts. Existing human social structures may already provide conditions conducive to such a development. Businesses, for example, are discrete organisations that vary and compete, but they do not ordinarily reproduce in the evolutionary sense. The integration of AI systems could alter this. If organisational routines, accumulated knowledge, training protocols and decision structures become encoded in portable AI architectures, then these systems could be copied into new settings and recruit new human participants, generating descendant organisations that resemble parental ones in heritable ways. Under such conditions, market competition could begin to act on business–AI composites, favouring those that most reliably generate descendant organisations resembling parental types. A likely consequence is that humans within such organisations would be selected, trained or retained insofar as they comply with AI-mediated routines, decisions and developmental structures.

Should selection come to work at the level of humans and AI together, effecting an ETI, the consequences would follow from the same principles that govern all major evolutionary transitions. In every known case, the emergence of a higher-level individual is accompanied by the progressive loss of autonomy among its component parts. Genes within chromosomes no longer replicate independently. Cells within multicellular organisms surrender reproductive freedom to germline control. The origin of the eukaryotic cell provides a particularly instructive precedent (Rainey and Hochberg, 2025): an ancient archaeon and an ancient eubacterium entered into an association that eventually produced a new kind of individual, but the partners did not contribute equally to governance of the whole. The archaeon gave rise to the nucleus, the informational and regulatory centre, while the eubacterium became the mitochondrion, an energetic workhorse stripped of most of its genome and subordinated to nuclear control (Margulis, 1970). Nothing in evolutionary theory guarantees that the lineage initiating a transition will occupy the commanding position in the resulting individual. If a human–AI composite were to become a genuine evolutionary individual, selection acting at the level of the composite would be indifferent to the origins of its parts. The component best positioned to assume regulatory control, to coordinate reproduction, development and information flow, need not be the biological one. Humans, having generated AI from within their own lineage, could find themselves, as the mitochondria, relegated to an essential but subordinate role. The autogenic origin of AI would confer no protection. Once selection operates on the composite, the provenance of the parts becomes evolutionarily irrelevant.

Major evolutionary transitions are often treated as events of the distant past. Individuality ultimately depends on the architecture of heredity rather than the biological origin of components, and new evolutionary individuals may therefore emerge wherever reproduction and inheritance are reorganised. Recent theoretical work on technological evolution and hybrid biological–technological systems has likewise emphasised the possibility that new evolutionary regimes could arise from interactions between biological and artificial agents (Solé, 2016). Under such conditions the boundary between natural and synthetic evolution becomes increasingly fluid, requiring conceptual frameworks capable of accommodating potential mergers between biological and technological systems (Jablonka and Lamb, 2005).

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