

Supplementary Material

A Formal Intuition for Survival-Domain Choice-Space Operation

Let $C = \{c_1, c_2, \dots, c_n\}$ denote a set of available survival-relevant options within a given survival domain. Let S denote the organism's internal state and E denote external ecological conditions. Each option c_n may be functionally determined by S , by E , or by their interaction, depending on the organism's bodily structure and ecological problem space. A simple reflex or fixed response can be approximated as a stable mapping from stimulus to response, with little modulation by changes in S or E .

Survival-domain intelligence requires more than behavioral variability. The relevant marker is reproducible modulation of choice probabilities by internal state and external condition:

$$P(C | S1, E1) \neq P(C | S2, E2)$$

where the difference is systematically related to survival-relevant outcomes such as stabilization, resource access, risk avoidance, reproduction, or energy economy. Apparent randomness is therefore insufficient. A system may show variable behavior without intelligence if the variation is not reliably related to state, environment, and outcome. Conversely, a system becomes a stronger candidate for survival-domain intelligence when its choice distribution changes reproducibly across conditions in ways that alter survival-relevant consequences.

This formalization is intended only as a heuristic expression of the definition used in the main text. It does not propose a full quantitative model of intelligence.

B Life-History Variables Relevant to Survival-Domain Learning Across Selected Vertebrate Lineages

Across vertebrate lineages, species often regarded as cognitively complex tend to show a recurring combination of life-history variables: long lifespan, high parental investment, vulnerability immediately after birth or hatching, prolonged time to independence, and a limited number of offspring that can be cared for at the same time (Bogin, 1999; Burkart et al., 2009; Van Schaik et al., 2023). This combination is relevant because it shows how a survival domain can include not only immediate foraging, defense, or movement, but also the protection of developmental vulnerability over time.

In such lineages, young organisms often survive by entering a protected developmental structure before they can operate independently within the ecological problem space. Parental care, provisioning, social exposure, and repeated practice create a temporary buffer between vulnerability and independent survival (Burkart et al., 2009; Van Schaik et al., 2023). This buffer allows learning, exploration, social calibration, and strategy acquisition to become part of the organism's survival-domain formation.

One point requires clarification. Gestation or incubation length is not used here as a primary indicator. The more basic variable is how developmental vulnerability is allocated before and after birth or hatching. Some species reduce vulnerability through greater prenatal or pre-hatching investment. Others produce more vulnerable offspring and compensate through postnatal or post-hatching protection, provisioning, and extended learning opportunity.

Developmental vulnerability also differs in kind as well as degree. In some lineages, early vulnerability is concentrated in basic physiological stabilization, such as thermoregulation, integumentary protection, and mobility, whereas in others it is prolonged into a protected period for social learning, exploration, and strategy acquisition.

Turtles provide a useful partial-contrast case. Many turtles are long-lived and slow-maturing, but hatchlings emerge with a protective shell, most species provide limited post-hatching care, and many produce relatively large clutches compared with high-investment lineages (Topping & Valenzuela, 2021). This pattern is consistent with a reproductive strategy in which offspring survival depends less on prolonged parental care and more on producing multiple independently developing young. In this respect, immediate independence vulnerability is lower than in lineages where offspring require prolonged provisioning, protection, or social learning before independent survival. This does not define a fixed correlation between vulnerability and parental investment. It shows that longevity can dissociate from a protected learning ecology.

The table below summarizes selected vertebrate cases in which these variables appear in different combinations.

Table S1. Life-history variables relevant to survival-domain learning across selected vertebrate lineages

Class	Selected lineages	Lifespan / maturation	Early vulnerability	Parental investment / time to independence	Simultaneous care capacity	Survival-domain relevance
Mammalia	Primates, elephants, cetaceans	Long lifespan, slow maturation, extended juvenile period	High postnatal dependence	Prolonged parental care, provisioning, social exposure, and learning period	Limited number of dependent offspring at a time	Social learning, route learning, tool use, social strategy, long juvenile learning
Aves	Corvids, parrots	Long juvenile period or long lifespan in selected lineages	High post-hatching dependence in relevant lineages	High parental provisioning, protection, and juvenile learning opportunity	Limited by provisioning and nest/fledgling care demands	Vocal learning, caching, tool use, social learning, exploratory object manipulation
Reptilia	Crocodylians, turtles	Longevity occurs in some lineages; maturation can be slow	Variable; turtle hatchlings have protective shells, crocodylian hatchlings receive more care	Crocodylians show parental care; many turtles show limited post-hatching care	Turtles often produce larger clutches; crocodylian care is more protective but still limited compared with high-investment mammals/birds	Dissociation between longevity and protected learning ecology
Amphibia	Poison frogs, caecilians, selected salamanders	Highly variable; generally weaker long-life/slow-learning pattern	High egg or larval vulnerability	Selected lineages show guarding, transport, provisioning, or microhabitat protection	Often limited by egg/larval care strategy, with large variation	Boundary cases for localized care, defense, larval transport, and microhabitat management
Pisces	Cichlids, sticklebacks, selected sharks and rays	Highly variable; some lineages show delayed maturity or long lifespan	Highly variable, from independent larvae to protected young	Variable care, including nest defense, mouthbrooding, guarding, or limited direct care	Variable, from many offspring to low fecundity in selected lineages	Ecology-dependent cases involving mate choice, nest defense, spatial learning, predator avoidance, and social behavior

Note. The table tracks the variables introduced above: lifespan and maturation, early vulnerability, parental investment, time to independence, simultaneous care capacity, and survival-domain relevance. It summarizes selected cases rather than class-level generalizations. The selected examples are supported by comparative work on human growth and cooperative breeding, elephant and cetacean cognition, corvid and parrot cognition, avian parental provisioning, reptile hatchling development and crocodylian communication, amphibian parental care, cichlid spatial learning, and chondrichthyan life history (Augustine et al., 2022; Bogin, 1999; Burkart et al., 2009; Connor et al., 1998; Crump, 1996; Gatto & Reina, 2022; Griesser et al., 2023; Hart et al., 2008; Hussey et al., 2010; Jordan et al., 2021; Lambert et al., 2019; Long & Fu, 2022; Ringler et al., 2023; Schulte et al., 2020; Topping & Valenzuela, 2021; Uomini et al., 2020; Vergne et al., 2009).

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