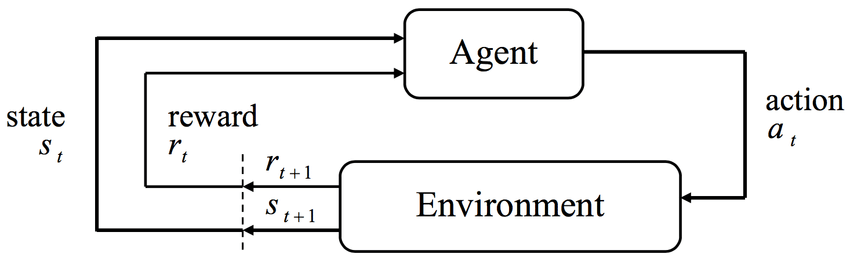
**Oscar Galrom | *Corvus* and Human Information Modeling | NSCI 4197**

**Introduction**

Organic life forms act as vessels for information to be imprinted and maintained, though with differing clarity as obfuscated through their neuroanatomy. Information is hard to store, as entropy tries to reduce it to static. (Maroney, 2009). The ability to model the world spatially and temporally is a complex neurological task requiring the perception and processing of information to be effectively organized. Figuratively, it is the ability of an animal to build an active model of information pertaining to experience, and then sequentially organize that information internally, discerning relevant information between past, present, and future contexts. The relevant information and the order in which it is processed work to combat information's natural degradation in a manner specific to the adaptations of the organism. The uniqueness of human experience stems from our significant neuroanatomical progression allowing us the extravagant means to quantify and model the information presented by reality. The *Corvus* genus of birds has neuroanatomical organization that has evolved comparable structures to humans that allow them to interact with the world with a striking degree of intent. They are capable of displaying incredible higher-order behaviors: theory of mind, meta-cognition, and delayed gratification (Güntürkün and Bugnyar., 2016). Both subjects are capable of the extremity required to be conscious - namely that our experiences of time and reality are similar enough that the system under which we organize time can be represented through a Markov Decision Process (MDP).



**Fig 1. Visualization of a Markov Decision Process (Akinbulire et al. 2017)**

An MDP represents a system in which an entity exists. As described by a set of states 's' where each state represents a possible configuration of the system, and a set of actions 'a' representing decisions or choices that they can make at each state (Smelser and Baltes, 2001). Actions have “weight” depending on preexisting logic set within the particular agent. The conditions of an MDP require an agent to discern reality through temporal order, namely the: past, present, and future. Previous “states” compose the bulk of past processing, fulfilled in *Corvus* and humans through their respective hippocampi. We experience previous states as memory. The simulation of potential future states, as well as the ability to interpret the ‘weight’ of the value of these potential states through reward mediation, is heavily influenced by the nidopallium and its correlate the pre-frontal cortex. These structures allow an entity to orient towards the future. The information is experienced in the organism's subjective present state. The organism interprets the system through a crossover of its past and future processing along with immediately available information. In *Corvus* species and humans, information crossover can be observed in the mesopallium and intratelencephalic neurons. In order to sustain an MDP, *Corvus* would be required to discern between information that is temporally relevant to the past, future, and most importantly present. It would require them to model both the environment and their own agentic self.

Increased proficiency in system modelling complicates the agent’s perception of its situation with supplemental information, thus increasing the pool of both states and actions. In the context of succeeding in an MDP, spatial-temporal proficiency defines the scope of information from which the organism can orient its conscious self. An agent that can incorporate information about the past, present, and future will be far more successful in navigating a complex MDP. In this way, information clarity is an advantage in natural selection, as it improves an animal’s chances of survival. The concept of the MDP is a machine learning principle. Viewing an organism through the lens of computational logic eases the complication of transcribing experience and allows for a model in which to represent the functional architecture of the neuroanatomy of information management.

**Anatomical and Functional Comparisons**

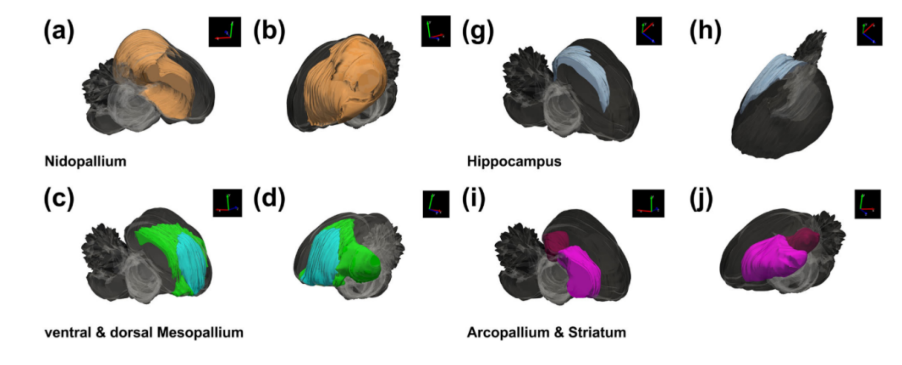
The *Corvus* and human hippocampi are generally considered homologous, though they have 300 million years of independent evolution between them. The regions developed to handle fundamentally similar tasks of memory formation, though the specific organization and functionality varies. The avian hippocampus can be arranged into three zones: dorsolateral (DL), dorsomedial (DM), and ventral (V) (Székely 1999). The DL hippocampus projects to the basal ganglia, limbic areas, lateral septum, and paraxial meso-diencephalic centers. Its vast effector range associates it with the subiculum of the human hippocampus, which connects the amygdala, hypothalamus, septum, and mammillary bodies, facilitating reciprocal stimulation of its regions. It also sends efferent signals to thalamic and other limbic areas (Fogwe et al., 2023). The avian V section mirrors Ammon’s horn through featuring commissural projections crossing opposite sides of the brain, and the DM section features intrinsic connectivity like the dentate gyrus. (Székely, 1999). Furthermore, both human and avian hippocampi have increased dendritic spine density, which correlates with excitatory transmission, and is indicative of a sensitive system (Uster and Bonhoeffer, 2001). Crows have a higher spine density than other birds (Srivastava et al., 2012), and spine formations on dendrites are a hallmark of excitatory synapses and spatial processing within the hippocampus. (Mahmmoud et al., 2015).

Functionally, in both humans and birds, the hippocampus is critical for spatial modeling (Srivastava et al., 2018). The human hippocampus makes use of spatially responsive cells to transfer spatial information and form a cognitive map of the physical environment (Herwig & Kahana, 2018). Known as place and grid cells, they fire in patterns according to the nearby environment as the organism spatially processes (Jacobs et al., 2010). Though not specific to the *Corvus* genus, the avian hippocampus also generally has spatially responsive cells. In pigeons, numerous spatial cells have been found including location cells, path cells, arena-off cells, and pattern cells (Sherry et al., 2017). The greater observed diversity of cells specialized for spatial discernment could indicate a difference in their interpretation of spatial reality.

There is an increase in hippocampal volume and neuron count amongst birds that frequently cache food, such as *Corvus* species. (Krebs, 1990). In humans, it is integral for transforming short-term memories and associations into long-term storage, influencing decision-making. Birds have a similar use-case to the hippocampus for spatial memory, particularly in food caching behaviors, where they geolocate previously stashed food deposits (Krebs, 1990). Significant hippocampal development and highly articulated memory behaviors indicate their ability to interpret and categorize their experience with the world. The similarity in structure for memory would imply that advanced birds are highly capable in processing and discerning in their own experience, potentially to the point of auto-noetic recall - the ability to re-experience past events. This ability is crucial for higher order functioning on the basis of carrying a non-degradable ego as a center of experience (Clayton et al., 2003). In both *Corvus* and humans, the hippocampus functionally serves the organisms to be able to interact with their environment with reference to past states.

Comparative studies across bird species reveal differences in dopaminergic pathways, similar to the diversity observed in mammals (von Eugen et al., 2020). Specifically, cognitive capability in birds is correlated with the diversity of myelinated dopaminergic fibers in the nidopallium caudolateralis (NCL), with carrion crows exhibiting a greater variety compared to pigeons and chickens. This complexity in myelination patterns within the dopaminergic system is analogous to the advanced dopaminergic regulation observed in primates’ prefrontal cortex (PFC), suggesting a convergent evolutionary development associated with cognitive abilities (von Eugen et al., 2020). In both birds and primates, these brain regions receive dopaminergic innervation from midbrain areas, integrate information from visual, auditory, and somatosensory regions, and have projections to motor and limbic systems (Diekamp et al., 2000). The dopamine system modulates PFC functions in humans, and a similar modulation is observed in the avian NCL. For example, when D1 receptor antagonists are introduced to the avian NCL, it results in decreased performance on visual discrimination tasks (Diekamp et al., 2000).

The nidopallium is a prominent feature in the telencephalon of intelligent birds, namely *Corvus*, and is generally one of the largest structures within it (Kersten et al., 2022). This region surrounds the avian striatum-arcopallium seated caudal to the mesopallium. Unlike mammals, birds lack clear brain region delineations, instead, these are inferred by gradients of markers like tyrosine hydroxylase (TH+) (von Eugen et al., 2020). The nidopallium's contact with the mesopallium is marked by the lamina mesopallialisventralis, and the NCL is distinguishable by increased TH+ fiber density, subdivided into medial, ventral, and dorsal regions based on this density (von Eugen et al., 2020). Functionally, neurons in the NCL perform roles similar to those of the human PFC, processing sensory and cognitive information, supporting working memory, and encoding time-based stimulus associations (Moll & Nieder., 2015). Neurons within both the NCL and PFC alter firing rates in response to task specifics, serving as processing centers for discernment (Rainer et al., 1998; Tang et al., 2022). Interestingly, crows' NCL does not seem to send feedback to the hippocampus regarding categorization, suggesting a one-way flow of qualia identification within the NCL (Ditz, 2018). Potentially impeding their ability to update personal understanding or interpretation of experience.



**Fig 1. 3d reconstruction of carrion crow neuroanatomy (Kersten et al. 2022)**

As centers of working memory the NCL and PFC have the unique ability to orient towards the future. Humans who experienced damage to the ventromedial prefrontal cortex had impairment in specifically future oriented processing (Ciaramelli et al., 2020) There is no analogue for assessing this affinity in *Corvus* species directly, but the NCL is implicated in coding stimulus value, and incorporates information about stimulus value and delay (Dykes et al., 2018) as so is similarly at the minimum functionally oriented towards potential states, fulfilling the MDP function of future processing and weight management along with the PFC.

The mesopallium in birds serves a transitional role in information processing, analogous to the intratelencephalic (IT) neurons in the mammalian neocortex, particularly because it shares transcription factors with neocortical layers 2, 3, 5, and 6 found in mammals (Briscoe et al., 2018) and both facilitate complex interconnection in the brain. IT neurons in mammals facilitate bidirectional communication between the neocortex and thalamus within cortico-thalamo-cortical (CTC) loops, integrating information across cortical areas and the striatum (Shepherd and Yamawaki, 2021), as well as higher-order thalamic nuclei and subcortical areas through connection with cortical layer 5 (Mease and Gonzalez, 2021). The fact that they minimally branch while connecting to such a vast array of regions signifies their importance for information transmission rather than processing as design is focused on connecting these distant brain regions (Mease and Gonzalez, 2021).

However, the mesopallium does not directly interact with the striatum due to the intervening nidopallium, which also separates it from the olfactory cortex. Instead, the mesopallium appears to have developed to more assist the nidopallium in processing information. The mesopallium contains regions that receive thalamic inputs and run reciprocal connections to the NCL and regions that reciprocally connect the NCL with other pallial regions (Atoji and Wild, 2011). The mesopallium also functions for pathway convergence of the output of two pathways stemming from the visual Wulst region, and the categorial informative tectofugal pathway. This architectural crossing is the *Corvus’s* distribution of information processing implying the MVL as the eminent center of qualia discernment (Niu et al., 2022).

The IT neurons fulfill the MDP role of the agent itself, interacting with the system at any particular moment. They are the physical embodiment of where all the information converges (Tonani et al., 2016), and the point from which a “present” can be discerned. IT neurons fire when encoding movement, during processing of information, making decisions, and when interpreting value of stimulus (Shinotsuka et al., 2023; Won Bae et al., 2021; Musall et al., 2023; Garcia et al., 2021). Fundamentally, they fire when an organism does something minimally consciously significant. Unlike mammals, where similar cell types are distributed across the neocortical area, avian neuroanatomy has evolved by grouping similar cells into nuclei resulting in the separation of the mesopallium into its own major structure of intercommunication (Briscoe et al. 2018). From a development standpoint, this can be considered a monolithic approach, loading multiple jobs and functions into a single entity leading to a snowball effect where the entity is overloaded with tasks. Under this view, the human method of organization is significantly more sophisticated, spreading out channels of communication and processing to avoid performance bottlenecks and scalability issues that arise from shuffling vast amounts of data across limited channels (Kalske et al., 2018). Nonetheless, the mesopallium functions for convergence of the output of two pathways stemming from the visual Wulst region, and the categorial informative tectofugal pathway, and so is still anatomically functional in weaving together varied information (Niu et al., 2022). In pigeons the mesopallium fires in response to visual discrimination (Anderson et al., 2020), and in parrots, auditory learning triggers firing (Eda-Fujiwara et al., 2012). Extrapolating, if *Corvus* would have an anatomical setback weakening their MDP agent relative to humans, it certainly appears to be their mesopallium.

**Evolutionary Significance**

If existing in a 3-D environment means being subjected to reality under the passage of time, then an organism with a higher dimensional understanding of time management would be at great advantage relative to its information blind competitors. "Self-control" as a model of behavior, stems from an agent spending energy reducing its own variance in accordance with a strategy. It is realizing that the self is also a factor in the environment; it is control of the subjective or objective self (Miller et al., 2019). The ability of self-control is seen in *Corvus* species through delaying food retrieval until necessary, delaying immediate satiation for the accordance of greater strategy for survival (Miller et al., 2019). A lack of "self-control" in humans is highly linked to issues such as behavioral problems, addiction, and other measures of life success (Miller et al., 2019). In humans and chimpanzees, general intelligence is also linked with self-control (Beran & Hopkins 2018).

Self-control is downstream of the scalar of agent strength. The more advanced, the better the modelling towards self, the better strategy revolves around optimizing the self, there-in lies the main difference in our neurology. Unlike most other animals, *Corvus* species have evolved to have impressive future and past modelling given their status as non-human, but the key difference that sets them back in the MDP is their inferior capability to model the present agent. The separation of the NCL from the striatum potentially harms the resolution of their weight discernment and general cognitive organization. For instance, the fact that birds are generally worse at discerning quality over quantity (Miller et al., 2018). Additionally, their lack of a truly integrated anatomical substrate for modelling of the present, like in IT neurons, may limit their abilities in developing a sense of self or particularly active consciousness.

The application of machine learning principles to understand these cognitive processes extricates the relationship between neuroanatomy, behavior, and the evolutionary adaptation of problem solving in both humans and crows. The neuroanatomy of *Corvus* species allows them to interact with the world from the position of an MDP complete entity. Allowing them to interact with the environment at a meta level - exempt from the immediate gain and loss, where the goal isn’t an immediate response or urge, but rather the ability to make the absolute best decision available given a context. In the same way that it is foundational to reaching the “optimal” for an algorithm, it is the fundamental strategy of cognitive evolution and the “reason” for the development of a consciously controlled, independently organized, neurologically capable organism. The trade-off in resources, energy, and time it takes to reach this point is offset by the amazing capacity to learn in the moment. This cognitive ability is crucial for predicting future outcomes based on past experiences while adapting to the current situation. With a static agent, dyssynchronous environments spell doom, the animal is condemned to be confined to the loop created by the interaction of the environment and its singular strategy (Barto et al., 1989). The ability to learn and adapt within a single lifespan, bypassing the slower process of genetic evolution, is a significant evolutionary advantage for both species. Evolution now takes place within the setting of an individual organism's constantly evolving interface with reality.

**Conclusion**

The comparative analysis of human and *Corvus* neuroanatomy reveals similarities in their cognitive processing abilities, particularly in parallel processing of past, present, future, and the ability to incorporate these dynamically.

The parallel processing afforded through the hippocampus' memory, NCL's future simulation, and the mesopallium’s facilitation of present processing collectively gives the *Corvus* genus a holistic anatomical toolset to manipulate and interpret multiple temporal realities at once. This parallel processing allows for advanced interaction with their environments, evident in their ability to adapt and manipulate situations to their advantage. This behavioral and anatomical complexity mirrors human problem-solving skills and brain architecture, where we interact with our environment, making calculated decisions based on our observations and experiences, able to summon forth actions against the environment and update the consequences in real time while our brain stores and shifts the ideas as needed.

They exhibit novel problem-solving ability due to their architecture having sufficiently powerful temporal organization to sustain an interpretation of the world as a sustained Markov decision process. *Corvus* and Humans are both anatomically sufficient to afford all these necessities in unison- namely the sustained reciprocal processing of agent and environment, modelling and consequences, organized in temporal context. The comparison reveals a design pattern to intelligence - the architecture of intelligent macro-organisms functionally mimics the logic in machine learning. Temporal clarity of the present moment allows an organism personal agency. The information we discern as relevant, which constitutes our model of reality, is limited by the context of the Markov decision process- the world, in which we have come to evolve.

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