

Priors in Animal and Artificial Intelligence: Where does learning begin?

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Abstract

A major goal for the next generation of Artificial Intelligence is to build machines able to reason and cope with novel tasks, environments and situations approaching the abilities of animals. Evidence from precocial species suggests that driving learning through suitable priors can help to successfully face this challenge.

Minds from scratch

Empiricists and nativists have clashed for centuries in understanding the architecture of the mind: the former as a *tabula rasa*, and the latter as a system designed prior to experience[1]. Today, the related burning question is how to *build* successful minds from scratch. The next generation of artificial minds is expected to far surpass the recent success of machine learning in specific tasks and formally structured domains, from defeating human Go masters to transcribing speech and recognizing objects of particular categories. This improvement will come through accomplishments in strong artificial intelligence that include reasoning, generalization to new tasks, and advanced language processing. “Common sense”, in the sense of flexibly reasoning appropriate responses, remains an unachieved goal for current AI. The question, summarized in the debate between the nativist Gary Marcus and the pioneer of Machine Learning Yann LeCun [2-4] is the following: Shall we search for a unitary general learning principle able to flexibly adapt to all conditions, including novel ones, or structure artificial minds with driving assumptions, or *priors*, that orient learning and improve acquisition speed by imposing limiting biases? Examining the well-studied example of a newly hatched precocial bird neatly shows how research on animal cognition can nourish design principles for Artificial Intelligences.

Predisposed cognition

Soon after birth, a chick orients itself towards the mother hen, recognizes its social partners even when partly occluded, emits pleasure and distress calls in different contexts, and performs simple

but effective arithmetic calculations without explicit training [5]. Dealing with animals (human and otherwise) for a large extent of our time, we realize how varied and flexible their behaviour is. But precocial species, namely those with a mature motor and sensory system at birth, tell us something more. Newly-hatched domestic chicks, for instance, are pre-disposed to orient towards objects that exhibit features associated with animate objects, such as biological motion, changes in speed, and face-like configurations [Figure 1a]. It has been hypothesized that this set of unlearned priors helps chicks orienting towards the mother hen and the chick's siblings. Mere exposure triggers a rapid and robust learning process called filial imprinting [Figure 1b-c]. Imprinted birds are able to recognize complex, multimodal objects such as conspecifics, and can imprint on other animals, or indeed any arbitrary stimuli, within certain constraints, to which they have been exposed – most famously Konrad Lorenz, who studied imprinting in ducks and geese. After imprinting, hatchlings not only recognise their mother from different and previously unexperienced points of view (including translational and rotational invariance, e.g. [6]), they also recognize their siblings as they change appearance during development. We recently discovered that the imprinting mechanism allows a remarkable degree of generalization to novel objects that have in common with the imprinting object only abstract features (such as the presence of AA (“same”) or AB (“different”) patterns) and that this is true in different species [7, 8]. While these abilities had previously been shown in extensively trained animals, these results make clear that such generalizations are a spontaneous competence available at the onset of life.

How can young birds orient towards the “right” stimuli in the absence of any previous experience, and master complex generalization tasks without supervision and reinforcement? Differently from machine learning systems, chicks do not require explicit reinforcement, supervised learning or thousands/millions of examples to feed learning. They are equipped with dedicated orienting mechanisms and learning mechanisms that work as adaptive priors and architectural structures. These priors imply some assumptions about the external world that guide learning but can, and must, allow errors, as was the case of goslings imprinted on Konrad Lorenz. Research has

shown that early preferences of chicks are not strictly species-specific but apply equally to hen face-like or polecat face-like features [9], or to the biological-motion appearance of either a hen or a cat [10]. This is due to the fact that the orienting mechanisms cannot be too specific on the individual features of the mother hen, which are to some extent unpredictable to the genetic repertoire. A level of non-specificity is functional in avoiding excessive false negatives in the form of failed recognition caused by variability between adults within a species, and by changes in the appearance of even a single individual. Optimal learning mechanisms must trade being open enough to allow a wide range of stimuli to be stored as imprinted memories against being sufficiently specific to avoid imprinting on inappropriate objects that in natural environments coexist with the chick's mother and siblings. In nature, this trade-off between error rates is tuned only by natural selection, but it can be emulated in artificial systems, where other paths to solve the problem exist. Functional assumptions paired with plastic learning, hence, enable the hatchling to be fast and effective in learning, so that a limited number of examples is sufficient to make ecologically valid generalizations in most biologically relevant cases. Moreover, preference for a slight *deviation* from the memory of the imprinting object allows the chick better to sample the properties of the desirable target, just as for adult birds deviation from the object of sexual imprinting (a similar process that occurs later in life) avoids inbreeding with immediate kin while promoting mating with a member of the same species (optimal outbreeding [11]), showing an effective modulation of learning by a priori preferences [Figure 1c].

Plasticity and priors

Learning from biological examples implies that high plasticity coupled with prior assumptions is not sufficient for strong Artificial Intelligence: a temporal dimension, with pre-designed critical or sensitive periods, is a fundamental part of the solution. When looking at biological systems, in fact, there is evidence that both early predispositions and high plasticity are transient phenomena, that terminate either with some maturational processes or when the necessary information (e.g. the

identity of the mother hen in the case of chicks) has been acquired. Critical and sensitive periods have been observed in avian and mammalian species in several domains and functions, including orientation to face-like stimuli [12], ocular dominance [13] and language acquisition [1]. The peak of plasticity in the wiring of the visual system observed in specific time windows points to the costs associated with plasticity, which cannot be indefinitely sustained. This is one reason why, after a certain age, learning new languages and solving amblyopia is so difficult, and why early experience is in many cases important for subsequent stages of life. Recent evidence in rodents suggests that the spontaneous plasticity of the nervous system is actively reduced by molecular “brakes” that promote circuit stabilization in mature brain function [13]. Declining plasticity is also ecologically adaptive; the realities of the perinatal period mean that the most relevant potential substrate for imprinting is the mother bird. If plasticity endured beyond the critical period, numerous erroneous substrates – any moving animals – would likewise trigger imprinting. The constraint in time also serves to constrain candidate substrates appropriately. A similar effect may be observed in bird song, wherein young altricial songbirds learn their mating songs whilst still confined to the nest, which prevents incorporation of irrelevant sounds experienced after fledging.

Considering the balance between priors, plasticity, and the observed brakes to plasticity, we argue that evidence from animal research suggests that (a) AI systems could benefit from being equipped with a rich but constrained set of priors and specialized learning mechanisms similar to those seen in precocial animal species, rather than being endowed only with general purpose, unifying mechanisms, (b) plasticity without priors and critical periods of expression for these priors might be associated with costs that prevent effective learning and stable cognitive functions. The ability to shift between priors and thus direct plasticity may speed our way to strong AI, while pursuing less structured AI may help to identify new and potentially unexpected useful priors.

Figure 1. Priors orient fast and efficient learning in precocial hatchlings. **a.** Without experience, some stimuli are more attractive to hatchlings: they preferentially orient towards face-like stimuli, biological motion, and objects of variable speed [5, 9, 10]. In the wild, these features are associated with the mother and siblings [14]. **b.** This initial orienting response directs fast, unreinforced learning (imprinting) towards “appropriate” stimuli. **c.** What is learned during the imprinting phase, with some degree of generalization (e.g. [7, 8]), determines subsequent choices. In the short term, hatchlings affiliate with the mother hen (filial imprinting), which is crucial for survival; in the long-term, mating choices will be directed towards individuals that are different from close kin (avoiding inbreeding) but belong to the same species (see optimal outbreeding in [11]).

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