

Analysis of decision making in an insect's gap-crossing behavior using Markov models

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Success or failure of particular behavioral tasks often depends on the selection of an appropriate action based upon the interpretation and accumulation of sensory information. However, it remains often unclear how sensory information is used to decide upon the appropriate action. We studied grasshoppers, which had to cross gaps of varying widths (>200 trials in 4 animals and ~5 gap widths; Niven et al., in preparation). These insects choose to either reach or jump across gaps or refuse to cross at all. Insects displayed a stream of dozens of behaviors (e.g. parallax movements, probing the gap with antennae, grooming) executed before the final action (reach, jump, refusal) occurred. These pre-action behaviors are interwoven with each other and are highly variable from trial to trial. This has previously made it difficult to understand what behavior (and thus what sensory information) contributed to the decision making process, which is symptomatic for behavioral studies of decision making in freely behaving animals.

We take a novel, computational approach to overcome this problem and analyze the behavior leading to the decision. We identified the initiation and termination of each behavior, such as beginning to groom a feet or finishing to probe the gap with antennae, as a discrete observable state ("emission states"). Thus, we converted the observed behavioral stream (video data) into a symbolic sequence of behavioral states (we distinguished 25 states at the beginning).

In a first step, we calculated the empirical transition probabilities between the behavioral states and reconstructed a Markov chain transition matrix. Unconditional state transitions (transition probability ~1) in the matrix suggested that we initially distinguished too many states, and so fused these state pairs together. The Markov matrix allowed us to visualize the behavioral sequence in terms of a directed, weighted graph of observed behaviors and allowed us to compare the overall behavior (irrespective of final action), to those leading to one of the three actions by using only the sequences with the respective outcome to reconstruct the transition probability matrix.

Finally, using decision trees we predicted the final action of a behavioral sequence. Prediction success rate overall trials was high (86%) after observing only the first 14 behavioral states in the sequence (sequences were as long as over 100 state transitions) – thus the decision was taken early on and much of the subsequent sensory behavior must have been only used to fine tune the action. We propose that this behavioral sequence approach is directly amenable to analysis using traditional bioinformatics techniques; for example Hidden Markov Models to estimate how sensory behavior affects internal states representing the build up towards an action decision.

Acknowledgments: We thank S.B. Laughlin for discussions.