Learning the Locomotion Behaviour of Lizards Transfers Across Environments

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Transfer Learning and LDA

Transfer Learning

Transfer Learning (TL) is at the core of machine intelligence and concerns how algorithms trained to perform a task can perform well on a different task. TL is motivated by the question of understanding how animals transfer and acquire knowledge much more quickly than machines. In our case, we concentrated on what is called zero-shot learning, namely the case in which the environment in the test phase was fully unseen during training.

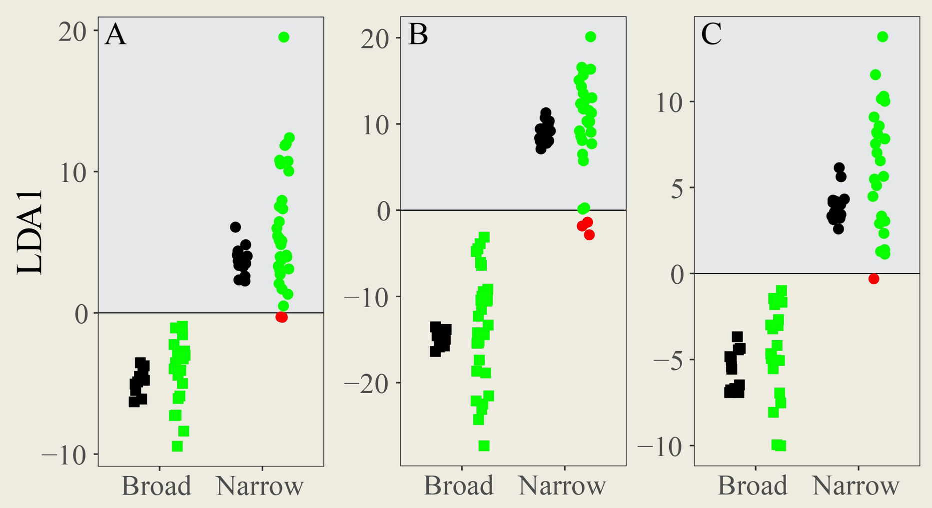
Linear Discriminant Analysis

Linear Discriminant Analysis (LDA) uses Bayes' Theorem to assign a label to a specific set of variates, through linear combinations of the features that serve as decision boundaries. LDA assumes that each class distribution is multivariate normal and that the variance-covariance matrix of the features is class- independent (similar to MANOVAs). We trained LDA on one environment and tested it on different environments. For example, we trained the model on an incline of 0 deg and tested it on 45 deg and 90 deg on the task of classifying each observation to the corresponding perch diameter (broad vs narrow).

Abstract

Successful locomotion is essential for the survival of most animals and crucial for arboreal species. In this work, we analyze the locomotor behaviour of a species of lizard, *Anolis carolinensis*, from the perspective of transfer learning. By analyzing the limb movements of 4 individuals on 6 different surfaces (3 inclinations × 2 perch diameters), we show that the strategies employed to improve stability during locomotion on narrow perches can be transferred across environments with different inclines. This transfer of behaviour is analogous to phenotypic plasticity, which likely plays a key role in the rapid adaptive evolution characteristic of *Anolis* lizards. This novel result emphasizes the valuable contribution that modern machine learning perspectives can give to the study of comparative biomechanics.

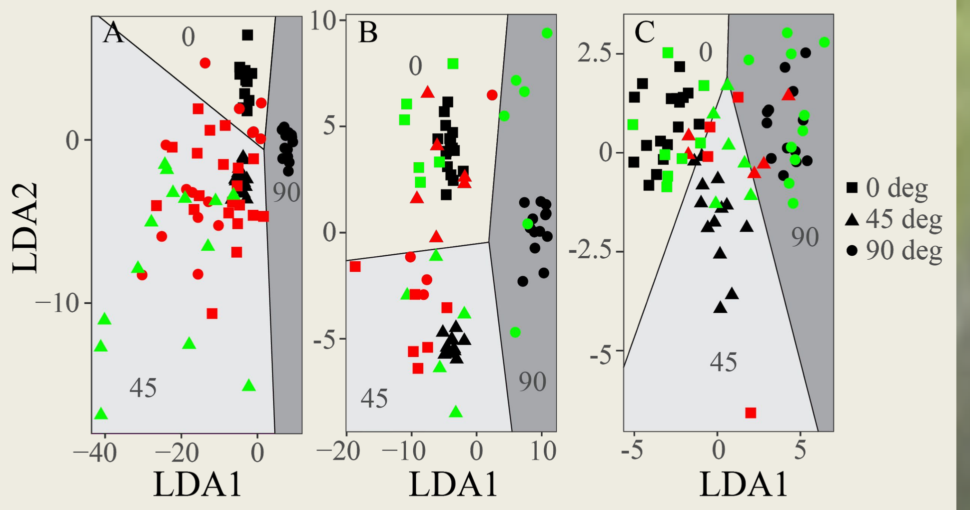
TL is Substrate & Limb/Input Specific



- Successful TL (prediction accuracy > 0.80) was achieved with LDA models trained to distinguish between perch diameters given a single incline, and tested on the remaining two inclines.
- LDAs failed to distinguish inclines when tested on unseen perch diameters.
- Angular velocities were not incorporated into the best models for the individual limbs, though the combination of angular and angular velocity data produced the best performing model when both limbs were combined.

Top: Plots of LDA scores for training (black) and test (red) sets, separated by perch diameter. Plots shown are for the best models: A) trained on 90 deg with the forelimb angular variables (prediction accuracy= 0.91), B) trained on 0 deg with the hind limb angular variables (accuracy=0.91), C) trained on 0 deg with the complete dataset (accuracy=0.94).

Right: Plots of the 2 LDA scores for models trained to distinguish between inclines given a single perch diameter. Plots shown are for the following models: A) trained on the broad perch diameter with the hind limb angular variables (accuracy= 0.29), B) trained on the narrow perch diameter with the forelimb angular variables (accuracy=0.52, C) trained on the narrow perch diameter with the forelimb angular velocity dataset (accuracy=0.73). Black symbols represent strides belonging to the training dataset, green symbols represent strides belonging to the test dataset that we correctly classified, and red symbols represent strides belonging to the test dataset that were incorrectly classified.



Features that Transfer

Correlations of our input variables against the LDA hyperplanes revealed that the key features used in the best models to distinguish between perch diameters were ones associated with stability [1]. For example:

- crouched posture on narrow perches to reduce shoulder/hip height via greater limb flexion
- wrapping limbs around the sides of narrow perches via greater humerus/femur depression
- greater proportion of stride in contact with the narrow perch

In models including data from both limbs, >75% of the variables that correlated strongly (>0.7) belonged to the hind limb.

Evolutionary Implications

The variables that transfer across inclinations are integral to known strategies for improving stability on narrow substrates. Further, the majority of the variables contributing to our best performing models relate to the hind limb, which has been suggested to take on a more stabilizing role on narrow surfaces in *A. carolinensis* [1].

The principles underlying TL and the results of our analysis connect to the rapid adaptive radiation, likely facilitated by plasticity [2,3,5], that has made *Anolis* lizards a model system in biology. If pre-existing behaviours that facilitate locomotion on narrow surfaces are useful on multiple types of inclines, then the locomotor plasticity manifested through the transfer of the traits that facilitate locomotion on those surfaces should give an adaptive advantage by improving stability of motion and indeed, survival in those new complex environments. Of particular interest will be to test how our models generalize to different species/ecomorphs of *Anolis*, as well as to other genera of lizards as this could provide insight into the plasticity and adaptability of reptiles.

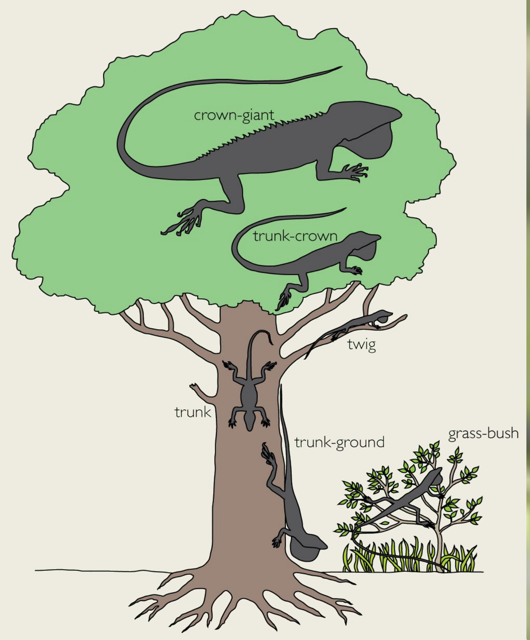


Figure adapted from [4]

Conclusions

In this work, we have leveraged machine learning methods, specifically TL, to gain insights into the functional demands on locomotion imposed by the arboreal environment. Our results demonstrate that it is possible to learn to identify the diameter of the surface that our anoles are running on, regardless of the inclination of the surface and that this TL capability is limb-specific. Further, we show that the variables integral to this TL process are the ones that relate to locomotor stability. Locomotor stability is a crucial factor for the survival of arboreal species, and the ability of *A. carolinensis* to adapt locomotor behaviour might reflect the evolutionary advantage of having limbs functioning in complex habitats and being able to transfer skills across heterogeneous environments for the sake of survival.

References

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