Locomotion energy landscapes to understand animal locomotor transitions in 3-D multi-component terrains

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Many natural terrains, such as forest floor, desert bushes, and mountain boulders, are comprised of multiple three-dimensional terrain components. Small animals often display rich locomotor transitions when moving through such 3-D multi-component terrain. For example, to traverse grass-like beam obstacles, cockroaches can push across, climb over, roll their body to the side to maneuver through gaps, and even transition between these modes, forming complex locomotor transition pathways. When flipped over, they can also use their wings to rapidly push against the ground to dynamically self-right. During such dynamic locomotor transitions, it is likely that animals' mechanical interaction with the terrain plays an important role in determining locomotor transitions. However, despite much progress in understanding in the mechanics of single-mode locomotion on simpler 2-D surfaces and of how animals use sensory information of the geometry of the environment to initiate locomotor transitions in 3-D terrains, we still know little about animal's locomotor transitions in 3-D environments. Here, we present recent progress in our lab integrating animal and robophysical experiments to develop the new framework of locomotion energy landscapes to understand the mechanics of locomotor transitions in 3-D multi-component terrains. For both obstacle traversal and self-righting, we discovered that locomotor transitions can be understood as the body-terrain interaction system evolving on a potential energy landscape. In addition, the intermittent leg-ground contact or leg flailing provide kinetic energy fluctuations (analogous to "thermal fluctuations") which help the system explore the landscape to find transition pathways that overcome lower potential energy barriers. Analogous to free energy landscapes that have allowed understanding and prediction of protein-folding pathways, we envision that the novel framework of locomotion energy landscapes will help understand and predict locomotor transitions in a diversity of 3-D multi-component terrains.