BOUNCING, SPLASHING, STEPPING AND CLIMBING: PHYSICS, BIOLOGY, AND ENGINEERING OF COMPLEX INTERACTIONS

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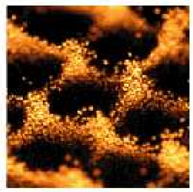

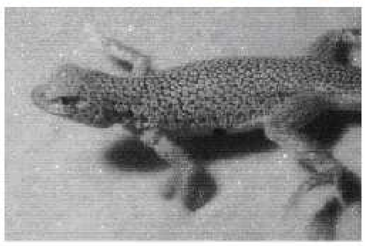

Seemingly diverse phenomena like the impact of golf balls in sand traps, robots climbing loose bark, and lizards scurrying on desert dunes all involve a complex interaction of matter (physical and biological) with materials (like sand, mud, leaves, bark) that can display properties of solids and fluids in response to stress. This talk discusses examples from physics and biology that display these features. Thin layers of oscillated grains form patterns like squares, stripes and hexagons above a critical acceleration. Fluctuations in these patterns are described by the same continuum equations that describe fluctuations in convecting fluids; however the noise strength in the granular system is an order of magnitude larger than the most sensitive convection experiments to date. The square patterns display phenomena (including normal modes and melting) that are surprisingly similar to a crystal lattice. Collections of hard spheres forced by a flow of fluid (a fluidized bed) display features associated with glasses including rate dependence, growing timescales, and dynamical heterogeneity; the grains solidify by undergoing a glass transition. Complex interaction with substrates is the rule in nature; we use controlled laboratory experiments to investigate the mechanisms that organisms use to negotiate complex terrestrial environments. A fluidized bed is used to vary the strength of sand to study the performance of rapidly running sand-dwelling lizards and crabs. While crabs suffer a decrease in speed as the material weakens, surprisingly the lizards maintain high speed, even when the material is fully fluidized. Spiders and cockroaches maintain high speed across substrates with low foothold probability, like debris. Laboratory experiments on wire mesh (with 90% of material removed) reveal that they achieve such performance by distributing contact along limbs. Spine and hair structures on the limbs increase effective contact; the addition of prosthetic structures to the limbs of ghost crabs enhances performance on wire mesh. Foot adhesion to a substrate is critical during rapid climbing. Despite differences in adhesion mechanism and body morphology, cockroaches and geckos display similar dynamics during rapid (>5 body-lengths/sec) climbs. Mechanical models of climbing cockroaches capture the forces produced during vertical locomotion; simple changes to the motor pattern capture the forces produced in level locomotion. Through collaboration with a multidisciplinary group of engineers and biologists, these studies have influenced the design of RiSE, a robot capable of negotiating complex vertical and level terrain.