105.4 CLARK, CJ; UC Berkeley; *cclark@berkeley.edu*
Hummingbird courtship displays reveal limits to avian flight performance
Courtship displays are a common feature of breeding behavior. While the information these displays convey between suitors and potential mate remains debated, the remarkable behaviors that result can be used to study the limits of locomotor performance. I provide an example of this paradigm based on the kinematics of the display dive of the Annas Hummingbird. I filmed diving male Annas Hummingbirds with a combination of high-speed and conventional video cameras. The dive consisted of five distinct stages based on stereotypical wing and tail kinematics. After powering the initial stage of their dive with flapping wings, males fold their wings and bound, at which point they reach an average maximum velocity of 27.3 m/s (385 body lengths /s). This suggests they have a body drag coefficient of less than 0.3. They then spread their wings to pull up, reaching centripetal accelerations of nearly 9 G, and concomitant torques. This acceleration appears to be higher than those attained by diving raptors, and may be limited by the torque the shoulder can withstand.

98.11 CLAVERIE, Thomas*; PATEK, Sheila N.; Univ. of California, Berkeley; *tclaverie@berkeley.edu*
Force transmission versus speed amplification in a four bar linkage mechanism: counterintuitive results in the mantis shrimps strike
Four bar linkages are simple mechanical systems that can amplify or reduce rotation. Most biological four bar systems have been studied in the context of rotational amplification with relatively little analysis of force transmission. Mantis shrimp (Stomatopoda, Crustacea) use a four bar linkage system to power their fast predatory appendages. Some species capture elusive prey (spearers) using highly elongate appendages while others break shelled-prey (smashers) with short, massive appendages. We examined the variation in force transmission versus speed amplification in this linkage system across 14 stomatopod species. We measured the four bar linkage configuration, geometrically simulated the contraction and release of the linkage system, and calculated the resulting force and speed transmission. Most species exhibited relatively small force transmission (up to 0.4 mechanical advantage (MA)) and a large rotational amplification (typically 10-fold). The transmission of speed and force during a strike was not synchronized and followed this sequence: maximal speed, maximal force, minimal speed, minimal force and then maximal speed again. Surprisingly, the four bar model did not predict greater MA in smashers than in spearers, but species having a large MA had the lowest speed amplification. Also, species with longer predatory appendages (spearers) exhibited a maximum force transmission earlier in the strike cycle. Thus, the spatial and temporal dynamics of the four bar linkage system may be as important, or more important, than the average behavior predicted by link length ratios. These results highlight the surprising dynamics between simple mechanical systems and evolutionary variation.

74.5 CLIFFORD, Andrew/B; Brown University; *andrew_clifford@brown.edu*
The Evolution of Unguligrady and Forefoot Mechanics in Even-Toed Ungulates
Most extant even-toed ungulates adopt an unguligrade foot posture whereby body weight is supported through hoofed distal phalanges. This foot posture is derived from a petadactyl and digitigrade foot comparable to extant canids. The digitigrade-unguligrade transition is marked by variable digit loss, except for the emphasis of digits III and IV, and ligamentous replacement of interosseus muscles. In order to test the hypothesis that interosseus ligaments (IL) resist torque at the metacarpophalangeal (MCP) joint during stance, I compared data collected *in vivo* with data collected through *in vitro* preparations. Extant suids possess characteristics similar taxa that first adopt an unguligrade stance, so minipigs were run in a trackway connected to a forceplate and filmed using bi-planar cinefluoroscopy to determine the total joint torque-by-angle relationship at the MCP joint during stance. Reduced preparations of the IL permitted calculation of the torque-by-angle relationship of the IL alone. These two relationships yield the proportion of joint torque taken up by a novel ligamentous structure present only in unguligrade species. Results indicate that IL in forefeet perform a majority of work during stance at the MCP and that this proportion increases with MCP extension. IL increase step length by permitting a functionally longer foot that does not require more metabolic energy through muscle contraction to maintain an elevated stance. Unguligrady may have first evolved to permit longer leg length without incurring additional metabolic cost, since longer legs generally permit cheaper locomotion. The extremely modified and highly cursorial limbs of most extant even-toed ungulates may be an exaptation of a limb originally modified to reduce the cost of locomotion.

11.5 CLOUSE, Ronald M.*; GIRIBET, Gonzalo; Harvard University, Cambridge, MA; *clouse@fas.harvard.edu*
Ancient signals of South East Asia's history found in mite harvestmen sequence and morphological data
Phylogenetic hypotheses of the cyphophthalmid family Stylocellidae (Arachnida: Opiliones), a type of harvestman, are used to test geologic reconstructions of South East Asia. Phylogenies based on molecular and morphological data recover close relationships among inhabitants of most major landmasses and place derived groups on more recently formed areas. Molecular data consisted of approximately 6 kb from two mitochondrial and four nuclear markers, and they were analyzed with the program POY. Morphological data consisted of 60 scaled measurements and were analyzed using the program TNT. The ancestral home of the family is apparently in the Central Thai-Malay Peninsula, which is also the ancestral terrane that rifted from Gondwana 255 million years ago. Sulawesi appears to have been populated by descendants of an ancestor on West Sulawesi, in concordance with geologic reconstructions of the island, and Borneo is almost exclusively populated by descendants of a single ancestor. Sumatra and to a lesser extent Java, which have had complicated histories of exposure above sea level and connection to the Thai-Malay Peninsula, appear to house multiple lineages. Species in North East India and China are closely related to each other, and, remarkably, to certain Thai species, a relationship that agrees with novel geologic hypotheses for the history of the Indian subcontinent.