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Title: 55-9: Utilising Geometric Morphometrics to identify snake and varanid fossils to answer macroecological Utilising Geometric Morphometrics to identify snake and varanid fossils to answer macroecological Utilising Geometric Morphometrics to identify snake and varanid fossils to answer macroecological questions

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The large-scale biodiversity and macroecological patterns we observe today are an outcome of a long and dynamic evolutionary history. Synthesis and integration of fossil data is critical for resolving the temporal dynamics of ecological communities, which will then allow an understanding of processes driving current patterns and predicting into the future. I aim to address some of these questions by looking at snake and varanid fossils from five fossil sites in different latitudunal gradients across Australia (Chillagoe Caves, QLD, Mount Etna, QLD, Cathederal Cave, NSW, Lower Glenelg Caves, VIC and Naracoorte Caves, SA) By using a geometric morphometric (GM) approach I hope to identify distinctive osteological characters in extant species and compare them with the most commonly retrieved element for varanids (the maxillae & dentaries) and snakes (vertebrae). Many sites have relegated snake vertebraes as unidentifiable down to a species or genus level due to the extremely homogenous shape of the vertebrae, however; utilising a GM approach has the potential to provide taxonomic resolution and allow us to identify these species to as far down the tree as possible, allowing further insights into species distributions and occurences, as well as answering macroecological questions and assisting in climate modelling. Past research has had promising results and I expect to find distinct characters hopefully in different genera, if not species, in these fossils which will in turn inform us on the biodiversity of each biome.

Title: Life and movement: The unbreakable bond

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Movement and life have been considered as intricately entwined from the dawn of philosophical thought in the Western world. In the context of scientific approaches, movement has frequently been addressed in relation to all organizational levels of living beings, from molecules to ecosystems. In the zygote embryonic cells migrate to realise their function; foetal movement is

necessary for healthy joints; swarms migrate to reach an appropriate place on earth; a hand moves to reach an object, and movement disorders generate profound disabilities and handicapped bodies or systems. As distinct as these themes seem to be, all of them are related to movement, and highlight its deep engagement in and importance for all aspects of the activities and health of living beings. With this presentation I offer ideas and studies dealing with movement in a biological context. My main goal is to present the notion of movement from a scientific perspective, turning it into a subject of interdisciplinary enquiry. Increased reciprocal knowledge between disciplines and perspectives will contribute to understanding movement as one of the strongest and most subtle links between life, health, and well-being.

Title: 16-1: Lessons from outside of the laboratory: naturally occurring TBI

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Traumatic brain injury (TBI) is one of the leading causes of death in the world. Little is known about how TBI develops into neurodegenerative disease, as most diagnoses can only be performed postmortem. Rodents are the main models for TBI, but have failed to provide any viable clinical therapies, likely due to the differences in size and anatomy between human and rodent brains. Outside of the laboratory, many animals display extreme behaviors that likely result in TBI and are increasingly studied for insight into TBI reduction. Bighorn sheep headbutting and woodpeckers drumming are a few popularized examples, and their biology has been lauded as a solution to improve helmet design. However, until recently, their neurobiology has rarely been the focus of scientific studies. Muskoxen and bighorn sheep were recently found to likely suffer from TBI. This serves as an indication that these animals are not the idealized solutions the public believes they are. However, their repetitive headbutting behavior makes bovids, and potentially other species, compelling comparative models to study the development of TBI into neurodegenerative disease. In a continuation of this work, my group is following experimental goats by periodically analyzing brain scans and biomarkers for indicators of TBI-related pathology in relation to their headbutting frequency. In doing so, we hope to shed light on the question of how TBI can develop into neurodegenerative disease.

Title: 12-6: Comparing stiffness and density of the skull and mandible across whales, dolphins, and even-toed hoofed mammals

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Reentering aquatic habitats involved drastic evolutionary changes in the physiology and morphology of whales and dolphins (Cetacea) compared to their terrestrial relatives (Artiodactyla). Properties of the skull and mandible, including density and material stiffness, are critically important for understanding mechanical loads associated with the evolution of feeding and sound reception in cetaceans. However, the extent of variation in the material properties of bone within and between vertebrate taxa is unclear. To evaluate bone material properties across cetaceans and their close terrestrial relatives, we sampled density and stiffness at five locations across the skull and mandible. Bone mineral density was tested using microCT and stiffness measurements on embedded and polished bones using nanoindentation. Nanoindentation was performed in both air and liquid (reflecting the naturally hydrated state of bone in vivo) to test for possible stiffness differences between different methodologies. Stiffness values obtained were consistent with previously measured values from mammalian bone. Within artiodactyls, stiffness differed across skull locations with the proximal mandible showing slightly higher stiffness values than the nasal, most likely reflecting functional differences between these elements. These data contribute to a wider understanding of the evolution of bone material properties within and between vertebrate taxa and, specifically, how this variation might contribute to functional specialization for different habitats and life habits within Cetartiodactyla.
Funding from Clemson Alumni Graduate Fellowship and Biological Sciences Graduate Professional Development GIAR.

Title: P4-15: Australian herpetological biodiversity under the spotlight of CT scanning using paleontological collections from the Quaternary period

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The forests of eastern Australia are a major biodiversity hotpot. The reptile and frog species of this biome are unique, with far higher levels of endemism than other vertebrates. Yet we still have limited understanding of past ecological and community dynamics that lead to current species composition. Australian paleontological museum collections are incredibly vast and that is where our research begins. Using a high-throughput CT scanning approach to scan dozens of fossils at the same time, we are undertaking a quantitative morphological approach to identification of Quaternary reptile communities. With these data, we test large-scale macroecological questions of evolutionary morphology of community structure through time and community change associated with climate shifts in this globally important fauna. This is the first comprehensive assessment of how the frog and reptile communities of eastern Australia have changed over the last 500,000 years along a 3000km latitudinal gradient. Our study provides a non-destructive high through-put approach to using existing museum collections to examine large-scale macroecological questions.

Title: 13-2: The 'indianaBones' R package and a novel protocol to study whole trabecular network: preliminary results from primates

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Since the advent of micro-computed tomography (μCT), a plethora of works has revealed how disparate factors, e.g. hormones, diet, phylogeny, allometry, biomechanical loading, are responsible of vertebrate trabecular bone architecture (TA). Most of these investigations focused on regular-shaped volumes of interest (VOI) extracted from whole TA networks. Although it has allowed straightforward workflows of TA quantification, this practice involves inherent biases related to VOI position, shape and size. This issue may be overcome through reproducible workflows of whole TA isolation and analysis. We present a protocol involving an R-based ('indianaBones' package) semi-automatic isolation of whole TA and characterization through BoneJ parameters (FIJI environment) and/or novel topological indices. We propose the first workflow of whole TA isolation/quantification largely based on non-proprietary code (fully open-access in the next future). We tested it studying a skeletal element, i.e. the fibula, never analyzed before due to challenging VOI extraction, and searching intra-generic (within *Saguinus*, Platyrrhini) locomotion-related TA differences, non-accessible with local VOI information. We aimed to identify i) drivers of primate distal fibula TA and ii) effects of subtle locomotor differences on *Saguinus*' humeral TA. Primate distal fibula TA arose as strongly related to phylogeny and/or body mass, and weakly driven by locomotion. Few humeral TA traits possibly reflect fine-grained behavioural differences among *Saguinus* species. Overall, these results highlight the analytical power of studying whole TA.

Title: 46-2: New insights on cetacean locomotion: a quadrupedal species from the middle Eocene of Peru as a transition toward a fully aquatic lifestyle

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Lifestyle transitions are major evolutionary processes that require extreme morphological modifications. One particularly conspicuous example is the secondary adaptation of whales to an aquatic lifestyle. Their early fossil record documents species that are crucial to understand this major evolutionary transition from the terrestrial to the aquatic environment: the archaeocetes. Members of the earliest known family, the Pakicetidae (early Eocene), were mostly terrestrial with some adaptations to the water. During the middle Eocene, Ambulocetidae, Remingtonocetidae and "Protocetidae", display major limb modifications. The still quadrupedal protocetids evolve a progressive water adaptation with the transition from foot-powered to tail-powered swimming. They represent a key stage of cetacean evolution during which the swimming style of modern otters was purportedly used. This presentation will focus on a functional interpretation of the postcranium of *Peregocetus pacificus*, a recently named protocetid based on an exceptionally well-preserved skeleton from the middle Eocene of Peru. *Peregocetus pacificus* –the travelling whale – is the first and only (to this day) four-legged whale of South America. Skeletal gross morphology and bone inner structure (accessed through computed tomography) were investigated. Both types of data allowed the identification of key structural features linked to specific locomotor modes. The postcranial skeleton was compared with other extinct and extant mammals, giving new insights on the early evolution of cetacean locomotion

Title: 5-3: Feats of supercontractile strength: testing for the presence of supercontracting muscle among chameleon hyoid musculature

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Force and length changes generated during muscle contraction are limited by structural features at the sarcomere level restricting how much muscles can shorten. Sarcomeres can only shorten until their myosin filaments physically press against the sarcomere's Z-discs, at which point force production ceases. However, supercontracting muscles have perforated Z-discs, allowing myosin filaments to slide into adjacent sarcomeres and continue interacting with actin filaments to produce force. Chameleons use ballistic tongue projection to capture prey from up to 2.5 body lengths away, necessitating that the tongue retractor muscle, the M. hyoglossus (MH), produce tension over a large range of muscle lengths. To achieve this, the chameleon MH represent the only known supercontracting muscle among vertebrates. Other hyoid muscles, however, also

undergo considerable length changes and may benefit from supercontractile capacity. We collected *in vitro* length-tension and transmission electron microscopy (TEM) data on two hyoid muscles, as well as on the M. triceps scapularis and MH as controls, to test for the presence of supercontractile muscles. We found both hyoid muscles showed similarly broad length-tension relationships to the MH, however the presence of perforated Z-discs varied. These results reveal a second supercontracting vertebrate muscle and a mechanism whereby typical striated muscle can mimic supercontractile muscle properties, with implications on patterns of hyobranchial apparatus morphological adaptation and insight into the functional demands associated with extreme length changes.

Title: 22-5: Fangs, Beaks and Spines-Oh My!: The Diversity and Energetics of Biological Puncture Systems

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Vipers inject venom into prey using fangs, woodpeckers drill into trees with their beaks, and porcupines protect themselves with elongate quills. These are a few examples of the diversity of biological puncture tools. Although disparate in materials, kinematics and scale, all three systems must adhere to the same set of physical laws that govern puncture. While the interplay between morphology, material, and puncture performance has been experimentally demonstrated in individual systems, these patterns have not been unified into a general framework. We take a step towards filling this gap by presenting a mathematical model for biological puncture events based on energy balance in soft materials. The initial energy applied by a puncture tool is split into three contributions during puncture: elastic strain energy, work to fracture, and work to overcome friction. We identify scaling relationships of different orders between these energy contributions and demonstrate the significant role of puncture tool geometries in determining puncture energies. We combine this energetics model with theoretical simulations and experimental data to create performance landscapes for puncture tool morphology in different biological scenarios. These landscapes are populated with measurements from 100+ species, showing how biological tools generally align with specific performance scenarios. These landscapes are a first step towards creating a physics-based framework for studying the evolution of disparate puncture systems across phyla.

Title: 7-4: Snakes – Have They Bitten Off More Than They Can Chew?

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Snakes have been able to bypass many of the functional and morphological constraints encountered within Tetrapoda by being released from bite-force related selection pressures. This

has produced a level of functional separation between cranial units unseen in other vertebrates, and has facilitated a high level of cranial disparity across modern snake taxa. Our ‘standard investigative toolkit’ is insufficient to deduce the origins, mechanisms, and drivers behind these novel anatomical changes, thus an integrative approach must be taken whilst considering the palaeontological and phylogenetic challenges associated within Serpentes research. With a focus on ‘gape-limited’ derived alethinophidians (Colubroidea), we tested whether modifying the skull from that of a ‘wide-gaped’ ancestor to a ‘small-gaped’ feeder leaves a distinct morphological signal across cranial skeletal anatomy and cranial muscle architecture in a morphodynamic context. Using DiceCT techniques to capture musculoskeletal relationships, soft tissue and cartilage structure in-situ, our results suggest the division of primary cranial muscle groups is highly variable within major snake clades, and can mechanically compensate for larger-scale changes in observed skeletal disparity. In addition to driving motion equivalent to fine-motor movements, our data suggest soft tissue structures are essential for restricting and bounding the range of motion of cranial skeletal elements. We also examine this in an ecological context, questioning the relationship between feeding strategies and phylogenetic signal, and examine diet from a multistate trait perspective.

Title: P2-12: What factors create mammalian complex molar morphology: classical theories revisited

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Complex molar morphology is an important characteristic of mammals and had been acquired in their ancestral non-mammalian synapsids. The factors that give rise to their molar morphology have long been discussed. A century ago, the "field theory," based on comparative morphology, proposed a "field" in the jawbone as the cause of the anteriorly simpler teeth and posteriorly more complex teeth in the dentition. The "field" can be translated in the modern context as a morphogen concentration gradient along anteroposterior (mesiodistal) axis in the jaw. The present study revisits this theory through comparative morphology based on modern phylogenetic information. Some taxa show a kind of "atavism" in molar morphology among extant mammals. That is, pinnipeds (e.g., seals), which belong to Carnivora, and toothed whales, which belong to Cetartiodactyla, possess simplified postcanine teeth. Based on the field theory, we hypothesized that an anteriorization of tooth position within a jaw causes tooth simplification. In this study, tooth morphological complexity was qualitatively evaluated in each of the Carnivora and Cetaartiodactyla Then, the correlation between tooth eruption position relative to jawbone elements and tooth complexity was analyzed after correcting for phylogeny. The results suggested that anteriorization of tooth position affects the simplification of molar morphology. A similar analysis was conducted in pre-mammalian synapsids, suggesting a complexity of tooth morphology correlates with the posteriorization of the tooth position in some indexes.

Title: 9-2: Pharyngeal jaw suction feeding in channel catfish (Ictalurus punctatus)

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The external flows used by suction feeding fish to draw food into the mouth are well described. However, intraoral waterflows, which bring food to the esophagus entrance, remain understudied. As water flows through the mouth, it eventually curves away from the esophagus and toward the gills. How is water, and the food suspended in the water, redirected toward the pharyngeal jaws and esophagus? To better understand how fish are able to manipulate flow and redirect food, we combined stereoscopic high-speed X-ray videos to quantify skeletal motion (XROMM) with buccal and esophageal pressure transducers, radio-opaque flow tracers, and tracked food particles to show internal waterflow within the buccopharyngeal cavity of channel catfish (*Ictalurus punctatus*). We found that food is redirected toward the esophagus through rapid opening of the pharyngeal jaws. This rapid opening creates a decrease in pressure and water flow similar to external suction flows in order to redirect the food toward the esophagus. We also observed the start of deglutition by capturing the moment of esophageal tightening using the esophageal pressure transducer. These results suggest a novel role for the pharyngeal jaws in producing intraoral suction to bring food into the entrance of the esophagus. By providing a more complete picture of the feeding process, this novel combination of techniques will open a new area of investigation to fully understand how aquatic vertebrates feed.

Title: 29-2: Does behavioral selection correlate with brain size? Testing the evolutionary plasticity of the brain with the cattle and dog breed models.

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Nearly all domestic animals that have been analyzed for brain size change present smaller brains than those of their closest wild relatives. Reduction varies across domesticated taxa, but phylogenetic signals for these differences remain elusive. Dissection studies have indicated that the domesticated brain reduces mosaically, with the limbic system—involved in fear processing—reducing most compared to other regions. Testing brain size change under domestication has traditionally been limited to binary comparisons of wild versus domestic samples. However, our study on cattle (*Bos taurus*), found evidence that brain size reduction varies according to breed type. More aggressive breeds like bullfighting cattle have larger brains than those of more docile dairy cows. Furthermore, brain size reduction appears correlated with the amount and intensity of the human-animal relationship. The dog is a good model for testing this further given their morphological and behavioral diversity resulting from intensive, controlled breeding. Using non-invasive methods, we have acquired endocranial volume data for 2683 pedigree dogs from ~260 breeds, comprising more than half of the global breed diversity, as well as quantifiable behavioral trait data including sociability, openness to strangers, and levels of aggression for these breeds. Results of analyses comparing brain size and behavioral

traits provide a better understanding of the relationship between brain morphology and behavior. Preliminary analyses support variation in brain size and shape according to breed type.

Title: 43-9: The influence of jaw muscle architecture on mandibular disparity in Lepidosauria

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The interplay between skull morphology and the arrangement and architecture of jaw muscles remains understudied, despite its importance in identifying functional and developmental constraints shaping head evolution. Combining data on muscular and skeletal anatomy in a phylogenetic context can provide a clearer picture on the integration of the musculoskeletal system and the functional and ecological implications of morphological change. Lepidosaurs are the most taxonomically diverse tetrapod clade, showing outstanding variation in skull anatomy and jaw adductor configuration, as well as a wide range of dietary habits. Thus, lepidosaurs are an ideal study case to investigate the relationship between osteology, myology and ecology. Here, we quantify mandibular disparity across Lepidosauria by applying 3D geometric morphometrics in a sample of over 100 species. The effect and covariation of muscular anatomy on mandibular shape is tested using phylogenetic comparative methods and different muscular parameters (muscle mass, fibre length, PCSA) obtained from dissected specimens. Finally, we test the relationships between diet, mandibular shape and muscular anatomy. Our results show that mandibular shape is partly explained by phylogenetic relatedness, and most muscle parameters significantly explain shape variation across lepidosaurs. Muscle architecture covaries with mandibular morphology, suggesting musculoskeletal integration. This suggests that the jaw and associated muscles have evolved as an integrated system in Lepidosauria, facilitating the acquisition of the remarkable ecological diversity of the clade.

Title: 37-3: Rates of evolution and morphological disparity in the primate tarsal skeleton

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The tarsals, which form the hind- and mid-foot, are likely to have played a key role in the evolution of the diverse range of locomotion seen in Primates. Given the complexity of the tarsal skeleton, and its role in facilitating this locomotor diversity, we expect that rates of evolution and morphological disparity have varied between tarsal elements as well as across lineages.

Here we use 3D geometric morphometric approaches to characterise rates of evolution and morphological disparity in the primate astragalus, calcaneus, cuboid and navicular. We applied newly developed landmark schemes to a scan dataset representing 45 extant species. We then analysed shape data in a phylogenetic framework to calculate rates of evolution and morphological disparity for each tarsal element.

In the astragalus and calcaneus, morphological disparity was highest in lorisiforms, reflecting their divergent morphology and specialised locomotion. For both these elements, faster evolutionary rates were observed along branches leading to taxa with more specialised locomotion; however, low evolutionary rates were observed in the lorisiform astragalus despite high morphological disparity and specialised locomotion. This suggests some disconnect between evolutionary rate and morphological disparity, and indicates that specialisation does not always lead to faster rates of evolution across all tarsals. These results, together with those from analyses of the cuboid and navicular, will inform our work on patterns of evolutionary rate in the primate tarsal skeleton.

Title: 37-1: The evolution of the knee sesamoids in Primates

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Sesamoids are variably present bones found in tendons and ligaments near joints. Their variability in size, location, and even presence/absence could be a critical source of skeletal innovation in the conservative tetrapod bauplan. Skeletal innovations in the knee could have played a key role in opening ecological niches, particularly in animals which load their hindlimb and move through a variety of habitats, like primates. We found knee sesamoids (the cyamella, medial fabella, and lateral fabella) are present in most primate families but absent from some species, particularly in Hominoidea. There was high phylogenetic signal in all sesamoids (Pagel's $\lambda = 0.777$ to 0.973) indicating variations in sesamoid presence/absence can be mostly explained by a Brownian model of trait evolution. Phylogenetic analyses revealed it is much easier to gain than lose a sesamoid, and sesamoid presence/absence is uncorrelated with mode of locomotion. Coincidental development of the fabellae suggests they may have similar developmental or evolutionary pathways which may be distinct from the cyamella. The cyamella, medial fabella, and lateral fabella almost certainly have a biomechanical, functional role in extant primates, but higher resolution data which includes muscle physiology and sesamoid position is needed to discern this relationship.

Title: 48-2: Morphological Variation and Ecological Signals in Extant Crocodylomorph Endocasts

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Nondestructive scanning and digital modeling technologies have allowed paleoneurologists to extract and describe endocasts from a rapidly expanding number of taxa. Crocodylomorphs are common subjects due to their abundant fossil record, ecomorphological diversity, and robust braincases. However, as endocast sampling increases, comparisons using qualitative methods become unwieldy, while linear measures capture limited endocast morphology. These constraints impact investigations of explanatory biological factors, like ecology, on morphology. Here, we use high-density 3D geometric morphometrics on a comparative dataset of 23 extant crocodylomorph endocasts. We exclusively sample extant taxa for their undeformed endocasts, more completely known life histories, and stable phylogeny. The densely packed digital landmarks capture six major regions of the endocast: the olfactory tract and bulb, cerebrum, pituitary, optic region, cerebellum, and medulla. We use an Ornstein–Uhlenbeck (OU) evolutionary modeling framework to search for shifts in morphological optima as well as phylogenetic and non-phylogenetic regressions to test the explanatory capabilities of ecological variables. Our results suggest an evolutionary shift separating most crocodyloids from alligatoroids primarily driven by the shape of the medulla. Differences in saltwater tolerance and habitat may explain this pattern; yet, the regression analyses indicate endocast morphology is principally accounted for by allometry and phylogeny. While extant crocodylomorphs have a diversity of ecologies, low disparity may lead to subtle impacts on the shape of gross neuroanatomical structures.

Title: 4-4: Using dynamic simulations to explore the sprawling-to-erect postural transition in synapsids

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The transition from sprawling to erect limb postures was a pivotal event in synapsid evolution, but when or how this transition occurred has remained unclear. Musculoskeletal modelling provides avenues to address these questions in a rigorous, physics-based approach. We developed a musculoskeletal modelling and predictive simulation framework for generating dynamic behaviours *in silico*, allowing us to reconstruct whole-animal gait cycles, test postural hypotheses and explore the interaction between different parts of the body. To apply it to the sprawled-to-erect transition, we first studied two representative extant species – tegu lizard (sprawled) and opossum (erect) – by building whole-animal models for each (>40 degrees-of-freedom and >130 muscles) and simulating steady, straight-line walking. These simulations are driven purely by the laws of physics; no prior knowledge of how these animals move is included

in their optimization. Nevertheless, the simulated gait cycles of both species successfully captured key kinematic and kinetic aspects of locomotion, recorded in prior *in vivo* experiments. Having validated our framework, we then used it to simulate locomotion in three extinct non-mammalian synapsids (pelycosaur, gorgonopsian and cynodont). Our preliminary results show a diversity in postures and muscle function across these taxa, and help clarify the confusing mix of 'sprawled' and 'erect' morphologies in therapsids. They also provide insight into how functional transformation of the hindlimb occurred in tandem with that of the forelimb and vertebral column.

Title: 53-2: The openVertebrate (oVert) Project: successes and shortcomings from the past six years

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Since 2017, the openVertebrate (oVert) Thematic Collections Network has created digital anatomical data of natural history specimens and made these available via MorphoSource for research, education, and more. To date, the project has created ~27,000 media files representing >12,000 specimens from >50 US institutions, representing >6,200 genera in >970 families of living vertebrates. Most of these data are from high-resolution CT-scanning, but we have expanded to include other imaging modalities including structured light scanning and photogrammetry. We also created contrast-enhanced (diceCT) datasets for more than 300 specimens representing diverse vertebrate families. All together, these data have been viewed on-line more than one million times, and downloaded more than 87,000 times by more than 3,000 users. As oVert is in its sixth and final year of funding from the US National Science Foundation, we take the opportunity to discuss the successes and shortcomings of the project. oVert provides a useful model for distributing digitization work across a network of museums and universities to achieve a common goal of providing data from museum specimens to a global community.

Title: P1-11: Lost in Endocranial Space: CT-based investigation of brain and endocast shape in frogs

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Anatomy textbooks often highlight the "frog brain" as an amphibian example in discussion of vertebrate brain diversity and evolution. Yet there remain few studies of brain shape across the

diversity of >7,500 species of frogs and little investigation of its relationship to size, sensory diversity, and ecology. We present a study of brain shape across ~80% of the diversity of extant anuran families using CT-scanning. By creating 3D meshes of brains from contrast-enhanced (diceCT) scans and endocasts of the skull from typical CT-scans, we explore how well variation in brain shape is reflected by the bones of the skull. We present new data for ~40 species of frogs, document their variation in shape, and explore the relationship between shape and body size (spanning adult frogs <1 cm to >32 cm snout–vent length). Neither diceCT representations nor typical CT scans perfectly represent the shape of the brain, but we evaluate which provides the most reliable and useful data to capture shape variation. We also discuss other factors impinging on estimates of brain shape and volume, including calcified endolymph which we found within the braincase of more than half of specimens examined. Last, we provide a first exploration on the efficacy of endocasts from fossil frogs to inform reconstructions of brain shape and size.

Title: 37-6: The hindlimb of Allodaposuchus (Crocodyliformes, Eusuchia) from a biomechanical viewpoint

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The postcranial skeleton is usually considered to be too conservative among all the eusuchian taxa. However, we have found striking morphological differences when comparing some appendicular bones (ilium and calcaneum) of *Allodaposuchus precedens* and *A. palustris*, between both taxa as well as with living crocodylians. Such morphological differences could not be explained by the intraspecific variability shown by living taxa, and we hypothesize they may reflect specific locomotor patterns in extinct allodaposuchids.

To test this, we digitized the disarticulated bones of the hindlimb of an *Alligator mississippiensis* specimen, the ilium of both allodaposuchids and the calcaneum of *A. palustris* (this bone is not known in *A. precedens*) using structure from motion photogrammetry. Then, the hindlimb was assembled and reconstructed in Blender, considering the volume occupied by soft tissues, generating three-dimensional musculoskeletal models for the three taxa. Origins and insertions for the different muscles in the hindlimb were identified, and muscle masses and volumes were calculated based on those of living eusuchians. Finally, a biomechanical analysis to assess the implications such different bone morphologies may have on the locomotion of these taxa is in progress. Considering the sedimentary data from the sites were both allodaposuchid taxa occur and their associated taxa, we suppose that the locomotion of *A. palustris* was more suitable for aquatic environments, whereas *A. precedens* had more cursorial capabilities.

Title: P1-17: Biting off more than you can chew: Using finite-element analysis to predict feeding biomechanics of Devonian lungfish jaws

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Dipnoans (lungfish) are extant piscine sarcopterygians and sister taxon to tetrapods (all-living land vertebrates). Only six species remain today compared to their heyday during the Devonian period (419 – 359 million years ago) with approximately 100 species known. The Frasnian Gogo Formation of Western Australia yields the world's highest diversity of Devonian lungfish, preserved in exceptional three-dimensional detail. The 11 described species display extreme variation in mandible morphology which has been proposed as a driver for their success. The effect these diverse mandible morphologies have on their feeding biomechanics is not well understood. Here we show through finite-element analysis that robust forms exhibit higher tolerance for strain during feeding activity when compared to gracile forms. We found regions of increased bone volume associated with low strain and vice-versa. Strain patterns in all taxa were optimised to unique bites with gracile forms preferencing contact distally on the mandible and robust forms preferencing the middle to proximal regions. Our results demonstrate that biomechanical function and feeding performance are constrained by mandible morphology in Devonian lungfish. This likely influenced prey selection and facilitated niche partitioning within the reef, whereby species with higher strain tolerance gained access to harder-bodied prey. These results build upon our understanding of the biomechanical capabilities of Devonian lungfish from the Gogo Formation and allow us to elucidate feeding behaviours and the reef's trophic relationships.

Title: 9-4: Feeding kinematics of algal grazing in the gobiid fish Sicydium punctatum: a missing link in the evolution of goby climbing biomechanics?

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Many gobiid fishes can climb steep waterfalls using one of two mechanisms: powerbursts, which involve pectoral fin adduction and axial undulation; or inching, in which the diagnostic pelvic sucker of gobies alternates attaching to surfaces with a novel oral sucker, thereby advancing the body. Inching has only been observed in the genus *Sicyopterus*, obligate herbivores that feed by grazing diatoms off surfaces. Such feeding contrasts with the omnivorous diet of most stream goby taxa. Measurements of cranial kinematics for both behaviors in *S. stimpsoni* have shown several similarities, including extreme forward extension of the premaxilla during both climbing and grazing. This suggests that the evolution of inching climbers from powerburst-climbing ancestors involved coopting the jaw movements used for algal grazing. To further test this hypothesis, we recorded high-speed video to measure the feeding kinematics of *Sicydium punctatum* from the Caribbean island of Dominica. This species belongs to an outgroup genus to

Sicyopterus that also grazes algae but uses powerburst mechanics to climb. We found that premaxillary extension for grazing was typically much smaller in *S. punctatum* than in *S. stimpsoni*. This is consistent with grazing behaviors evolving before the incorporation of oral movements for climbing in gobies. Elaboration of ancestral levels of premaxillary extension may have been enabled the exaptation of feeding mechanics that enabled the evolution of inching as a locomotor mechanism.

Title: 22-6: Leveraging the Bite: Comparative humeral strength in Smilodon fatalis and extant pantherine cats

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With an estimated weight range between 160 to 300kg, *Smilodon fatalis* is comparable in body size to modern jaguars (*Panthera onca*), lions (*Panthera leo*), and tigers (*Panthera tigris*). While they are similar in body size, comparatively the humeri of *S. fatalis* are much more robust that those of extant pantherines, leading researchers to hypothesize they could resist relatively higher stresses, which may have come in handy for preserving their sabers. The biomechanical capabilities of *S. fatalis* humeri as related to their robust size is unknown, but crucial for reconstructing the species' potentially unique ecological niche. We modeled prey-grappling motions involving the triceps brachii and pronator teres muscles using humeral models of *S. fatalis*, *P. onca*, *P. leo*, *P. tigris*, and leopards (*Panthera pardus*) in the first finite element analysis (FEA) study to utilize postcranial elements. When modeled with identical muscle magnitudes, results indicate the humeri of *S. fatalis* are more resistant to strain than extant pantherines. Strain patterns most closely resembled *P. leo*, suggesting *S. fatalis* may have utilized its humeri in similar ways to *P. leo*. However, with only half the von Mises strain magnitudes compared to those observed in *P. leo*, *S. fatalis* could have handled larger prey or used that additional strength to more effectively restrain similar sized prey to preserve their sabers.

Title: 19-3: Aquatic feeding in pinnipeds: Does the masticatory musculature reflect dietary specializations in grey seals and harbor seals?

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In terrestrial carnivorans, the main masticatory movement involves a straight, forceful occlusion with a scissor-like action of the teeth for shearing and shredding meat. During the land-to-sea transition, pinnipeds underwent an evolutionary shift in emphasis of craniomandibular function

from prey processing to prey capture. The reduced oral processing capabilities are accompanied by the secondary loss of the dental innovations emblematic of carnivoran feeding. Despite the simplification of the dentition, there remains a notable degree of disparity of the teeth across extant pinnipeds that has been related to functional differences (i.e., puncture performance). We hypothesize that the dental morphofunctional diversity is reflected in the masticatory musculature.

To test this hypothesis, we obtained qualitative and quantitative data of the masticatory muscles in Harbor seals (*Phoca vitulina*) and Grey seals (*Halichoerus grypus*) via dissections. Both taxa significantly differ in dental morphology with *P. vitulina* having multi cusped teeth and *H. grypus* having cone shaped teeth. Our analysis revealed a slight difference in the insertion point of the digastric muscle. It also appears to have a higher force-producing capacity in *P. vitulina* as compared to *H. grypus*. The muscle aids to open the jaw and to elevate the hyoid bone. It, thus, is also involved in suction feeding. Suction behavior is more common among *P. vitulina* than in *H. grypus*, which may be related to the observed muscular differences.

Title: P4-1: Investigating the relationship between neck length and vertebral morphology at the cervicothoracic transition in ungulates

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In terrestrial mammals, the transition from neck to trunk poses biomechanical challenges to the vertebral column. This involves the functional change from a relatively mobile region (cervical vertebral column) to a rather stiff region (thoracic vertebral column). Furthermore, the cervicothoracic (CT-) transition has to bear the weight of the head-neck system which can be quite high in animals having cranial structures such as horns or antlers and a long neck, respectively.

Here, we quantified the vertebral morphology at the CT-transition in a diversity of perissodactyls expanding a previous study focusing on artiodactyls. The landmark-based 3D geometric morphometric analysis revealed a link between neck length and shape differences between the last cervical vertebra (C7) and the first thoracic vertebra (T1). In long-necked taxa, T1 is significantly distinct in its morphology from C7. By contrast, the morphological difference between T1 and C7 is less pronounced in short-necked taxa. The latter supports an apparent general trend of a “thoracalized” C7 in ungulates having a massive head and a rather short neck as it is the case in the wild boar, for example. The “thoracalization” of C7 may contribute to a less mobile but more stable neck basis.

In a next step, we aim to investigate the intervertebral mobility and stability at the CT-transition in order to quantitatively relate the morphological features to function.

Title: 24-3: Developmental mechanism for pelvic fin evolution in chondrichthyans.

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Pelvic girdles and fins first appeared in the extinct placoderms, with fin radials articulating directly onto the girdle whereas in extant chondrichtyans, the pelvic fin radials articulate principally onto the basipterygium. To understand the evolutionary mechanism underlying this morphological transition, we examined the adult morphology and development of the pelvic fins of a holocephalan *Callorhinchus milii* through nano CT-scanning, 3D modelling, dissections as well as histology. The pelvic fin skeleton first develops as a series of radials articulating onto the pelvic girdle in a stage 30 embryo, which later fuse to form the basipterygium. To put these findings in an evolutionary context, we mapped the pelvic morphology of fossil and extant Chondrichthyes onto a recent phylogeny and confirm that a trend towards the enlargement of the basipterygium and the relocation of the fin radial articulation onto it occurred in both elasmobranch and holocephalans. We translated late 19th century descriptions of elasmobranch fin development which also suggest that the basipterygium is formed through radial fusion. We suggest that alterations in the fusion of radials to form the basipterygium is the mechanism underlying changes in fin morphology during elasmobranch and holocephalan evolution, occurring in parallel in these sister groups.

Title: 20-2: Short and Long-Term Effects of Mild Traumatic Brain Injury on Aggressive and Risky Behavior

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Mild traumatic brain injuries (mTBIs, concussions) result in hundreds of thousands of hospitalizations each year, with significant mortality. Repeated mTBIs also can provoke changes in aggression and risk-taking behavior. We determined how mTBIs affect aggression and riskiness in fish that voluntarily exit water and jump on land, making them susceptible to infrequent concussions. We designed a concussion administration contraption and tested the hypothesis that mTBI would affect aggression and riskiness, contingent upon the number of concussions and interval between concussion and behavior

testing. Half the fish received three concussions on consecutive days. The remainder received one on the first day, enabling us to assess short- and long-term behavioral effects of mTBIs and whether repeated mTBIs magnify behavioral change. To evaluate aggression, we presented animals with a 3D-printed fish intruder before and after mTBI, and three months later. Risk-taking behavior was examined using an open field test; movement in the arena center indicates riskier behavior. Fish were more risk-prone three months relative to one week post-mTBI. Individuals with three (but not one) mTBIs showed lower aggression one week after but became significantly more aggressive three months later. We are thin-sectioning brains and staining for tau, microtubule-associated proteins in neurons, to assess brain injury. We predict that higher tau densities will be associated with more pronounced behavioral changes and higher in fish given multiple versus single mTBIs.

Title: 28-1: Subsonic symphonics of duck-bill dinosaurs: Computationally reconstructing acoustics in the nasal-crest of Parasaurolophus (Dinosauria: Hadrosauridae: Lambeosaurinae)

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Lambeosaurine dinosaurs were unique for elaborate head crests incorporating complicated nasal passages. Paleontologists have hypothesized these ornamental head crests functioned as acoustic resonators. However, few studies have tested this hypothesis, due to difficulties in capturing the delicate internal architecture. We assessed acoustic potential of the 'simple' U-shaped crest in *Parasaurolophus* with a composite, digital model created from CT scans of three undescribed specimens. We performed a computational aeroacoustic analysis (CAA) of the airway by simulating expiration in a transient flow field at two flow rates (2.5 and 5 L/s). An acoustic wave function was overlaid on the solved air field to assess sound wave propagation at multiple hypothesized glottal frequencies. Our results support low-frequency harmonics (50–70 Hz) as the primary acoustic function of the crest, regardless of the incoming laryngeal signal. Hypothesized mucosal infilling of the nasal cavity in life suggested that only the rostral 1/5th of the nasal passage functioned similar to other amniote noses, leaving the remaining length of the nasal passage as an acoustic resonator. Extensive elaboration of the nasal passages in *Parasaurolophus* and other lambeosaurines is similar to the nasal anatomy of gharials, suggesting that lambeosaurines likely used closed-mouth vocalizations. Disparity between external and internal crest shape supports a dual role for lambeosaurine head crests as both acoustic and visual communicators.

Title: 54-1: Evolution of lung ventilation in tetrapods

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The evolutionary transformation from buccal pump to aspiration breathing involved the transfer of responsibility for lung ventilation from the head to the trunk. Comparative analysis of extant tetrapods indicates a two-step transformation: first to the use of the transverse abdominal muscle for expiration at the base of Tetrapoda, retaining the buccal pump for inspiration, then to inspiration by costal aspiration in Amniota. However, the evolution of costal aspiration remains a mystery. There does not appear to be good evidence that costal aspiration is a 'better' lung ventilation mechanism, i.e., the selection pressure for using the body instead of the head for lung ventilation remains obscure. Indeed, reliance on costal aspiration introduced a constraint that limits locomotor endurance in extant lizards. Why, and how, did costal aspiration evolve? The 'why' problem is difficult. Lack of reliance on buccal pumping appears to have released the amniote head to diversify in form and function, so it is possible that selection on head shape reduced the efficacy of the buccal pump and led to selection for an alternate inspiratory pump. We may have made some recent progress on the 'how' question. XROMM analysis of rib kinematics in monitor and tegu lizards revealed that costal kinematics are similar in locomotion and ventilation, suggesting an evolutionary pathway to aspiration breathing in which costal locomotor kinematics were co-opted for lung ventilation.

Title: 52-4: Intra-horn insemination in the alpaca: Copulatory wounding and deep sperm deposition

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Alpacas are reported to be the rare mammal in which the penis enters the uterus in mating. To date, however, only circumstantial evidence supports this assertion. Using female alpacas culled for meat, we determined that the alpaca penis penetrates to the very tips of the uterine horns, abrading the tract and breaking fine blood vessels. Female alpacas sacrificed one hour or 24 hours after mating showed bleeding in up to 14% of their reproductive tract, including the hymen, cervix and the tips of each uterine horn. Unmated females had only up to 2.4% bleeding in their tract. Histological examination revealed widespread abrasion of the cervical and endometrial epithelium, injuries absent in unmated females. The male alpaca's cartilaginous penis tip with a hardened urethral process is likely responsible for the copulatory abrasion. Immediately after mating, sperm in the tract were detected in the oviduct lumen within an hour after mating, suggesting some of it is deposited at the oviducal entrance during copulation. Alpacas are induced ovulators, and wounding may hasten delivery of the seminal ovulation-inducing factor beta-NGF into the female's blood stream. The entire female reproductive tract interacts with the penis, functioning like a vagina. This copulatory mode likely influences uterine immunity to manage wounding and pathogen exposure, while fostering a receptive environment for pregnancy.

Title: 1-3: Extant functional and morphological traits used to predict dietary ecology in Cretaceous birds

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In extinct animals, the lack of one-to-one correspondence between skeletal form and function presents a challenge when trying to reconstruct species' ecological niches. In birds, however, extensive data sets drawn from the phenomenally diverse range of extant forms can be used to place fossil morphologies into context. We categorised the diets of a large, phylogenetically broad sample of extant birds, and measured four different functional and morphological proxies: body mass, claw morphometrics, jaw mechanical advantage, and jaw strength via finite element analysis. We then used principal components, discriminant analyses, and phylogenetic comparative methods to predict the likely diets of three groups of Cretaceous Enantiornithine birds: Longipterygidae; Pengornithidae; and Bohaiornithidae. Among extant birds, body mass is a strong segregator of dietary niches, but overall there is enormous overlap between dietary categories in all of our proxies. However, while no one proxy can be used to predict a species' diet, evidence from multiple proxies together can be used to eliminate certain dietary niches. Thus, we present an effective way to hone in on a consensus prediction, which can then be considered alongside other sedimentological, geochemical, and trace fossil evidence. We find evidence of complex trophic interactions in Enantiornithine birds, recovering various herbivorous and invertivorous niches, piscivory, and carnivory as likely avialan feeding strategies within Cretaceous ecosystems. These interactions predate crown birds by ~30 million years.

Title: 27-5: What causes differential colouration and banding in the dentine and enamel of fossilized teeth?

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Banding and other colouration patterns in the dentine and enamel of fossilized teeth are relatively common in vertebrate non-mammalian carnivores. However, it is unknown if these colourations are due to the fossilization process (i.e., diagenesis) or if they formed during tooth development and have biological significance, such as marking life history events or periods of stress, as demonstrated in some mammals. We conducted a series of analyses to examine the chemical,

isotopic, and microstructural nature of tooth tissues in different groups of Cretaceous-aged terrestrial and aquatic animals, including dinosaurs, crocodiles, mosasaurs, plesiosaurs, and fish. Macroscopically, banding patterns differ between dentine and enamel, and are more regularly expressed in the enamel of crocodiles than in other examined taxa. Consistent groups of three to five whitish bands frequently appear in theropod dinosaur (Tyrannosauridae) enamel. In-situ rare earth element and oxygen isotope analyses show that the composition of dentine and enamel does not systematically correlate with banding in either tissue. Micro and nano-structural analyses show differences in dentine tubule densities in banded areas of dentine and differences in enamel crystallite sizes in banded areas of enamel, suggesting the structure of the tissues leads to differences in colouration. Further analysis of these tooth tissues will elucidate a cause for the structural differences and will help shed light on the taphonomy, biology and paleoecology of extinct organisms.

Title: 24-7: The origin of tympanic hearing in crown reptiles from a paleo-evo-devo perspective

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The evolution of a tympanic ear directly impacted the water-to-land transition in vertebrates, a landmark event that reshaped Earth's terrestrial biotas. The origin of this structure is one of the most iconic examples of a long-standing debate in evolutionary biology. Although the hypothesis of multiple origins of the tympanic hearing in Tetrapoda is now consensual, it remains uncertain when tympanic hearing originated among reptiles. We tackle this question from the perspective of modern integrative biology, combining data from two distant but complementary research areas: palaeontology and evolutionary developmental biology. Using DiceCT scans and in-situ hybridizations, we show a topological correspondence and similarities in the process related to the formation of the tympanic membrane in embryos of lizards and crocodylians. Similarities include the formation of the tympanic membrane within the second pharyngeal arch, a condition similar to that of birds but different from that of mammals, in which the membrane arises from the first pharyngeal arch. Additionally, our analyses using phylogenetically-inferred methods of reconstruction of ancestral morphology based on a comprehensive sample of early reptiles indicate that a tympanic ear was present at the base of the clade including crown reptiles. Thus, our analyses show consistency between data from the fossil record and the developmental

biology of reptiles to support the hypothesis of a single origin of the tympanic ear in crown reptiles.

Title: 49-2: Molecular markers of bone marrow tissues in modern and ancient samples

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The evolution of bone marrow (BM) through geological time is poorly understood, particularly from a biomarker perspective, offering an excellent opportunity to investigate key specimens through a combination of organic and inorganic geochemical techniques. In extant terrestrial vertebrates, red bone marrow (RBM) serves as the centre of blood production, and marrow adipose tissue (MAT; a type of fat tissue) can support bone ossification. Most aquatic and semi-aquatic vertebrates, however, produce blood in organs such as the liver and kidneys. A comprehensive study of the biomolecular composition of BM tissues across a range of extant taxa will highlight biomarker candidates in geological samples. Biomarkers will be extracted using organic solvents and analysed *via* various chromatographic techniques. The biomolecular and stable isotopic profiles of extant BM tissues will be applied to the organic extracts of exceptionally preserved fish vertebrae, crocodilian, and turtle bones (Green River Fm, ~53.5-47 Ma), and disarticulated ichthyosaur mandible, teeth, and vertebrae within a carbonate nodule (Toolebuc Fm, ~105 Ma). Previously, evidence of red blood cells and intact cholesterol has been reported in an ichthyosaur vertebra encased in a carbonate nodule (~183 Ma). Marrow structures have been studied in the humerus of seymouriamorph tetrapods (~300 Ma) to suggest potentially haematopoietic marrow. Identifying BM in geological samples *via* a molecular approach offers complementary direct evidence to non-destructive imaging techniques (see Sanchez *et al*., these proceedings).

Title: 32-1: Comparative anatomy of the vocal apparatus in bats: insights into the evolutionary history of echolocation.

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Laryngeal echolocation allows bats to sense their surroundings and foray in different environments, explaining their evolutionary success and current high species diversity. However, the origin(s) and evolution of laryngeal echolocation remain disputed. The larynx is the organ responsible for sound production during laryngeal echolocation, yet its anatomy, and variation in relation to echolocation strategy, remain poorly described. In order to understand the relationship between echolocation behaviour and laryngeal anatomy in bats, we three-dimensionally examined the larynges of 18 various bat species from 10 families using high-resolution iodine contrast-enhanced microtomography. We found that, in contrast with the established idea of a common laryngeal morphology in mammals, bats exhibit great morphological diversity. This laryngeal diversity, mainly impacted by phylogeny, could reflect adaptations to different echolocation strategies. The Pteropodidae share similar laryngeal morphology with non-bat mammals, suggesting retention of the mammalian morphology by this bat family and, therefore, by the last common ancestor of all bats and all Yinpterochiroptera. This configuration could imply that the derived laryngeal forms observed in Rhinolophoidea and Yangochiroptera were acquired independently.

Title: P1-14: Analysis of a three-dimensional musculoskeletal model of the forelimb of Guanlong wucaii (Theropoda: Tyrannosauroidea)

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The function of the highly reduced and modified forelimbs of late-branching tyrannosaurs such as *Tyrannosaurus* has long been the subject of speculation, but most prior studies have not considered the evolutionary context of forelimb morphology. The early tyrannosauroid *Guanlong wucaii* possessed gracile, elongate forelimbs, which make it an ideal choice to serve as a model for plesiomorphic forelimb biomechanics within the clade. We constructed a three-dimensional (3D) musculoskeletal model of the forelimb of *Guanlong* in order to analyze potential forelimb function in this taxon as well as serve as a basis for future comparisons. The model was constructed using a standardized software workflow that involves rearticulating the individual forelimb elements, defining joint axes, and reconstructing muscle lines of action in 3D. Muscle moment arms for each muscle were then calculated across a wide spectrum of potential limb positions, allowing identification of individual muscles' primary actions as well as

how these actions change over the range of motion. For instance, shoulder retraction moment arms for some muscles improve with increased joint elevation, which could suggest a habitually elevated shoulder posture during these movements. This musculoskeletal model of the forelimb of *Guanlong* provides an important basis for comparisons with future 3D models of other tyrannosaur forelimbs, as well as offer insights about forelimb function among gracile-limbed theropods, which have received comparatively less biomechanical study.

Title: 22-7: The Utility of Saber-like Canines in Gentle Giants; a study of Uintathere teeth

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Despite the fact that carnivore saber-teeth have long been of interest. The use of saber-like canine teeth in herbivores has received less attention. This is true of the extinct Order Dinocerata. This study evaluated hypotheses regarding the utility of these teeth; (1) mastication (2) rooting (3) open mouth hippopotamus style aggression (4) closed mouth walrus style aggression (5) closed mouth head to flank style aggression. Examination was undertaken of PM 53933; the best-preserved skull of *Uintatherium anceps* at the Field Museum. The long spear-shape canine teeth have narrow posterior-anterior edges. The enamel is crenulated to help buttress the tooth from compressional forces. Conchoidal patterns in the tooth's enamel are found on the lingual surface due to regrowth related to frequent downward striking forces. There is no evidence for wear facets which would be evidence for mastication or rooting behaviors. The dentary is reduced when compared to hippopotamus, with smaller attachments for the masseter muscles, while the temporalis muscle attachments are greatly expanded and the glenoid fossa is robust facilitating downward stabbing motions. Adults exhibit broad protuberances on the dentary to shield the saber-like teeth, suggesting that walrus-like aggression was unlikely. Microwear of the enamel surface show a reduced density of pits and scratches, indicating canines were protected from abrasive substances. In conclusion, *Uintatherium* likely exhibited head-to-flank aggression, a behavior observed in modern saber-toothed musk deer.

Title: 3-6: Short Primate Faces and Gums: Facial Sutures in Gouging Primate Gummivores Close Early

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Gummivory is rare among mammals and is found primarily among primates. The obligate gummivorous marmosets gouge tree bark to access gums while their close relatives, tamarins, are frugivorous and consume few gums. Marmosets anchor the upper anterior dentition against a tree and gouge upwards with the lower anterior dentition to stimulate gum flow, presumably

resulting in facial sutures that experience forces differing from tamarins. We tested the hypothesis that the sutures nearest to the upper anterior dentition, the interpremaxillary (IP) and maxillopremaxillary (MP) sutures, have altered closure schedules between marmosets and tamarins. Heads from age-matched, adult cadavers (4 tamarins: *Saguinus oedipus*, and 7 marmosets: *Callithrix jacchus*) were micro-CT scanned and every second slice was visualized to assess status of the IP and MP sutures. Sutures were rated along a continuum from "completely open" to "completely closed". Results showed that 46% of the viewed slices in tamarins) had IP sutures that were completely open vs. 17% in marmosets. In the MP suture, 44% of the viewed slices in the tamarins were completely open vs. 11% in marmosets. Present results match findings that a wide phylogenetic range of gummivorous primates have shorter skulls than non-gummivorous primates. Additionally, results from the present study suggest that earlier closure of select facial sutures may be associated with short faces in gummivorous primates.

Title: 21-3: Quantification of avian postcranial pneumaticity sheds light on the evolution and function of skeletal pneumatisation

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Postcranial skeletal pneumaticity, the presence of epithelial-lined air-filled cavities within bones, is unique to birds among living vertebrates. This key feature of extant avian structure and biology first evolved among the non-flying archosaurian ancestors of birds. The presence or absence of pneumatic bones across the avian skeleton has been studied in specific clades and shown to vary across taxa, related primarily to ecology and body size; however the true extent of skeletal pneumaticity has never been quantitatively investigated—hindering fundamental insights into the evolution of this key avian feature. We used microCT scans of fresh, frozen birds to directly quantify the fraction of humerus volume occupied by bone, marrow and air across a phylogenetically diverse taxon sample to test longstanding hypotheses regarding the evolution and function of avian skeletal pneumatisation. Among other insights, we provide clarity on the hypothesised negative association between extent of humeral pneumatisation and aquatic diving behaviour, and show that the extent to which air replaces marrow within the internal cavity of avian humeri simply scales with humeral size, lacking independent effects of body mass. Our quantitative evaluation of humeral pneumaticity across extant avian phylogeny sheds new light on the evolution and ontogenetic progression of an important aspect of avian skeletal architecture.

Title: 11-6: Integrating histology and vertebral anatomy to reconstruct cardiopulmonary evolution near the divergence of Avemetatarsalia and Pseudosuchia

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Evolutionary origins of the crocodylian-style hepatic piston and avian-style pulmonary air-sac systems are enigmatic due to a lack of fossil soft-tissue preservation. However, archosaur lung embryology suggests a shared ancestral condition. Archosaur cardiovascular evolution is also obscured by the absence of preserved red blood cells (RBCs) and blood vessels that constrain kinetics of gas exchange. Here, we ask: Are fossilizable (histologic) indicators of cardiovascular and pulmonary evolution correlated, and does their evolution reveal divergent patterns near the Triassic avian and crocodylian divergence? First, because smaller RBCs facilitate faster O_2 uptake in the lung and delivery in muscle, histologic inference of RBC size has provided insights into fossil tetrapod energetics. Building on a published dataset, we used vasculo-lacunar histometrics and phylogeny to accurately retrodict RBC sizes in 20 extinct and 20 extant tetrapods via phylogenetic eigenvector mapping. Second, macro- (fossae, laminae, foramina) and microscopic (pneumosteum) vertebral features in non-aquatic birds and dinosaurs indicate invasion of pulmonary diverticula into bone. Assessing states in Triassic taxa will clarify whether pseudosuchians lacked these features, or secondarily lost them later in Crocodylomorpha. Preliminary results suggest early-diverging pseudosuchians exhibited specialized vertebral morphology more similar to early avemetatarsalians than to extant crocodylians. Furthermore, RBC size increased in crocodylians, suggesting slower O_2 uptake kinetics. We hypothesize that cardiopulmonary evolution in crocodylomorphs shifted to the extant 'hepatic piston' in a secondarily aquatic environment.

Title: 55-3: Morphological and ecological correlates of inner ear labyrinth in limb-reduced Australian skinks (Scincidae: Sphenomorphinae)

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The inner ear labyrinth is the seat of balance perception in vertebrates. Despite the sensory importance of this organ, studies investigating the evolutionary drivers of its morphology found conflicting results. Two competing hypotheses exist to explain its morphological variation: whether it correlates with functional aspects of locomotion, or if it is

influenced by the developmental constraints of skull morphology. We test these hypotheses using a sample of 52 species of Australian sphenomorphines, a lineage of scincid lizards that evolved dramatic body-shape and locomotory adaptations to fossoriality in several independent instances, including exhibiting varying degrees of limb reduction. Our results highlight a prominent correlation between the shape of semicircular canals and the degree of limb reduction in these lizards, indicating an influence of locomotory mode. The inner ear morphologies of limb-reduced skinks indicate higher agility and manoeuvrability compared with fully-limbed skinks, potentially explained by adaptations to navigating cluttered environments. Substrate ecology was a predictor of shape in its interaction with the degree of limb reduction. Conversely, our results demonstrate how in fossorial skinks the influence of skull constraints on semicircular canal shape is minimal and instead tends to act on its size. This supports the hypothesis that inner ear shapes and sizes are adapted to specific locomotory strategies and their functional interactions with the environment more than they are constrained by cranial anatomy.

Title: 36-3: Comparative anatomy of the musculoskeletal feeding system in plethodontid salamanders

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Lungless salamanders (Family:Plethodontidae) represent the largest family of extant salamanders. Like most terrestrial salamanders, plethodontid salamanders primarily rely on tongue prehension for prey capture (both muscle-powered and spring-powered). In addition to differences in feeding mode, salamanders in this family are diverse in their microhabitat use (aquatic, semiaquatic, terrestrial) and in life history mode (biphasic, direct developers, and paedomorphic). While much has been done to understand morphological differences of the tongue skeleton (particularly between spring-powered and muscle-powered feeding modes), studies understanding how other morphological structures vary are lacking. For example, are there differences in cranial musculature between salamanders that vary in feeding modes, microhabitat, or life cycle? Understanding how these other morphological structures vary allows for a more integrative understanding of the salamander feeding system. Here, we utilize diceCT and digital segmentation to describe differences in feeding musculature and connective soft tissues for salamanders representing spring-powered tongue prehension (*Eurycea*) and muscle-powered tongue prehension (*Desmognathus*).

Title: 17-1: Characterizing the complex relationship between limb morphology, microanatomy and posture to draw reliable paleoecological inferences in early amniotes and relatives

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A relationship between limb bone mid-diaphyseal microanatomy and lifestyle adaptation (terrestrial, aquatic, flying) has been demonstrated in extant tetrapods. The resulting inference models are commonly used to decipher the lifestyle of extinct taxa whose ecology is debated. However, such models often yield erroneous reconstructions contrasting with taphonomic and isotopic evidence when applied to early amniotes and relatives. Representatives of Diadectidae, basal Synapsida, Therapsida, and Pareiasauria, that were most likely terrestrial, show microanatomical patterns consistent with extant pelagic species (i.e. thin to inexistent compact cortices and a medullary cavity filled by a trabecular network). We thus postulate that extant tetrapods are poor morpho-functional analogues to some Paleozoic groups when considering limb microanatomy alone. Here we use a combination of multivariate methods and finite element analysis to better characterize the complex relationship between limb bone morphology (stout *versus* elongated), internal three-dimensional microanatomy (cortical compactness, trabecular network architecture) and the biomechanical constraints associated to posture in tetrapods (on the sprawling to parasagittal continuum). A first phase of our project focuses on the stylopodium of selected extant and extinct taxa for which we gathered high-resolution CT scans. Ultimately, our results will contribute to improve paleoecological inferences in early amniotes and relatives, and help to constrain better the progressive sprawling to parasagittal postural shifts seen during the evolutionary history of synapsids and archosaurs.

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Title: 26-3: Developmental transcriptomics and morpho-informatics of bats provide new insights into the evolution of laryngeal echolocation and hearing

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Whether laryngeal echolocation has a single origin in bats or evolved multiple times independently remains disputed. The inner ear is the key anatomical organ for echolocation which facilitates sound perception, signal processing and transmission of high frequency sound. Here, we compared time-series transcriptomes in the developing inner ear among echolocating bats and non-echolocating mammals to assess the dynamics of gene expression through prenatal to postnatal period, using next generation sequencing and morpho-informatics approach. Constant-frequency echolocating (CF) bat *Rhinolophus cornutus*, frequency-modulated echolocating (FM) bat *Vespertilio sinensis*, and non-echolocating *Cynopterus sphinx* and *Mus*

musculus were used as our target species. The cross-species transcriptome comparison revealed that up-regulated gene sets in CF bat was associated with ear morphogenesis and neuron system development, providing insights for the molecular mechanism of perceiving and processing high-frequency sound in CF bat. Further investigation of hearing related and morphogenesis related genes among the distantly related two echolocating species identified inconsistent gene expression dynamics during inner ear development. The two echolocating species appear to employ surprisingly different gene sets to achieve their similarly enlarged inner ear and hearing function, which potentially supports the convergent origin of echolocation ability in bats. Furthermore, we provide insights into the molecular basis behind the inner ear diversity and high frequency hearing in vertebrates.

Title: 2-3: Dormaal lizards in Belgium – a rare window into the earliest Eocene 'greenhouse world'

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During the Eocene, world climate experienced rapid and intense global warming, reaching a peak during the Palaeocene–Eocene Thermal Maximum (PETM), 56 my ago. The warmest global climate of the past 66 my occurred during the early Eocene epoch (about 56 to 48 mya) when megathermal floral elements, including palms, reached Antarctica. The increase in temperatures led to a rise in sea level, turning Europe into an archipelago. Data regarding the early Eocene herpetofaunas are scant, but the locality of Dormaal in Belgium represents one of the rare exceptions. The lizards consist of gekkotans, acrodontan and pleurodontan iguanians, anguimorphs such as glyptosaurines and the varanid *Saniwa*. These groups are believed to be thermophilic, and their appearance in this high latitude locality indicates that the tropics were expanded during this time. Some of these records also represent first appearances of these clades in Europe. Among them, a new iguanian taxon is represented by a unique tooth morphology – the teeth are bifurcated – indicating a specialization on trophic resources. However, because terrestrial ecosystems changed substantially during the Palaeogene, this might have caused higher extinction risk relative to generalists (e.g., the iguanian *Geiseltaliellus*). Understanding this geological epoch is relevant for present global climate change, including sea level rise, as well as the expansion of distribution of thermophilic taxa, including parasites that cause serious infectious diseases such as malaria.

Title: 26-2: Diversification in the hearing and vestibular organs of elasmobranch fishes in 3D

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Compared to other animal taxa, there is an astonishing diversity in the size and shape of the inner ear and vestibular organs fishes. This high variability exists across multiple morphological elements: size and area/volume of the inner ear and macular organs, semi-circular canals, and sensory epithelia (relative to body and brain size); presence, mass and shape of otoliths; and the orientation of hair cells. The evolutionary and functional implications of this anatomical diversity are largely unknown and represent one of the biggest mysteries in sensory biology. Here, we use contrast-enhanced, micro computed tomography (mCT) to investigate the hearing system of elasmobranch fishes (sharks, skates and rays), which are uniquely and phylogenetically positioned to contribute to our understanding of the evolution of hearing capabilities across all fishes and other vertebrates. Preserved inner ears from a range of elasmobranch species were stained in Lugol's solution, an effective agent for rapidly differentiating many types of soft tissue, scanned, and then reconstructed into digital 3D models. The morphological differences between species are examined and quantified with 3D geometric morphometrics, and contextualized within phylogenetic and ecological parameters. Future avenues to explore the functional morphology of the fish inner ear will also be discussed and how anatomical differences may confer variation in auditory capacity.

Title: 22-2: Mandibular shape and mechanical performance of Smilodon fatalis through ontogeny

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Smilodon fatalis is one of the most extreme sabertoothed felids to have ever existed. Their peculiar phenotype undergoes dramatic transformation through ontogeny: cubs have much shorter fangs than adults and erupt their permanent upper canines at a relatively late age. Therefore, the ontogeny of *Smilodon* partially recapitulates the evolutionary shift from a more 'feline-like' to a 'sabretoothed' phenotype. We scanned 24 mandibles of *Smilodon* from La Brea, representing an ontogenetic sequence, and quantified growth-related morphological changes using geometric and linear morphometrics. Comparisons were made to an ontogenetic sequence of the extant lion (*Panthera leo*). We used finite element analysis to study the change of mechanical behaviour through ontogeny in both species. *Smilodon* undergoes much more morphological transformation during growth than *P. leo*, the former showing growth in two phases: the mandibular corpus of *Smilodon* cubs resemble that of lions at early stages and the eruption of permanent M1 (around 10 months of age) marking a clear shift in morphology. Although *Smilodon* cub mandibles are perfectly shaped to handle stress and deformation, our

analyses showed that they are particularly inefficient to convey the muscle force on the incisors and lower canines. These findings suggest that *Smilodon* cubs did not used their mandibles as anchors and were poorly equipped to perform a sabretooth killing bite until they erupt their full adult dentition (past 20 months).

Title: 21-4: Patterns of morphological convergence in the crania and hindlimbs of Anseriformes

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Anseriformes are an incredibly successful group of vertebrates, being found on every continent other than Antarctica, and across a wide variety of environments. They occupy a wide range of ecological niches including freshwater filter feeder (dabbling), terrestrial grazer, and both freshwater and coastal divers feeding on a wide range of invertebrates. Most of these niches have evolved independently multiple times within anseriformes. Previous studies have shown multiple instances of morphological convergences, including bill shape and tarsometatarsus shape. However, how these individual elements have evolved in conjunction with other related elements (e.g. the rest of the cranium and other hindlimb elements) have not been thoroughly examined. Using a variety of 3D imaging techniques (CT, Structured light, photogrammetry) and 3D geometric morphometrics we examine the interrelation between morphology and ecology. We also examine the level of integration and co-evolution between different elements, in particular between the skull and hindlimb. Our preliminary findings suggest that despite a significant relationship between skull shape and diet, the patterns of convergence are more complex than previously suggested, particularly among grazing species. Our research provides further insight and nuance to the patterns of morphological divergence and convergence within anseriformes.

Title: P3-9: Convergent evolution and innervation patterns of caudal ear muscles in distantly related constant-frequency echolocating bats

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Three major groups, pteropodids, rhinolophoidss, and yangochiropterans, constitute extant bats. Ear movements are known to differ considerably among bat species, possibly reflecting their divergent echolocation strategies. Here, we compared the anatomy of the caudal ear muscles, cervicoauricularis, that facilitate ear movements in mammals. We found that non-bat laurasiatherians, pteropodids, and the majority of yangochiropterans commonly have three cervicoauricular muscles which are all innervated by the retroauricular branch of the facial nerve. This suggests that the three-muscle pattern is a widely shared trait among laurasiatherians and that it is the ancestral pattern of bats. However, we found that rhinolophoids and *Pteronotus*, one genus of New World yangochiropterans, have one additional muscle not found in other bats, making their caudal ear muscles composed of four muscles. Observations on the innervation pattern revealed that the "fourth muscle" found in both lineages is innervated by non-homologous nerves, which suggests that the fourth muscle found respectively is a product of homoplasy and that each should be treated evolutionarily as different muscles. Behaviorally, these two distantly related bats are the only groups known to conduct constant frequency (CF) echolocation while other laryngeally echolocating bats employ frequency modulated (FM) echolocation. Our results indicate that CF bats have convergently acquired the four-muscle pattern in the caudal ear, which possibly facilitates more delicate and subtle ear movements than FM bats.

Title: 13-5: Does carnivoran trabecular bone morphology reflect differences in intensity of locomotor strategy?

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Increased mechanical loading in the skeletal system often results in bone modeling and remodeling in response to loading frequency and strain. Studies show a relationship between bone morphology and locomotor strategy however, few have investigated bone morphology among felids and canids occupying disparate geographical spaces. We quantified trabecular bone volume fraction (BVF) and degree of anisotropy (DA) in the femoral and humeral heads and distal tibia of felids and canids. We hypothesized that: (i) felids occupying large home ranges (cheetahs) have significantly greater BVF than those with small ones (jaguars); (ii) dogs (greyhounds) have high BVF and DA because of stereotypic loading during racing, dingoes also have high BVF due to their large home ranges and low DA due to less repeated locomotion. Felids showed no significant differences across species in both femora and humeri, but in the distal tibia cheetahs had significantly greater BVF than jaguars. Dingoes' BVF was greater than greyhounds' in the hindlimbs however, the greyhounds had significantly greater DA than the dingoes in all elements. Whereas the proximal elements did not reflect differences in locomotor strategy, the distal element did, suggesting greater differences at the point of substrate contact. The canid results reflect locomotor behavior in exhibiting greater DA among racing dogs. Although a form-function relationship is partially supported, a cautious approach is needed in inferring locomotor behavior using trabecular morphology.

Title: 33-6: Raise your head: Evaluating mechanical advantage of predorsal region of terrestrial quadrupedal amniotes

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Terrestrial quadrupedal amniotes raise their head and neck (predorsal region) off the ground to enhance vision, foraging, and other functions. Mechanical balance can be achieved when the moment from the head-neck weight is counteracted by that of the force from anterior epaxial muscles. Previous predorsal biomechanical studies mainly emphasized the morphology of specific animals rather than offering a comprehensive investigation across species. Here we analyzed and compared the mechanical advantage of the head-supporting system (MA_{HSS}) of 98 amniotes, including those with a large predorsal region such as *Loxodonta africana* and *Triceratops horridus*. To this end, we constructed an estimation method for the lever arm of predorsal weight (L_P) using head-neck lateral silhouettes, and validated it by comparing the L_P results with those obtained from 3D models of the analyzed taxa; statistical similarity between two methods suggested our method effective and reliable. Finally, the MA_{HSS} was calculated as the ratio of the previously reported lever arm of epaxial muscle force (L_M) to our estimated L_P. The results show that the MA_{HSS} is strongly correlated with head size, head-neck size, body size, and the presence of cranial ornaments, indicating that head-supporting ability is closely linked to the morphology, posture, and behavior of the predorsal region. This study also offers a comprehensive method for understanding the predorsal biomechanics in both extinct and extant vertebrates.

Title: 55-5: A new diminutive durophagous Miocene dasyuromorphian (Marsupialia, Malleodectidae) from the Riversleigh World Heritage Area, nothern Australia

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Malleodectes? *wentworthi* sp. nov. is a highly specialised durophagous marsupial from a middle Miocene limestone cave deposit in the Riversleigh World Heritage area, northern Australia. It provides the first information regarding the lower dentition of malleodectids, an extinct family of dasyuromorphians. It is also the smallest durophagous member of Metatheria (marsupials and

their stem relatives) known to date, with an estimated body mass of ~70–90 grams, an order of magnitude smaller than other known malleodectids (*Malleodectes mirabilis* and *M. moenia* ~ 1 kilogram). As in other malleodectids, *M.? wentworthi* has a hypertrophied, dome-like premolar specialised for crushing hard foods. Tentative assignment to the genus *Malleodectes* is based on derived similarities of the premolar and molar dentition to those of larger species of *Malleodectes* (known only from upper dentitions), and occlusal compatibility. Quantitative morphofunctional analyses of dental indices and mandibular bending strength are congruent with the previously proposed hypothesis that malleodectids may have been uniquely-specialised snail-eaters. Maximum parsimony phylogenetic analysis of a 173 morphological character dataset, with a molecular scaffold enforced, placed *M.? wentworthi* within Dasyuromorphia, in a basal polytomy with Dasyuridae and *Mutpuracinus archibaldi*, to the exclusion of *Barinya wangala*, Myrmecobiidae and Thylacinidae. Bayesian analysis of a total evidence dataset that combined morphological with nuclear and mitochondrial DNA sequence data places *M.? wentworthi* as a sister taxon to crown-clade Dasyuridae, although support is weak.

Title: 55-6: Three new late Oligocene thylacinids (Marsupialia: Thylacinidae) from the Riversleigh World Heritage Area

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Here we describe three new species of Thylacinidae from the late Oligocene Hiatus Site (species 1) and White Hunter Site (species 2 and 3) within the Riversleigh World Heritage Area. The Hiatus taxon is estimated to be 6.7 kilograms in adult body mass, whilst the two White Hunter taxa are estimated to be 3.7 kilograms and 5.1 kilograms respectively. Maximum parsimony phylogenetic analysis suggests the Hiatus thylacinid forms a well-supported clade with *Badjcinus turnbulli* sister to the rest of Thylacinidae. The same analysis places the two White Hunter thylacinids within a basal polytomy alongside *Ngamalacinus* timmulvaneyi, *Wabulacinus ridei* and *Nimbacinus dicksoni*. Synapomorphies of m1 shared by the Hiatus thylacinid, *B. Turnbulli* and *T. Macknessi* tentatively indicate a new subfamily of Thylacinidae to the exclusion of other thylacinids. Calculations of mandibular bending strength suggest the Hiatus thylacinid was highly durophagous, with a dorsoventral bending stress profile most similar to the largest thylacinid *T. Potens* and significantly more suited to dorsoventral forces during biting than other similarly sized dasyuromorphians (e.g. *Sarcophilus harrisii* and *N. dicksoni*). The mandibular bending strength profile of White Hunter thylacinid 1 and 2 is most similar to the more gracile *B. turnbulli*, suggesting they were not durophagous like the Hiatus thylacinid.

Title: 54-3: Rib kinematics in lizards provide insight into the evolution of ventilation and locomotion

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Lizards move using lateral undulation and generally rely on costal aspiration for breathing, so the kinematics of their vertebrae and ribs during locomotion and ventilation should provide insight into how the axial skeleton evolved for both roles. Using XROMM, we've measured the movement of the axial skeleton in green iguanas (*Iguana iguana*), savannah monitors (*Varanus exanthematicus*), and Argentine black and white tegus (*Salvator merianae*). Kinematics differ between species during ventilation. Monitors ribs move with a combination of bucket and pump handle rotations, while iguanas and tegus use primarily bucket handle rotation. Monitors were also found to uniquely include their floating ribs in ventilation, and these data were used as boundary conditions for computational fluid dynamics (CFD) simulations of pulmonary airflow. During locomotion, we recorded substantial rib rotations from tegus and monitors, which is significant because lateral undulation could be accomplished with intervertebral motion alone. Interestingly, we found that locomotor and ventilatory rib rotations were similar within each species, such that the ribs rotated similarly during inspiration and ipsilateral stance phase, and expiration and ipsilateral swing phase, respectively. Because lateral undulation arose first, this suggests a new pathway for the evolution of costal aspiration, where ribs first became mobile to serve locomotion and then took on the role of ventilation by expressing stance and swing phase kinematics simultaneously on both sides.

Title: P2-2: Structure and function in the Cetacean pulmonary airway tree

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The pulmonary systems of Cetaceans are the largest in evolutionary history and tell a fascinating story about secondary adaptation to marine life. Many species of Cetacean use explosive ventilation, where high volumes of air are exhaled and inhaled rapidly during a brief surface interval. Cetaceans also expose their respiratory systems to frequent high external pressures during diving. Cetacean lungs usually contain only one lobe, have a high degree of smooth muscle and cartilage reinforcement, and have subjectively relatively larger airways than those in terrestrial mammals. These adaptations are thought to enable high relative flow rates, prevent barotrauma, and facilitate the movement of air from the gas-exchanging to the conducting airways during lung collapse at depth, but how these traits and airway topology vary within Cetacea, and the influence of these adaptations to the flow of air through the lung is unknown. We are studying the structure and function of the pulmonary airway tree in whales and dolphins using computed tomography (CT) scans and computational fluid dynamics. Airway geometry, such as branching angle, the pattern of branching, relative airway diameter, airway cross-sectional shape, and relative parenchymal to airway volume vary between terrestrial mammals and Cetaceans. Although we lack CT data for the largest Cetacean species, an allometric approach may give us insight into how breathing works in the largest animals of all time.

Title: 6-4: Brain and endocast evolution over the fish-tetrapod transition: insights from extant taxa inform interpretation of Palaeozoic Sarcopterygians

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The brain is one of the most significant organs found in vertebrates. It coordinates interaction with the environment, processes sensory information, regulates bodily functions and performs complex higher functions including communication and cognition. However, insight into palaeoneurological evolution is hampered by the incredibly low preservation potential of neural tissues. As brains rarely fossilise, palaeontologists rely on cranial "endocasts" as proxies for brain morphology. Recent advances in imaging technology (e.g. Computed Tomography and synchrotron imaging) means that more of these moulds of the internal space in the skull which housed the brain can now be revealed virtually. While birds and mammals typically have a relatively tight correspondence between the brain and endocast, fish and other "lower" vertebrates often possess brains that fail to completely fill the internal space of the braincase and have thus been neglected in the literature. Surprisingly, recent findings show that this relationship is far more variable than reported, particularly so for taxa bracketing the fish-tetrapod transition, highlighting the need to adequately assess the brain-endocast relationship in a broader range of vertebrates. In this talk I detail recent findings concerning the brain-endocranial spatial relationship of extant piscine sarcopterygians (lobe-finned fish) and basal tetrapods, and discuss how they can thus inform our interpretation of fossil taxa, in particular extinct stem tetrapods from the Palaeozoic.

Title: 55-4: Locomotor joint moments in Varanid lizards and the scaling of locomotion in sprawling tetrapods

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Geometric scaling predicts a major challenge to legged, terrestrial locomotion with increasing body size. Locomotor support requirements at dynamically equivalent speeds scale isometrically with body mass (M^1), while force generation capacity should scale $M^{2/3}$ as it depends on tissue cross-sectional area. Mammals compensate with more upright postures at larger sizes, but it

remains unknown how sprawling tetrapods deal with this constraint. Varanid lizards are an ideal group to address this question because they span a large body size range with similar posture and body proportions. We report the scaling of joint moments from the hindlimb and forelimb from varanid species ranging from 7-37,000 g. Joint moments were calculated via inverse kinematics and inverse dynamics in forelimb and hindlimb musculoskeletal models with 23 and 26 muscles, respectively, and 12 dofs in OpenSim. Peak joint moments scaled generally with isometry ($M^{1.30}$ isometry; $M^{1.31}$ hindlimb mean; $M^{1.26}$ forelimb mean) with the exception of hip adduction ($M^{1.45}$). Impulses of joint moments scaled with positive allometry ($M^{1.167}$ isometry; $M^{1.55}$ hindlimb mean; $M^{1.45}$ forelimb mean). Previous work found that muscle parameters (muscle mass, length, CSA) as well as duty factor scale with positive allometry, suggesting that varanid lizards use both anatomical and kinematic adjustments to produce sufficient joint impulses for locomotion without suffering high peak joint moments. These results suggest that hip adduction may provide a biomechanical limit to sprawling locomotion at large body size.

Title: 46-1: Two limbs or four: evaluating the role of forelimbs in protocetid swimming

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Tetrapods have repeatedly returned to life in water, with the evolution of whales representing a notable instance of secondary aquatic specialisation. An important shift in the evolution of swimming in whales was the transition from quadrupedal to hindlimb paddling, after which the forelimb was primarily used for manoeuvring and stabilising swimming. The recent discovery of a nearly complete protocetid forelimb complicated this model, as the forelimb seems to have been actively used in swimming– in a group previously viewed as hindlimb paddlers. While the authors of the original study interpreted the forelimb being used as a drag-based paddle in swimming, it has been suggested that it might be moved in a flapping motion to generate lift (as observed in some modern taxa).

We examined the potential function of the preserved forelimb quantitatively, by building a digital 3D reconstruction of the forelimb and investigating it using computational fluid dynamics. The model was posed according to the competing hypotheses in fluid simulations, enabling calculation of lift and drag. The flapping motion was also modelled computationally in order to evaluate thrust generation. Concurrent models were produced with modern semi-aquatic analogues for comparison, including mustelids and otariids. We were able to evaluate the most likely use of the forelimbs in protocetid locomotion, and consequently suggest that the evolution of swimming in whales was more complex than previously thought.

Title: 54-5: Breathing inside a box & how it constrains movement

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Armoured, rigid bodied animals, such as Testudines, must self-right should they find themselves in an inverted position. The ability to self-right is an essential biomechanical and physiological process that influences survival and ultimately fitness. Traits that enhance righting ability may offer an evolutionary advantage. However, the energetic requirements of self-righting are unknown. Using respirometry and kinematic video analysis, we examined the metabolic cost of self-righting in the terrestrial Mediterranean spur-thighed tortoise and compared this to the metabolic cost of locomotion at a moderate, easily sustainable speed. We found that self-righting is, relatively, metabolically expensive and costs 1.8 times the mass specific power required to walk. Rapid movements of the limbs and head facilitate successful righting and, combined with the constraints of breathing whilst upside down, contribute a significant metabolic cost. Consequently, in the wild, these animals should favour environments or behaviours where the risk of becoming inverted is reduced.

Title: 1-5: Evolutionary shifts in the morphological diversity of turtle hyoid structures are subjected to feeding behaviour

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The hyoid apparatus is a structure that belongs to the axial skeleton of tetrapods, originated from fish gill arches. It is highly diverse in its morphology among different tetrapod groups, and plays an important role in feeding, breathing, sound production and various other behaviours. Among turtles, the diversity of hyoid apparati has been recurrently linked to their habitat. The ossification of the hyoid corpus is often the main trait used in correlations with niche occupancy, being ossified corpi associated to aquatic environments and cartilaginous corpi to terrestrial life. Most studies conducted so far focused on species belonging to Testudinoidea, as it is the turtle clade that occupies the biggest diversity of habitats (i.e., different lineages of terrestrial, semi-terrestrial, and aquatic animals), but failed to include representatives of other lineages. We accessed the hyoid apparatus of 114 turtle species from all ‘families’, together with ossification sequences from embryological series of 10 species, somefirst described here, and samples from the fossil record. Using over 30 different discrete characters, we discuss the evolutionary patterns and the biological significance of morphological shifts in turtle hyoid bones. Our findings indicate that morphological changes are strongly subjected to feeding modes and do not suffer

great constrains from habitat. Some of the hyoid character states we describe are diagnostic of turtle clades, some thus providing information to the taxonomic assessment of fossils.

Title: 30-4: Multiple evolutionary pathways to piscivory in Neotropical freshwater fishes (Characiformes)

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Piscivores structure aquatic food webs by transferring energy across trophic levels. However, piscivores are no ecological monolith, exhibiting varied functional and behavioral repertoires to ambush, maul, or pursue elusive prey. Studies on piscivores have revolved around marine systems dominated by suction- and ram-feeding percomorphs. Here, we investigate the evolutionary and functional diversity of biting and ram/suction-feeder Neotropical otophysan piscivores. To test for divergence among the dentitions and jaws of fish-eating characiforms we (1) characterize diversity of tooth shapes, (2) describe how functional homodonty profiles vary across piscivores, (3) assess how these profiles co-vary with prey functional categories, and (4) quantify phenotypic convergence among piscivores. We hypothesize that within biters, piranhas (Serrasalmidae) will differ from other lineages given they use their teeth for prey processing, unlike impalers like payaras (Cynodontidae). We also suggest that functional homodonty profiles will vary between biters (pike-like, lateral strikers like *Acestrorhynchus*, *Hepsetus*) and suction-feeders like *Cynopotamus* or *Charax*, (anterior ram/suction-feeders). Unlike other piscivorous lineages that often rely on highly kinetic skulls and pharyngeal jaws to manipulate prey, characiforms are limited to a single pair of non-protrusile oral jaws. By comparing the feeding phenotypes of all piscivores and each lineage's nearest non-piscivore cousins, our analysis will answer an underlying question – are particular jaw shapes or dentitions more suited to the evolution of piscivory?

Title: P3-15: Replacement, regeneration, or maintenance? Deployment of the dental developmental toolkit in skin denticles of adult small-spotted catshark (Scyliorhinus canicula)

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Teeth and denticles (odontodes) have been evolving for 450 million years representing incredible diversity and function. Teeth and other skin appendages like denticles, share a common developmental toolkit or genetic regulatory network (GRN) for their initiation and renewal. Oral teeth in sharks are continuously regenerative due to their ongoing connection to the dental lamina. Unlike oral teeth, skin denticles have no clear connection to a lamina-like structure and it remains unclear whether adult denticles are capable of replacement. Here, we describe the maintenance of regenerative pathways in adult

catshark denticles. We used hierarchical imaging to evaluate if the GRN characterization for denticle morphogenesis, maintenance, and regeneration is preserved through adulthood and where in the skin it is deployed. Using a range of molecular techniques, we are able identify the prolonged expression of key genes into adulthood. Denticles may only regenerate in response to wounding and not like the programmed replacement of the oral dentition. We find that adult denticles are restricted beneath functional denticles and develop superficially compared to embryonic units. Unlike teeth, we have yet to find denticle buds beneath a functioning locus. We suggest that denticles do not replace, and instead develop in response to wound healing or to fill in gaps as the shark grows.

Title: 42-3: Bioimaging of sensory organs and the central nervous system in fishes and reptiles

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Bioimaging is changing the field of sensory biology especially for overlooked, rare and difficult to source taxa. When integrated with traditional sensory biology approaches, developing an archival, digital repository of morphological information can bring about a profound advance in our understanding of whole systems without the issues of surgical intervention, the risk of damage and artefactual interpretation. This presentation will focus on bioimaging of sensory organs and central nervous system in fishes (cartilaginous and bony) and reptiles *in situ* to assess the levels of morphological variation, sensory adaptation and predict structure-function relationships in light of phylogeny, ontogeny and environmental variability. Our Group uses a range of bioimaging techniques, including diffusible iodine-based contrast-enhanced computed tomography, magnetic resonance imaging and phase contrast X-ray imaging to render high resolution 2D and 3D models of the chemoreceptive, visual and auditory organs and their afferent-recipient brain regions. *In situ* imaging of these soft tissue regions are being used to quantify the relative size of the brain and sensory brain regions to predict the relative importance of different sensory modalities, identify sensory specialisations, and construct geometrical meshes for biomechanical investigations. These datasets also assist stereotaxic targeting for subsequent tract tracing studies, electrophysiological recording and targeted ultrastructural analyses. Ultimately, this multidisciplinary approach improves our understanding of the evolutionary drivers of sensory adaptation and developmental plasticity in key taxa of fishes and reptiles.

Title: 31-4: Leveraging kinematic performance landscapes to model the macroevolution of feeding in reef fishes

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A central goal of the evolutionary biology is understanding the processes that lead to the accumulation of phenotypic diversity. Biomechanists have an advantage for understanding this puzzle: the unavoidable physical and mechanical principles that govern organisms' movements. Yet how these physical principles directly affect the evolution of lineages through time remains unclear. A major innovation in the recent years is to use these biomechanical principles to estimate the topography of the performance landscape for a given task, such as building the performance landscape from hydrodynamic models of the suction feeding strike. Here, we develop a model-fitting framework to estimate the evolutionary trajectory of lineages across performance landscapes, with reef fishes as a model system. We discretize the landscape to fit biogeography-style models estimating the history of lineages' paths across the performance landscape, where transition rates between regions of the landscape are weighted by the performance gradient between them. This model-fitting framework provides a toolkit for asking a range of questions about the history of kinematic evolution and has wide applications for bridging macroevolutionary processes with the biomechanical principles that underly animals' every move.

Title: 22-4: Taking a bite out of the controversy: A practical method for investigating the killing bite of sabertooths

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The role of elongated canines in kill bites of extant and extinct big cats remains controversial. Extant big cats typically kill by biting high on throats of their prey, often without penetrating skin. A long-standing hypothesis, the so-called 'stabbing hypothesis', suggests that saber-like canines of extinct big cats were used to sever large superficial vessels, presumably causing rapid death by exsanguination. We recently investigated how three felid canine morphotypes, conical (*Panthera leo*), dirk (*Smilodon fatalis*), and scimitar *(Homotherium serum*) might incapacitate/kill when applied high on throats of prey of different sizes and skin thicknesses. We applied compressive and penetrative bites to prey specimens to observe whether upper canines obstruct or sever critical viscera. Compressive bites to throats of all tested prey species by all tested cat species were successful in collapsing those viscera at relatively low bite forces. Penetrating bites by both sabertoothed forms compressed the viscera, but failed to sever vessels. Our findings suggest that some sabertoothed cats could have killed by employing a bite similar to their modern relatives. Our findings do not preclude the 'stabbing hypothesis', but are not supportive. We presume to offer our experimental apparatus and procedure as a prototype for exploring 'sabertoothy' in the absence of observable behavior.

Title: 37-2: Maximum force and fingers implication of tip trunk in African savannah elephants.

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Elephants use their trunk in various contexts such as communication, grooming, food and water handling and tool use and manufacture. Composed of 150,000 muscle bundles and without a rigid structure, this muscular hydrostat has excellent freedom of movement. Although it fulfils fundamental functions for elephant survival, little is known about how it works. It has recently been shown that the distal conformation of the trunk varies with the shape of the objects grasped but scant data is quantifying its strength. In this context, we wondered how the forces are distributed across the involved fingers of the trunk's prehensile tip. An experiment was conducted with five captive African savannah elephants (Beauval Zoo, France). Using a device equipped with force sensors and a reward system, we were able to record the maximum strength of trunk tip pinching and its distribution. The results showed that the strength of the trunk tip is relatively weak regarding the total force that elephants can display with their entire trunk, so we hypothesise that the trunk tip has mainly a precision function. We also highlighted that the maximum strength varies according to the grasp type, trunk fingers used and morphology of the trunk tip. The results are discussed about the morphological and kinematics data of the trunk tip.

Title: 15-2: Diet-induced morphological change in red squirrels

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Red squirrels (*Sciurus vulgaris*) in Great Britain have severely declined in numbers over the last century owing to habitat loss, disease and an invasive competitor, resulting in a fragmented population. Here, we set out to determine if the remaining isolated populations of British red squirrels vary in morphology, and whether such variation can be attributed to differences in diet. Shape variation was assessed via geometric morphometrics of the cranium and mandible of red squirrel specimens from four populations. The red squirrel population from Formby (Lancashire) was found to be significantly different in both its cranium and mandible, with shape changes indicating a smaller and less efficient temporalis muscle. These differences were found to be less pronounced in more recently collected individuals. These results are consistent with the known diet of Formby squirrels, which in the 1990s was heavily supplemented with peanuts, which are less mechanically resistant than naturally available squirrel food. Supplementary feeding of Formby squirrels has been much reduced in recent years, which is consistent with the less extreme morphological difference in the more recent squirrel specimens and suggests the morphological variation represents within-lifetime remodelling rather than a population-wide genetic shift. The relationship between skull morphology and feeding biomechanics in squirrels is now being explored using virtual modelling techniques such as multibody dynamics analysis and finite element analysis.

Title: 40-5: Investigating the only extant vertebrate with three sets of paired appendages

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Holocephalans exhibit appendages called pre-pelvic claspers (PPCs) that are located anterior to the pelvic fins, while pelvic claspers are pelvic fin modifications located posteriorly as modified metapterygia. Articulation points of the PPCs have not been evaluated, therefore they may represent modified pelvic fin structures if they articulate with the propterygium, or the only example of an independent third set of paired appendages in an extant taxon, if they articulate independent from pelvic fin basal cartilages, challenging the current paradigm that extant jawed vertebrates are constrained to two sets of paired appendages. Two extinct groups, including Placoderms and Acanthodians, exhibit variation in the number of paired appendages, suggesting this may be a plesiomorphic trait. We evaluated PPC morphology, the origin of insertion, and development in four Holocephelan taxa. Both the pre-pelvic and pelvic claspers increase in size until sexual maturity, relative to standard length, and then level off, suggesting synchronous development via shared regulatory pathways. CT scans revealed that PPCs are not modified propterygia, nor do they articulate with the propterygium. They articulate with the puboischiadic bar (or pelvic girdle and homologous to the coracoid in the pectoral fins), as part of the lateral pelvic process, suggesting that while they are associated with the pelvic girdle, they may indeed represent a third, independent set of paired appendages in extant holocephalans.

Title: 48-4: How does brain region size and neuronal investment compare in ecologically diverse snakes?

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Establishing the relationship between brain region size and underlying neuronal traits is fundamental to addressing questions in vertebrate brain evolution. In mammals, changes in the size of brain regions often coincide with major adaptive shifts and can facilitate new sensory specialisations and/or behavioural flexibility. In birds, brain size is generally constrained by the physics of flying, but dense 'neuronal packing' compensates for their diminutive overall brain size. Lizards and snakes are the closest living relatives to birds and represent nearly 50% of terrestrial vertebrate diversity, yet this group is comparatively understudied in neurobiology. We assessed volumetric brain region changes in 75 ecologically diverse species of snakes using diffusible iodine contrast enhanced microCT (diceCT). To link gross volumetric changes with neuronal investment, we are trialling a range of neuronal counting techniques in representative morphotypes in snakes. By integrating gross phenotypic bioimaging of brains with microneuroanatomical techniques, we aim to test the 'universal' rule of proportional scaling of brain region size in snakes for the first time. These integrative data and techniques can be used to address pertinent questions on brain development and evolution including how reptile brains are impacted by increasing temperatures under climate change and the role of sensory integration in ecological adaptation.

Title: 11-3: Was Pelagosaurus typus (Crocodylomorpha: Metriorhynchoidea) an ambush predator or an active hunter? Warm-blooded or cold-blooded?

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Non-metriorhynchid metriorhynchoids (*Magyarosuchus fitosi* and *Pelagosaurus typus*) are considered as having a predominantly marine lifestyle. The possible presence of a rudimentary hypocercal tail fin in *M. fitosi* suggests that it could have been an (endothermic?) pelagic active hunter, whereas the presence of dorsal and ventral osteoderm armors suggests a more (ectothermic?) sit-and-wait ambush predator. The fin tail is absent in the close relative *P. typus*. To evaluate the basal metriorhynchoid metabolism, we inferred in *Pelagosaurus typus* (a) the maximum metabolic rate, using the radius of femoral nutrient foramina quantified from CT-

scans (MNHN.F.RJN470), and (b) the resting metabolic rate using bone paleohistology (MNHN.F.1914-9). *Pelagosaurus* has a compact cortex showing a cyclical growth, with zones mainly composed of woven bone containing abundant vascularization, and annuli composed of parallel fibered bone containing lines of arrested growth. Inferences performed using phylogenetic eigenvector maps show that (i) the maximum metabolic rate of *Pelagosaurus* was higher (marginally non-significant) than those measured in extant ambush predators (Crocodylia) but lower (marginally non-significant) than those measured in extant active hunters (Varanidae), and (ii) the resting metabolic rate of *Pelagosaurus* was significantly lower than the threshold separating ectotherms from endotherms. In conclusion, *Pelagosaurus typus* was "cold-blooded" and had a hunting behavior more active than that of extant sit-and-wait ambush predators, but not as active as that of extant varanids.

Title: 36-5: Gotta catch them all: a novel view of the anatomy and functional morphology of the masticatory apparatus in hystricomorphous rodents

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Hystricomorphy is one of the main cranial morphotypes of rodents and has repeatedly evolved in independent clades, especially in extant Ctenohystrica, Anomaluromorpha, Dipodoidea, and Gliridae. It is characterized by an enlarged infraorbital foramen in which passes the most anterior part of the *zygomaticomandibularis* muscle. However, due to limited taxonomic and anatomical scope in previous analyses, the extent to which this cranial condition varies as well as its relationship with function and phylogeny remains elusive. To address these questions, we first used traditional dissection and diffusible iodine-based contrast-enhanced computed tomography (diceCT) to describe and compare the anatomy of the masticatory musculature in half the extant generic diversity of hystricomorphous rodents (n = 40 genera). Then, we explored covariation patterns between muscles and cranio-mandibular morphology using geometric morphometrics and linked it to masticatory movements using cineradiography in some key taxa. We show that substantial variations in the anatomy of the masticatory apparatus can be observed at the sub-familial level, which corroborates recent phylogenetic hypotheses. Our observations cast doubts on the previous recognition of convergently evolved hystricomorphous states in distant rodent clades. Additionally, preliminary results based on cineradiographic data dispute simplistic biomecanical views based solely on dental morphology and tooth microwear analyses. These results are promising and highlight the need to incorporate more experimental data to capture the extent and complexity of masticatory biomechanics in rodents.

Title: P4-6: Anomaluromorph rodents: evolution through masticatory muscle anatomy

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The Anomaluromorpha are one of the five suborders of rodents and include three different families: the Pedetidae, Anomaluridae, and Zenkerellidae. As their name suggests, anomaluromorphs —which include scaly-tailed flying squirrels and springhares— are extremely puzzling rodents. They evolved independently over long periods of time and present very disparate cranial morphologies. In order to investigate how their masticatory apparatus was shaped over time, we first described and then compared the anatomy of the masticatory muscles of all extant anomaluromorph genera (n = 4; *Pedetes*, *Anomalurus*, *Idiurus*, and *Zenkerella*). We used diffusible iodine-based contrast-enhanced computed tomography (diceCT) methods as they offered the opportunity to accurately and non-destructively dissect specimens from historical museum collections and combined it with traditional dissection when possible. Our observations indicate that the infraorbital part of the *zygomaticomandibularis* muscle shows an orbital division, which is uncommon for rodents. Moreover, the morphology of the *masseter profundus* muscle of *Zenkerella* illustrates the importance of the taxa in understanding the progressive reduction of its relative size to the benefit of the *zygomaticomandibularis* muscle. In conclusion, the study of the masticatory muscle anatomy can provide valuable informations regarding the evolution and relationships of anomaluromorph rodents as well as to infer ancestral muscle morphologies within the group and compare them to the existing fossil record.

Title: 49-1: Bone microstructure across ocean depth in teleost fishes

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Bone microstructure has recently risen as a prime proxy to ecology and locomotion mode in terrestrial vertebrates. On the other hand, in teleost fishes representing half of vertebrates, microstructural diversity has been barely characterised.

One of the most often-discussed aspect of bone structure in teleosts is its presumed variation alongside depth gradients. Bone in deep-sea teleosts is generally described as “poorly mineralised”, in relation with depth-related constraints such as water pressure and the scarcity of mineral nutrients. However, few comparative data across deep-sea teleost diversity exist, limiting our understanding of this phenomenon.

In this project, we tested the relationship between bone microstructure and water depth in a large taxon sample covering the whole diversity of deep-sea teleosts. Using propagation phase contrast synchrotron X-ray μCT, we imaged the microstructure of abdominal vertebrae in ~60 teleost

species. The taxon sample covers all major lineages of deep-sea teleosts, alongside close shallow-water relatives.

Preliminary analysis of the dataset shows that the vertebrae of deep-sea taxa tend to have a lower compactness. Trabeculae tend to become extremely thin and to encompass the whole volume of the vertebrae. This pattern appears to be consistent from one lineage to another, although other factors may be at play, particularly the benthic-pelagic axis.

This study is a crucial first step in deciphering patterns of adaptive changes in the hard tissues of deep-sea fishes.

Title: 36-4: Masticatory Motor Patterns in Frugivorous Phyllostomid Bats

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Of many factors influencing craniofacial morphology in mammals, the importance of mastication has been well documented. The generalized mammalian head is adapted to the unique demands of rhythmic chewing, and because foods vary widely in material properties, dietary specializations correlate with species-specific morphological and functional characteristics (e.g., timing of jaw adductor muscle activity—"*motor patterns*") during chewing. Many compelling hypotheses regarding the influence of integration, adaptation, and constraint on functional morphology across Mammalia have been difficult to assess due to limited sampling currently heavily skewed toward primates. Although Chiroptera is among the most speciose and ecomorphologically diverse mammalian orders, *in vivo* masticatory studies have previously only been carried out in two species of bats. In this study, electromyography was recorded from jaw adductors during rhythmic mastication of fruit in two species of frugivorous phyllostomid bats (*Carollia perspicillata* and *Artibeus jamaicensis*). Analysis suggests that frugivorous phyllostomids exhibit motor patterns that previous studies have correlated with a fused mandibular symphysis, resembling patterns found among other frugivorous mammals and diverging from previously studied bat species and mammalian generalists. This provides further evidence that while some features of the mammalian motor pattern may be highly constrained, others readily adapt to dietary pressures. These data add critical dietary and phylogenetic diversity to the available sample and an opportunity to better assess existing hypotheses regarding evolutionary patterns in craniofacial diversity among mammals. Funding (NSF IOS-1931135).

Title: 23-3: Investigating the strength of mechanical function in controlling the shape of vertebrate jaws

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The vertebrate jaw is an often cited example of a biological system tightly controlled by mechanical function. As a lever system that is utilised in food processing, it's functional performance should be linked with a vertebrate's survivability. While many studies have linked jaw morphology with function, whether natural selection has optimized this system is not clear. By using 2D theoretical morphology, biomechanical function and Pareto optimality, we test whether the range of jaw shapes explored by evolution is biomechanically optimal compared to the theoretical variety that could have evolved. We assess three key transitions in the macroevolution of the vertebrate jaw: its initial appearance and radiation in the fossil record; the transition from water to land and the origin of tetrapod feeding systems; and the reduction of the number of jaw bones in the evolution of synapsids, following which the modern diversity mammals is observed. We find that the 2D shape of the mandible remains remarkably conserved over very large evolutionary time spans within mechanically optimal regions of morphospace. Additionally, transitions in environment regularly represent shifts in morphospace occupation, further supporting a strong mechanical bias on jaw morphology. Despite this, there is significant phylogenetic bias in our morphological datasets, and the transition to a singular bone jaw in mammals allows further exploration of morphospace. Phylogenetic and morphogenetic controls on jaw form still limit the evolution of jaw shape.

Title: 38-4: The bizarre bulbous bucklers of skates: Denticles, dermal bone or something else?

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The morphology and arrangement of skin denticles in sharks is often related to hydrodynamic function, whereas denticles of batoids (rays) are often sparser and considerably larger. In particular, some skates (*Raja*) bear modified 'bucklers', denticles with greatly swollen bases, often far larger than the denticle's cusp. Our imaging/materials/histology techniques reveal bucklers have a curiously bipartite structure: the cusp is a standard placoid scale jutting from the skin, whereas the massive spheroidal base envelops it from beneath, like an inverted mushroom cap. The base is tethered to the cusp by dense arrays of Sharpey's fibers and anchored into underlying muscle by connective tissue seams. Contrary to previous interpretations, we show bucklers are not bone, but involve multiple types of dentine. Like other placoid scales, the cusp is mostly a dense orthodentine, perforated by microtubular passages and pulp cavity. The base, however, is more similar to a bone-like osteodentine, forming concentric, irregular layers

indicating accretive growth with no remodeling, with some specimens suggesting the cusp can be shed independently from the base. Whereas superficial layers of the base are rich in vascular passages, the tissue beneath the cusp appears to be a third type of dentine, peppered with lobulate voids, often associated with regions of higher mineralization. We compare bucklers to other elasmobranch skin ornaments and discuss the functional implications for their bizarre structure.

Title: P3-18: The evolution of cochlea shape in primates and other euarchontans

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A coiled cochlea is a unique feature of therian mammals. Given its crucial role in hearing its detailed functional morphology has been studied in a few model organisms. As part of the inner ear , the bony cochlea is housed inside the dense petrous bone and is often well-preserved in the mammalian fossil record. Thus, non-invasive computed-tomography provides the opportunity to perform evolutionary and functional comparisons of this sensory organ using broad samples of extant and extinct species of mammals. One aspect that has not been investigated extensively is its three-dimensional shape, a feature presumed to have functional implications for hearing, particularly for those related to the frequency of the hearing-limits. Here, using microCT, landmark-based 3D geometric morphometric analyses, and ancestral reconstructions, we investigated cochlea shape changes of 95 species of extant and extinct primates and their phylogenetically most closely related groups (Dermoptera and Scandentia) and estimated plesiomorphic states to reconstruct its evolutionary history. Our results show that cochlea shape allows for morphological distinction between all major taxa, also suggesting that these differences could be associated to various ecological variables. Our results also show that cochlea shape has a complex history in euarchonta, with taxa like Tarsiiformes and Hominoidea acquiring their derived morphology early, while others have retained plesiomorphic traits throughout their entire evolutionary history.

Title: 39-4: Dental microwear texture attributes in similar tooth forms can reasonably be compared in phylogenetically disparate mammals

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Dental microwear texture analysis (DMTA) is commonly used to assess the dietary ecology of modern and fossil taxa, including mammals with herbivorous to carnivorous diets. In carnivorans, teeth with different functions record dietary behavior differently and one must be careful not to compare functionally distinct teeth to one another. If forms are similar, comparisons of different tooth positions and/or comparisons between phylogenetically distinct

taxa may be appropriate—though currently untested. Here, DMTA variability in diverse mammalian taxa is assessed to test the following hypotheses: 1) dental microwear of tough and/or hard food consumers is recorded similarly in functionally similar teeth, regardless of phylogenetic relationships; and, 2) phylogenetic relationships are not necessarily predictive of dental microwear texture attributes preserved on tooth wear surfaces. DMTA was compared in taxa with teeth that have similar functions and in taxa with teeth that have different functions. Results demonstrate that while different forms do yield different DMTA attribute values, similar forms also result in similar DMTA attribute values across a wide range of taxa. For example, comparisons between possums, kangaroos, and phylogenetically distinct tapirs are suitable when all teeth being compared are bilophodont in form. As opposed to needing to apply phylogenetic corrections to DMTA data, if forms are similar, one may reasonably compare diprotodons to tapirs and the shearing teeth of thylacines to the shearing carnassial blades in canids.

Title: 39-5: Dietary correlates of primate tooth root surface areas

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As food is processed initially by contact with tooth crowns, primate tooth crown morphology, and dietary correlates thereof, have been studied extensively. However, as force is applied to foods via the tooth crown, it is transmitted through the tooth root. Therefore, the surface area of those roots should correlate with the forces transmitted through them. As different diets and ingestive behaviors require different magnitudes of force, tooth root surface area (TRSA) should also reflect these correlates. Previously, we published dietary and scaling correlates of mandibular postcanine TRSA and have presented on ingestive and gouging correlates of anterior TRSA, but we are now presenting functional correlates of the TRSA of the maxillary postcanine teeth themselves and in relation to these other dental functional regions. While the masticatory forces transmitted through the mandibular and maxillary teeth should theoretically be equal because the maxilla has functions beyond mastication, the maxillary tooth roots may be under different constraints. Although maxillary and mandibular postcanine teeth largely scaled similarly, differences were observed in two lineages: some members of the genus *Cercopithecus* have relatively very small mandibular postcanine TRSA while almost all strepsirrhines have relatively large mandibular postcanine TRSA. Additionally, while the strongest dietary signal across all regions differentiated folivores from frugivores, signals differed for mandibular and maxillary TRSA and, surprisingly, did not correlate with gouging behaviors for anterior TRSA.

Title: 27-4: Squamates as a model to understand the key dental features of vertebrates

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Thanks to their exceptional diversity, teeth are among the most distinctive features of vertebrates. Parameters such as tooth size, shape, number, identity, and implantation can have substantial implications on the ecology of a given species. The laboratory mouse is a classic mammalian system in which many key mechanisms and signaling pathways of odontogenesis have been identified. However, the mouse has a highly derived and reduced dentition and displays tooth characteristics contrasting with the situation in most non-mammalian taxa. As a result, the molecular developmental basis underlying evolutionary patterning and variation in key dental features such as tooth implantation, complexity, and regeneration capacity remains largely understudied in vertebrates. Here, we exploit the large array of dental phenotypes in squamate reptiles (lizards and snakes) to assess major aspects of vertebrate tooth diversity. In particular, lizards in the clade Acrodonta such as the bearded dragon show a wide range of heterodont phenotypes, including variation in the size, shape, number, implantation, and/or renewal of teeth at posterior and anterior positions, and thus offer valuable models for studying these fundamental properties. Our comparative studies in new extant species indicate that the origins and diversification of major dental features, long a focus of multiple research fields, can be approached through a combination of evolutionary developmental biology (evo-devo) approaches, thus providing a deeper insight into evolutionary patterns of vertebrate dentitions.

Title: 10-8: Variation in curvature and cortical geometry in the primate humerus and their consequences for inferring biomechanical performance

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Long bone morphology has long been in predicting locomotor ecology of fossil mammals. In particular, the degree of curvature and cortical cross-sectional geometry (CSG) have been associated with specific forms of locomotion. These metrics of bone function are universally measured at midshaft which, under a simplifed homogeneous beam model, will experience the greatest strain under load. However, more biologically accurate models of bone biomechanics have shown that strain is often distributed away from midshaft. It remains poorly understood how variation in bone curvature controls strain patterns and cortical reinforcement along the diaphysis, which may impact the reliability of biomechanical inference from midshaft measurements. Here variation in curvature and CSG are investigated along the diaphysis of humeri in a comprehensive sample of primates representing terrestrial, arboreal, and suspensory species. The spatial position of peak curvature and CSG metrics deviate significantly from midshaft, and are predictive of ecology. The magnitudes of curvature and CSG are strongly correlated, though their spatial positionings are not. These results suggest that curvature and CSG may have complex biomechanical relationships, and that using simple beam bending models from bone properties measured only at midshaft may not be biologically accurate.

Title: 33-5: Analysing the intervertebral articulation and center of rotation using digital methods: the caudal series of Giraffatitan brancai (Sauropoda, Dinosauria) as case study

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After decades of neglect, biomechanical studies of dinosaur tails are currently thriving. In fact, the simulation of a dinosaur's locomotive and behavioural patterns cannot be complete without considering the tail's motoric capabilities. A complete biomechanical analysis of the hindlimb and caudal series of *Giraffatitan brancai* (sauropod from the Late Jurassic of Tendaguru, Tanzania) is currently in progress. This is the most detailed biomechanical model of a tail created to date. Important considerations that are not well-constrained by the fossil record include the reconstruction of the intervertebral joints and their centers of rotation (CoR). We have investigated two CoR positions in order to test the impact of these uncertainties: 1. center of the reconstructed intervertebral cartilage; 2. dorsal third of the posterior articular surface of the centrum, as in some extant archosaurs. The second position resulted in greater motion ranges. *Giraffatitan*'s amphiplatyan/amphicoelous caudal vertebrae may have articulated with fibrocartilaginous discs or synovial intervertebral joints, both of which are found in living birds. The presence of fibrocartilaginous discs has been also suggested for some deep amphicoelous *Haplocanthosaurus* caudals. Alongside powerful epaxial and hypaxial muscles, intervertebral fibrocartilage would aid in stabilising the amphiplatyan/amphicoelous caudal series. The integration of all these hypotheses and data will be of great help for investigating more complex roles and functions of *Giraffatitan*'s tail and its implications for locomotion.

Title: 53-1: he Visible Ape Project: A free, comprehensive, web-based anatomical atlas to raise public awareness about apes and conservation

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In this talk I will describe, discuss, and seek collaborations within the ICVM members to participate in the multidisciplinary Visible Ape Project. Based at Howard University, this project (www.visibleproject.com) is an example of a new, broader, more inclusive way to research, explore and disseminate anatomy. Namely, it aims to provide free, publicly accessible anatomical research and educational resources for scholars, teachers and the broader public. It

focuses on anatomy and anatomical variation within and between extant ape species, including humans, including photographs, MRI, CT scans, and 3D models to explore homologies and variations in soft and hard tissues across apes and humans. These include detailed, labeled 3D artist renderings of the musculoskeletal system, nerves and blood vessels as well as 3D models of the skeletal and central nervous system based on radiological imaging of apes. These models can be manipulated or downloaded and 3D printed to explore anatomy interactively, promoting active learning. Additional educational materials are available, including information about non-human ape species, lesson plans, and a glossary of evolutionary and anatomical terms. The primary goals of the project are to promote human and ape evolutionary anatomy, broadly, and to integrate and disseminate to communities underrepresented in anatomy, anthropology and evolutionary biology, specifically, including several outreach activities to disseminate science and promote awareness of apes, forming partnerships with rural communities, NGOs and conservationists in Africa, Asia and South America.

Title: 44-4: More than just a platey face: the versatile role of armor in fishes

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An often overlooked trademark of vertebrate evolution is dermal armor. It has appeared in some of the earliest vertebrates (i.e. heterostracans, placoderms) to some of the most recent (i.e. poachers). Though we often think of armor as an adaptation for defense, it has likely evolved to serve multiple functions. Here we investigate armor's role in locomotion, specifically on its hydrodynamic effects and its potential as an energy storage system using poachers (Agonidae) as our model group. Armor diversity within poachers is outstanding, raging from intricate protruding spines and bumpy notches to smooth flat plates. Though the external morphology differs, there are some recurring characteristics such as the overlapping, hexagonal plates and the presence of a locking rail-like system in each armor row. In this work, we first characterized poacher armor diversity using CT scans. We then designed and manufactured idealized models to test the function of the specific shape of poacher armor (i.e. hexagonal, overlapping) as well as other shapes and arrangements (i.e. squares, octagons). To understand armor's hydrodynamic role, we tested idealized and realistic models in flow. We used a universal testing machine to explore how different armor shapes and arrangements affect body mechanics and energy storage using both idealized models and real specimens. Our results reveal the multifunctional role of dermal armor and may inform future bio-inspired designs.

Title: 17-2: BoneJ status and the evolving ecosystem of bone analysis software

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Image analysis is indispensable for testing hypotheses about trabecular bone's important roles in vertebrate life. X-ray microtomography uses contrast from mineralised tissues' attenuation of X-rays to generate accurate 3-dimensional reconstructions, with isotropic resolution (1-100µm pixels) relevant to trabecular scale (Tb.Th 10-500µm). BoneJ measures trabecular bone as a porous continuum rather than as discrete elements. BoneJ2 has improved engineering and introduced new features: Ellipsoid Factor to replace the flawed Structure Model Index; a fast multithreaded Particle Analyser; updated Mean Intercept Length for measuring anisotropy; better integration with Python scripting. BoneJ remains focused on measurement. For segmentation of trabeculae from cortices new classical approaches have emerged, while machine learning (ML) is becoming practical for filtering (e.g. Noise2Void) and segmentation (e.g. Trainable Weka Segmentation). ML is well suited to repetitive, small tasks, while "boutique" analysis on large data may be more efficient using natural rather than artificial intelligence, until pre-trained models become available for immediate use or for transfer learning. Increasing data scale has in general been matched by computational scale with regard to storage size and speed, RAM, CPU and GPU multithreading and network transfer rates, but the "memory wall" throttling data transfer from RAM to CPU remains problematic when iterating over gigapixel images. Government and charity funders now recognise research software development and fund it directly, while image data science has become a distinct role.

Title: P1-7: Limb development GRNs are alternatively spliced during limb development

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Gene regulatory networks (GRNs) governing limb development are highly conserved throughout tetrapods, however, the resulting morphology is incredibly diverse. Differences in the amount and temporospatial dynamics of gene expression are thought to underlie this variation. Previous work has shown that differences in regulatory sequences and epigenetic modification contribute to evolutionary differences in gene expression. We hypothesize that alternative splicing (AS) is an additional mechanism contributing to limb GRN differences. AS produces multiple mature mRNAs from a single precursor mRNA. This may alter effective GRN levels. To test this hypothesis, we used rMATS to identify AS events and patterns within RNAseq data from mouse and opossum limbs at the ridge, bud, and paddle stages. rMATS analysis revealed that splicing of key limb development GRNS including signaling factors such as the FGF family and their receptors changes over developmental time and between species. In particular, AS is more frequent in opossum, but both taxa show that skipped exon is the predominant mechanism. Notably, retained introns decrease across developmental time in both taxa, suggesting a mechanism to subtly reduce gene expression levels. Given that splicing of *Fgf8* and Fgfrs is known to affect their function, we are investigating how splicing of these genes differ among vertebrate limbs. As part of this comparison, we evaluated structural elements of the apical ectodermal ridge in chick, salamander, mouse, and stickleback fish.

Title: 30-2: Beyond the fangs: the untold story of snake tooth microstructure

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Teeth are one of the key tools for animals allowing them to capture, transport, reduce and ingest their prey. Consequently, tooth morphology and structure has been studied for years to infer the diet of many animals. However, only few studies have focused on reptiles and specifically snakes. Snakes have a diverse diet (from durophagy to soft diet) associated with different teeth morphology. Here, we used CT scanning and microscopy observations in order to investigate the tooth structure of 63 different snake species in a functional and ecological context. The results show that enamel is deposited asymmetrically in the labial facet of their teeth. The enamel distribution ranges from entirely recovering the facet to being restricted to the tip only and is dependent on the properties of their prey eaten. Our study suggest that snakes' tooth evolved in response to mechanical challenges imposed by their diet, allowing them to acquire a wide variety of preys. These new results are discussed to understand better the biomechanical properties of the snake teeth and vertebrates more generally.

Title: 36-2: The impact of diet on vertebrate intestinal length

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The relationship between intestinal morphology and feeding ecology is often assumed. Herbivores, consuming low-quality diets, are thought to require an elongated intestinal tract to digest and assimilate their diet. The opposite is assumed for faunivores. We collected data on intestinal length related to body mass from published sources and our own dissections. We analyzed the relationship between diet and total intestinal length for 1474 vertebrate species, including mammals, birds, reptiles, and fish. Species were classified as herbivores, omnivores, or faunivores, acknowledging that these categories may have different relevance for individual vertebrate clades, and they ignore microbes as a prey source, particularly for fish and mammals. Our analysis revealed that mammals have the longest intestinal tracts followed by birds, reptiles, and fish. However, the overlap between clades is large. With and without accounting for phylogeny, intestinal length is greater in herbivores compared to omnivores, and faunivores have

the shortest intestines proportionally. Diet digestibility is the likeliest explanation for this pattern: large proportions of fiber or inorganic substrate reduce digestibility, which can be compensated by longer intestinal tracts, increasing the surface for absorption and nutrient assimilation, and in some species providing space for microorganisms aiding with digestion. Our study in principle corroborates the correlation between consumed diet and intestinal length, however, with considerable overlap between dietary groups. Convergence, in this case, is a majority rule rather than a fixed biological law.

Title: 9-3: Comparative feeding mechanics of extant lungfishes

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Lungfishes are the first vertebrate lineage that evolved durophagy. This ability to eat hard prey entails a series of anatomical specialisations that drove the divergence of lungfishes from the ancestral sarcopterygian morphotype during the Early Devonian. The sequence of morphological transformations associated with durophagy is now better understood and appears to have occurred rapidly during the early evolution of lungfishes. However, the significance of these transformations for skull biomechanics remains unclear. Filling this gap requires a detailed appraisal of the variation in skull musculoskeletal function and structural mechanics among living lungfishes. We here focus on the Australian lungfish (*Neoceratodus*) and the African lungfish (*Protopterus*) because they show conspicuous difference in the morphology of the head and feeding apparatus. We first performed quantitative dissections and 3D reconstructions from high-resolution synchrotron scans to compare the morphology and musculature of the feeding system. We then used 3D static modelling to assess the musculoskeletal performance of the jaw-closing system. Our results show that the feeding system of the African lungfish is more efficient in transmitting muscle force and minimizing joint-reaction force during biting. Finally, we used finite element analysis to compare the mechanical behaviour of the jaw under feeding loads. This study lays the foundation for a broader comparative study of cranial biomechanics in extant and fossil lungfishes.

Title: 20-1: An amphibious fish that might self-inflict TBI?

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In what is known as the “Krogh Principle”, August Krogh championed a broadly comparative approach, recognizing that even strange organisms might unlock important secrets in physiology and medicine. That traumatic brain injury (TBI) has manifold effects on neurobiological function and behavioral expression is not an enigma. However, the precise mechanisms linking neuronal injury to crippling changes in behavior still elude us. To address this challenge, we require an organism that: 1) infrequently encounters opportunities for brain damage in the wild - while too common in human populations, concussions remain relatively infrequent; 2) live terrestrially/amphibiously and exposed for part of its life to relevant gravitational forces; 3) laboratory friendly. Here, I introduce mangrove rivulus fish (*Kryptolebias marmoratus*) as a potentially powerful model in TBI research. Rivulus inhabits highly tidal mangroves and often occupies areas with little to no water. It has numerous adaptations for terrestrial living, including tail-flip jumps where the fish turns itself into a projectile and propels into the air. If jumping unimpeded, the fish typically land on their head, which inspired us to investigate whether this might induce brain injury. Their life history is highly amenable to laboratory work, and they are self-fertilizing hermaphrodites that naturally produce isogenic lineages. This will enable us to gain some traction on, for instance, the genetic underpinnings of susceptibility to TBI-induced brain damage.

Title: 26-4: Avian olfactory bulb evolution informed by the Late Cretaceous neornithine Asteriornis maastrichtensis

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Reduction in the olfactory system is a hallmark of avian brain evolution, along with expansion of the visual system and cerebrum. As brains almost never fossilize, cranial endocasts provide the best evidence of brain morphology in deep time. Identifying the timing of macroevolutionary changes in avian brain morphology is hindered by the scarcity of three-dimensionally preserved Mesozoic bird fossils. Towards clarifying the evolutionary history of the avian olfactory system, we generated a digital cranial endocast of the type specimen of *Asteriornis maastrichtensis* (NHMM 2013 008), a Late Cretaceous neornithine. This specimen preserves the anterior portion of the braincase, including the olfactory bulb region. The incompleteness of the skull of *Asteriornis* precludes unambiguous estimates of its total endocranial volume, so we regressed brain volume against body mass for >1,900 extant birds, and used the resulting relationship to predict the brain volume of *Asteriornis* from its estimated body mass. We then regressed olfactory bulb volume (n=30) and diameter (n=40) against brain volume for both our sample of extant birds and *Asteriornis*. We found that the relative size of the olfactory bulbs of *Asteriornis* fell within the range of relative olfactory bulb size seen in extant birds. These values suggest that a reduction in relative olfactory bulb size arose early in the evolutionary history of crown birds, and may have preceded the origin of crown birds themselves.

Title: 38-3:Lizards in Chain Mail: Reconstructing the Enigmatic Past of Dermal Armour in Squamate Reptiles

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Every living organism must sustain a boundary with its external environment. Despite this fundamental role, certain features of the vertebrate integumentary system remain poorly understood. This is particularly the case for dermal mineralisations (osteoderms), their ecological significance, and their evolutionary history. Osteoderms are structures that occur widely but inconsistently across the tetrapod phylogeny. The largest number of osteoderm-bearing taxa are found in the ecologically highly diverse Squamata (lizards and snakes). However, due to a lack of a systematic quantification, it remains unresolved if squamate osteoderm microstructure, like that of other vertebrate hard tissues, might be diagnostic for certain lifestyles. In order to bridge this gap in our understanding, we investigated squamate osteoderm expression based on >600 micro computed tomography (μCT) scans and literature resources. Ancestral character state reconstruction revealed that osteoderms likely evolved independently in different squamate lineages. We are currently developing a protocol for performing a large scale μCT-based quantification of squamate osteoderm cover microanatomy to identify lifestyle correlates in a phylogenetically informed analysis. These may then allow the reconstruction of historic lifestyle transitions and thus provide novel insight into evolutionary trajectories and constraints that shaped present day biodiversity.

Title: 36-1: The Impacts of Various Modalities of Esophageal Stimulation on Infant Mammalian Feeding Physiology

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The morphology of the infant mammalian aerodigestive system necessitates the precise coordination of structures in the oral cavity, pharynx, and esophagus to maintain airway protection. Neural connections allow for sensorimotor integration among these structures – for example, esophageal afferents project to the nucleus tractus solitarius, which in turn projects to pharyngeal motor neurons. Furthermore, the extensive interconnectivity of behaviors in the oral cavity and pharynx may imply that esophageal sensation indirectly alters oral motor outputs. Despite these known functional and neuroanatomical links, the effects of various modalities of esophageal stimulation on oral and pharyngeal behaviors remain relatively unexplored. To assess these effects, we collected videofluoroscopic and electromyographic feeding data for six infant pigs under normal conditions and following perfusion of 1) saline, 2) capsaicin, and 3) HCl into the lower esophagus. Both saline and HCl perfusion slightly decreased swallow rates relative to controls, while only saline perfusion decreased suck rate relative to controls – though suck rate increased with HCl perfusion relative to saline. Esophageal capsaicin perfusion did not significantly alter suck or swallow rates, and genioglossus activity was unchanged across stimulation modalities. These results suggest that neural pathways among oral, pharyngeal, and esophageal structures may facilitate minor changes in sucking and swallowing neurophysiology following disrupted esophageal sensation. Moreover, different modalities of esophageal stimulation may elicit differential motor responses in earlier stages of infant feeding.

Title: P1-4: Trunk morphology in the Asian and African savanna elephant

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The elephant trunk is not only one of the most fascinating grasping organs but also contains the most complex musculature known in the animal kingdom. For centuries scientists have tried to figure out how elephants are able to skillfully use their trunk for grasping. However, because of the sheer complexity of muscle fascicles and the limited access to elephant material, only rough estimates of muscle fascicle numbers in elephants have been made. Presently, using high-resolution microCT (microfocus computed tomography) scans, we performed dense reconstructions of trunk muscle fascicles in an Asian baby elephant, to better understand this unique musculature. Given the differences in trunk tip anatomy between the Asian and African elephant – Asians have one, while Africans have two ‘fingers’ – we continued with reconstruction of an African elephant trunk tip to investigate their musculature. We show that the trunk tip is composed of about 7000 fascicles consisting of only two types of muscles (radial and longitudinal), whereas the middle and proximal trunk shaft is composed of five types of fascicles (transversal, radial, and parallel, downward and upward longitudinal). We estimate the total number of trunk muscle fascicles to be around 120 000. Our findings provide perspectives into

the evolution of grasping in the elephant trunk, which has led to minute fascicles and an explosion of muscle fascicle number.

Title: 27-3: General principles of form and function in vertebrate teeth

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The primary task of most vertebrate teeth is to acquire or process food, but the forms of teeth result from the interplay of their development, function and evolution. In development, cusp shape is largely generated according to the power cascade rule of growth, with the power cone as the fundamental cusp shape. Early-developing cusps inhibit later cusps, such that the final number and arrangement is due to the patterning cascade. The inhibitory cascade strongly influences the size and number of teeth along tooth rows, and enables integration along and between jaws. For function, the force to puncture or fracture food must be balanced against the risk of fracturing the tooth itself. For unicuspid teeth, robustness, curvature and cross-sectional shape are important shape characteristics, as are rake angle and approach angle for bladed teeth. The number of features on a tooth will alter its effectiveness according to the physical properties of the food, such that higher complexity is important for plant feeders, but is disadvantageous for carnivores. When the complexity of a tooth varies due to wear during the life of an animal, this alters its performance in fracturing food. Certain shape factors of teeth, such as inhibitory cascade and complexity in murids, appear to be developmentally linked, and I show that their evolution is not independent of each other.

Title: P4-2: The effects of shape and complexity on the performance of mammal teeth

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Teeth must break food without themselves being broken. The shape of a tooth influences how stresses are applied to puncture and fragment food, and how it resists these stresses within itself. Slender and laterally compressed unicuspid teeth of mammalian carnivores require the lowest force to puncture tough, soft foods during physical performance testing. However, these same teeth show higher risk of fracture in finite element analysis (FEA). For bladed teeth, high rake angle and moderate approach angle maximise the performance for cutting tough, soft foods. Increasing the complexity of a tooth, or the number of features on its surface, is expected to improve the operation of herbivore teeth, as more food can be fractured for each chew. However, this has not been demonstrated. Koalas (*Phascolarctos cinereus*) are arboreal folivores whose teeth significantly change shape with wear, such that older animals with very worn teeth are unable to sufficiently process leaves to obtain sufficient nutrition. Here we show that young koalas have moderately high dental complexity (measured as orientation patch count OPC), which increases in middle-aged animals and drops precipitously in old animals. The sizes of

chewed leaf particles correlate inversely with tooth complexity, indicating that complex teeth are more effective at leaf comminution.

Title: 14-5: A novel mode of jaw protrusion in the hingemouth, Phractolaemus ansorgii

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Premaxillary protrusion and the performance advantages it confers has been implicated in the success of diverse teleost lineages such as cypriniform and acanthomorph fishes. Highly kinetic systems that actuate jaw protrusion have long been fascinating to functional morphologists as they represent multiple solutions to the same ecological challenge— that of feeding in a viscous, fluid medium. Few studies characterize jaw protrusion beyond Cypriniformes and Acanthomorpha and fewer yet investigate the functional anatomy beyond the relatively conserved musculoskeletal system enabling it. Here we investigate an isolated and independent origin of jaw protrusion in the hingemouth, *Phractolaemus ansorgii,* which employs a complex arrangement of bones, musculature, and connective tissue to feed on detritus via a deployable proboscis. Using high-speed videography, we characterize feeding behavior and kinematics and find this mechanism performs comparably in protrusion distance and velocity to several minnow and cichlid species. Furthermore, we describe a novel functional mouth at the end of the proboscis that is used to probe along the substrate. This mouth is highly flexible, composed of cartilages and other connective tissues, covered in keratinous tooth-like structures, and uniquely unsupported by the oral jaw bones. The reorganization of cranial anatomy required to construct this deployable mouth represents a morphological and functional novelty, a novelty whose monotypic origin belies its evolutionary significance as a highly specialized mechanical solution for benthic feeding.

Title: P2-4: Comparative Anatomy of Otomorphan Epibranchial Organs

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The ability to extract small prey items from large volumes of water is widespread among microphagous fishes, all of which face the same metabolic hurdle of consuming enough food particles to meet their nutritional needs. Certain planktivorous and detritivorous

fishes possess an epibranchial organ (EBO) in their posterior pharynx that facilitates the aggregation of small prey. Morphologically complex and phylogenetically diverse, EBOs are novel trophic structures that have evolved independently in at least six families across teleosts with the majority of both morphological and taxonomic diversity occurring within otomorphan fishes. Otomorphan EBOs range from the small slits in the roof of the pharynx to medioventrally expanded, papillae-lined pouches, yet despite their phenotypic diversity, they share several anatomical components including an internal tube with an epithelium rich in mucus cells, a surrounding layer of skeletal muscle, and support from the posterior branchial arches. Here, we present a comparative study of EBOs from ten otomorphan species. Using gross dissection, histology, and scanning electron microscopy, we describe the degree to which architectural components of the EBO exhibit patterns of convergence in shape, size, muscularity, adiposity, and the morphology of the papillae that line their internal surface. Grounded within both a functional and phylogenetic framework, we discuss whether differences in this intricate anatomy can best be explained by specializations to a similar feeding ecology or by phylogenetic relatedness.

Title: 35-1: Many roads lead to herbivory: Phylogenetic Constraints on the Convergent Evolution of Marine Herbivorous Fishes

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Convergent evolution is widely celebrated as direct evidence for the effect of the environment on shaping the evolutionary trajectories of organismal phenotype. Highly specialized life histories are thought to drive strong patterns of convergence among distantly related species by limiting the range of phenotypic variation within a particular specialized ecology. Herbivory has evolved multiple times across metazoans and is typically accompanied by suites of traits that allow for the effective ingestion of plant material. Spiny ray-finned fishes (Acanthomorpha) have also evolved various forms of herbivory repeatedly, and in the process, have evolved a stunning diversity of morphological adaptations that allow them to feed on this specialized food source. Here, we test for convergence in both form and function of the skull across 227 species of acanthomorph fishes spanning eight families using three-dimensional geometric morphometrics and performance surface modeling. We additionally test for differences in the rate of shape evolution between herbivore and non-herbivore acanthomorph species. We find little evidence for convergence among herbivores in either skull shape or in the mechanical advantage of the mandible. Instead, we find that herbivores tend to more closely resemble their non-herbivorous closest relatives than they do other herbivores. Interestingly, we find that herbivore skull shapes evolve significantly faster than non-herbivores. These results suggest that herbivores rapidly diverged from their non-herbivorous relatives by slightly modifying existing body plans.

Title: 46-3: Middle Jurassic fossils from England and Scotland document early stages in salamander evolution

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Salamanders are model organisms for understanding locomotion and life history. However, the earliest history of salamanders is poorly known which restricts evaluation of character polarity and character assembly. Here we investigate the Middle Jurassic fossils from Skye (Scotland) and Kirtlington (England) which include at least three taxa (*Marmorerpeton* spp., Salamander-A, Salamander-B), some of which are represented by exquisite 3D bones and undistorted articulated skeletons. We employed a new phylogenetic analysis, greatly expanded from previous works (413 characters and 70 taxa: seven dissorophoids, 17 non-urodele lissamphibians, 24 fossil salamanders, and 22 extant salamanders), analysed in MrBayes 3.2 with a relaxed MkV model of character state transitions, independent gamma branch rates, and a fossilized birth-death tree prior. Results place all three taxa outside the crown group but unrelated to each other as part of a diverse stem-group. *Marmorerpeton* helps consolidate the extinct clade Karauridae, characterised by an ornamented skull-roof and large prefrontal process that enclosed the orbit. Their pelvis, femur, skull, and tail indicate an aquatic lifestyle analogous to modern cryptobranchoid salamanders. Salamander-A, with its elongate ilium and poorly ossified joint surfaces, is placed just within total group salamanders. The diminutive and terrestrial Salamander-B (e.g. well ossified scapulocoracoid and femur) is placed just outside the crown. We also find stem-group affinities for several Jurassic-Cretaceous salamanders from China (e.g. *Chunerpeton*) previously reported to be crown-cryptobranchoids.

Title: 25-2: The emergence of domestic dog morphology

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As the first domesticated species, dogs have co-habitated with humans for millennia. While it is well established that the grey wolf is the progenitor of all modern domestic dogs, the identification of the exact ancestral population remains elusive and there is yet no clear evidence to when, where, or even how many times disparate wolf populations were domesticated. We

used 3D landmark based geometric morphometrics to explore the the cranial size and shape variation of several hundred specimens of modern dogs and wolves, as well as archaeological remains including some dating from the Pleistocene. We explored the geographic variation of the grey wolf across the Northern Hemisphere and tracked the early emergence of domestic dog morphology and its evolution through time.

Title: 24-2: Positive allometric shift of prenasal cartilage during craniofacial development underpins the origin of the avian beak

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The avian beak is composed of elongated, edentulous, fused premaxillae. This contrasts with the relatively small premaxillae characterizing all other extant non-avian reptiles. From an evolutionary perspective, it is yet unclear if the appearance of the avian beak was a gradual event and how potential developmental innovation led to this anatomical feature. We applied 3D geometric morphometrics to capture the shape of the face among extant and extinct reptiles, including dinosaurs. We find that bird-like premaxillary dominance evolved multiple times independently in Panaves: in pterosaurs, duck-billed dinosaurs and, within Avialae, in Confuciusornithiformes, enantiornithines, and ornithuromorphs among avialans. Macroevolutionary increases in premaxillary size occurred abruptly, suggesting that the appearance of an avian beak might be related to a sudden shift in craniofacial development. Although the gene regulatory networks affecting face development have been intensively studied, the early moments of craniofacial morphogenesis remain unclear. We followed craniofacial development with immunostaining and confocal imaging of developmental series of model and non-model organisms (9 species including avian and non-avian reptiles) cleared with CLARITY. Our results demonstrate negative allometry of the prenasal condensation in non-avian reptiles, switching to positive allometry in birds. This chondrocranial feature acts as a scaffold for the dermatocranial ossification, therefore leading to the avian bill or the reptilian small premaxillae. Our findings stress the importance of development as a source of evolutionary innovation in deep time.

Title: 1-4: Does metamorphosis foster the morphological evolution of feeding structures in Caudata?

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Metamorphosis is an incredible developmental process implying a drastic morphological, functional, and ecological transformation during the life of an animal. However, the origin and evolution of metamorphosis as well as its impact on morpho functional variation remains rather poorly understood. In this study, we investigate the patterns of morphological and functional variation using Caudata with different life-history strategies (bi-phasic, direct-developing, and paedomorphic). To do so, we acquired new data for the cranial system of larval and adult stages for over 200 species (skull and lower jaw), including different life-history strategies. Using geometric morphometric approaches, we explored the patterns of morphological variation using phylogenetic comparative and discriminant analyses. Our results show strong differences in morphology depending on life cycle. Interestingly, we found that adults and larvae do not share the same morphological space for crania but do so for lower jaws suggesting that constraints of feeding in different media associated with life history differentially drive the evolution of the morphology of the feeding system in salamanders.

Title: 21-5: Phenotypic evolution influences speciation and extinction in birds

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Taxonomic diversity is highly heterogenous across lineages. A key question in evolutionary biology is whether such patterns of differential speciation and extinction can be influenced by species-level traits, including morphological traits. In birds, it has frequently been hypothesized that body size is a phenotypic trait that influences diversification patterns because it is correlated with nearly every aspect of physiology and life history. However, previous research on body-size-dependent diversification has largely excluded the essential evidence from the fossil record. Using trait-dependent diversification modelling and a dataset including 9993 extant and 315 extinct species, we demonstrate that speciation, extinction, and fossilization rates are each dependent on body mass. Smaller birds (< 80 g) have higher speciation rates and lower extinction rates than the largest birds. These patterns are not driven by the correlation between large body size and the loss of flight: for any given body size, flying and flightless birds have equal speciation and extinction rates. This suggests that these trait-dependent effects are more related to metabolic, genetic, and behavioral correlates of body size itself rather than flight ability. Excluding fossil data results in completely different estimates of diversification rate, emphasizing the importance of the fossil record in diversification models. Together, these findings demonstrate the importance of intrinsic factors and phenotypic traits in shaping macroevolutionary patterns of diversity through deep time in birds.

Title: 55-8: Morphological and ecological shifts in Australian reptile community assemblies over time, using fossil records

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The species community structure we observe today, and its variety of species and body shapes, results from a long and dynamic evolutionary history, with temporal contingencies due to climate fluctuations, organisms' phylogenetic history, and past biotic interactions. Australia has the world's highest number of reptile species, with high endemic diversity. Yet, the drivers of these richness patterns are virtually unknown. The same is true for paleontological research on Australian reptiles - critical for resolving the temporal dynamics of ecological communities. We aim to quantify how reptile community composition (i.e., taxonomic and size/shape diversity) has changed over the past 500,000 years. Our study initially focused on samples from Death Trap Cave, Australia, a significant deposit for reptile fossils. Bone fragments were used for species identification, using shot-gun sequencing of ancient mitochondrial DNA. The material extracted was compared with vertebrate DNA reference libraries. Modern-day fauna data was obtained from a compilation of occurrence records in the region, alongside paleo and current climate conditions. CTscan images were used to assess changes over time. Preliminary results identified viable DNA and species no longer found in the region. It also showed evidence of

species community changes linked with climate shifts in the Holocene. We highlight the importance of ancient DNA and geometric morphometric analyses of fossil data as keys to understanding species assemblage patterns and body size shifts over time.

Title: 21-7: Remarkable insights into modern bird origins from the Type Maastrichtian

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Only a handful of phylogenetically controversial fossils have yet been put forward that cast light on the early morphology of crown birds (Neornithes), precluding robust assessment of the nature of the last common ancestor of what is arguably the world's most conspicuous clade of terrestrial vertebrates, represented by nearly 11,000 extant species. However, two remarkable fossils deriving from the Type Maastrichtian of Belgium (~66.7 million years ago) have recently illuminated important aspects of cranial and postcranial morphology early in crown bird evolutionary history. Together, *Asteriornis maastrichtensis* (among the world's oldest-known crown birds) and *Janavis finalidens* (a crownward stem bird) represent the first documented example co-occurring crown birds and non-neornithine avialans, and the excellent three-dimensional preservation of both specimens enables long-sought inferences into the origins of key avian morphological features. For instance, both the discrete morphology and three-dimensional geometry of the skull of *Asteriornis* reveal a remarkable degree of evolutionary stasis in the cranial morphology of galloanseran birds, and *Janavis* illustrates both that the ancestral crown bird was neognathous—not palaeognathous, as long assumed—and exhibits an extraordinary degree of vertebral pneumaticity, exceeding that of virtually all known stem birds. Although important aspects of crown bird origins remain shrouded in mystery, these late Maastrichtian fossils reveal that some of the longest-standing assumptions about crown bird origins may need to be reconsidered.

Title: 22-3: Bite me: comparing cranial biomechanics in Smilodon fatalis vs Barbourofelis fricki

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Sabertooths mammals were "cats" or cat-like forms that have convergently evolved into specialized killers of ''megaherbivores'' that relied on their large, and laterally compressed (saber-like) canines to rapidly subdue their prey. During the last decades, the use of

biomechanical simulations to analyse key functional parameters have revealed a remarkably high diversity in functional performance among sabre-tooth lineages and that different cranial function and prey killing strategies evolved within clades. Here, we compare skull biomechanics between two large and highly-derived saber-tooths belonging to different clades, the "false" sabertooth *Barbourofelis fricki* and the iconic "sabertoothed tiger" *Smilodon fatalis*, which differ in the presence/absence of postorbital bar, the rounded/straight incisor arcade, or the presence/absence of mental process in their mandibles. We use FE analyses from skull models in 3D to simulate various killing scenarios and to assess for differences in functional performance between these two forms, including extrinsic (i.e., stab, pull-back, and torsion) as well as extrinsic (i.e., carnassial bite). Our preliminary results indicate that the skull of *Barbourofelis* exhibits the least stress during stabbing but both species show similar stress distribution across the skull during a pull-back scenario. Differences between their functional performance and, by extension, between their killing behaviour are discussed in the light of these new results.

Title: 46-5: Morphology and kinematics of amphibious marine vertebrates for transition to biorobotic systems

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The biomimetic approach holds that the structure and performance of animals can be used as innovation in the development and improvement of engineered technologies. In examining locomotion, two groups of aquatic animals demonstrate amphibious capabilities that can be emulated for the development of robotic systems that can move on land and in the water. These animals include sea turtles and sea lions which use elongate fore flippers for lift-based thrust production. While these species are different phylogenetically, they have converged on morphologies and mechanisms for efficient swimming and have the capability for quadrupedal movement onto land. Turning is accomplished using fore and hind flippers for both species. Sea lions display faster turning rates for translational with small turning radii compared to sea turtles, which are constrained by their rigid shell. However, sea turtles are capable of performing pure rotational turns with a zero radius. The flipper and body morphologies and swimming and turning performance along terrestrial ability were integrated into two robotic systems based on the sea lion and sea turtle. This amphibious bio-robotic systems present a new and innovative approach in the development of autonomous underwater vehicles with advanced capabilities.

Title: 23-4: Functional morphology of the pharyngeal teeth of the ocean sunfish, Mola mola

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Many fish use a set of pharyngeal jaws in their throat to aid in prey capture and processing, particularly of large or complex prey. In this study —combining dissection, CT scanning, and performance testing— we demonstrate a novel use of pharyngeal teeth in fish. The pharyngeal teeth of the ocean sunfish (*Mola mola*), in contrast to their beaklike oral teeth, form an array of curved, caudally-pointed spikes, arranged in three rows, with smaller teeth between the larger ones, suggesting tooth replacement. Tooth curvature was not different between smaller and larger teeth. Examination of musculature surrounding the jaws revealed an undescribed band that, we demonstrate, functions to deploy teeth, everting them like a cat's claw. Adult sunfish suction feed almost exclusively on gelatinous prey (e.g. jellyfish), however, due to an inability to tightly close their oral jaws, water jets out of their mouths during processing. In a flume set to adult sunfish jetting speed, adult pharyngeal teeth caught simulated gelatinous prey with 70-100% success. Even at 50 times the jetting force, teeth did not move in their sockets, suggesting an extremely high safety factor. We therefore propose that sunfish pharyngeal teeth function as an efficient retention cage for mechanically-challenging prey, a curious evolutionary convergence with the throat spikes of divergent taxa that employ spitting and jetting (e.g. sea turtles, alpaca).

Title: 29-3: Feral cats in Australia – skull shape as a reflection of diet

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As carnivorans rely heavily on their head and jaws for prey capture and handling, skull morphology and bite force can therefore reflect their ability to take larger or more difficult-to-handle prey. Animals that regularly feed on larger prey experience greater mechanical stress on their skull and mandible, which can influence the shape of both the skull and mandible. The domestic cat (Felis catus) was introduced to Australia ~200 years ago. In addition to owned pets and 0.7 million unowned stray ('semi-feral') cats around urban areas, it is estimated that there are ~1.4–5.6 million feral cats across the continent that live completely undependably of human supplement. For 568 feral and stray cats, we recorded their demographics (sex and age), source location (feral or stray) and measured body mass and body condition. We estimated potential bite force from skull measurements and quantified mandible shape for n=268 of these cats, and quantified diet composition from stomach contents for n=358. Body mass had the strongest influence of bite force. In our sample, males were 36% heavier and had 20% greater estimated bite force (206.2 ± 44.7 N, n=168) than females (171.9 ± 29.3 N, n=120). Young feral cats had greater estimated bite force than young stray cats, suggesting that they developed the mechanical advantage required for restraint and consumption of prey earlier than do stray cats.

Title: P1-20: Influence of muscular mechanical forces during the embryonic development of the opposable hallux of birds and its evolution from basal theropods.

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The opposable orientation of the hallux or perching digit I of birds is acquired throughout development as a result of embryonic muscular activity, involving the torsion of its metatarsal (mt1). Experimental embryonic paralysis results in a non-opposable hallux, with a straight metatarsus, as in basal theropods. However, how muscle activity produces this change is not well understood. Unlike the other (non-opposable) toes, the hallux does not articulate at the ankle, but rather at the mid-ventral surface of metatarsus 2 (mt2). The condition in basal theropods is similar, but the hallux was not opposable and articulated in a more medial position on the mt2. Using immunofluorescence confocal microscopy and molecular markings for the skeleton, muscles and tendons, and radiopaque staining we generated a reliable three-dimensional reconstruction of the embryonic foot of birds, to understand the biomechanical environment, and especially, the effect and magnitude of muscle action on the metatarsal during embryonic developmental changes, and the influence on insertion sites of tendons that affect the orientation of forces. This approach plus the modeling by Finite Element Analysis will allow delimiting the possible mechanisms involved during the evolutionary transition from a non-opposable hallux in basal theropods, to the opposable hallux of birds.

Title: P2-13: What's diet got to do with it? Analysis of craniofacial evolution in Lake Victoria cichlids

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African cichlids have many examples of repeated evolution of trophic adaptations. However, most of the better-documented cases illustrate these instances between lakes and radiations. Here we study trophic adaptations within the Lake Victoria radiation that emerged over the last 15,000 years. Previous work primarily focused on oral and pharyngeal jaw morphology, but there has yet to be a comprehensive study on Lake Victoria species using the whole skull. This study

examined 301 skulls representing 131 species using CT-scanning and geometric morphometrics. We estimated a phylogenetic tree using whole-genome sequencing, assessed levels of convergence using R to assess repeated evolution, and compared these data to dietary guilds. Our results show certain specialized phenotypes evolved multiple times within this clade, with significant levels of similarity. We also found that craniofacial morphology is most closely tied to diet, particularly in species with specialized diets (i.e., algae scraping, mollusk crushing, and piscivory). Shape changes across this lineage fall into two major patterns: heterocephaly (relative braincase and snout size) and the proportion of head depth and head width. Both trends appear closely linked with diet, with discernable patterns correlating diet to head shape. Additional examination is imperative to understanding how such a large diversity of craniofacial morphologies evolved in such a short period of time.

Title: 9-6: To Bite or Not to Bite: An investigation into the Tongue-Bite-Apparatus in mormyrid fishes (Osteoglossiformes)

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A large portion of teleost fishes have pharyngeal jaws, a secondary set of jaws located in the throat of the fish that are repurposed from gill rakers. These jaws are used for processing prey items after the prey is captured by the oral jaws. In a smaller subset of teleosts, the Osteoglossomorphs, the pharyngeal jaws are noticeably absent, and instead enlarged hyoid and palatine bones protrude into the oral cavity, a morphology called the Tongue-Bite-Apparatus (TBA). Mormyridae is a family of weakly electric fishes within this group that contains a high amount of craniofacial diversity. While the overall skull shape diversity has previously been quantified in Mormyridae, far less is known about the morphological diversity of the TBA in this family. This study will examine the TBA of Mormyridae using 3D geometric morphometrics and phylogenetic comparative methods. We expect to find correlations in size and shape of the TBA based on phylogenetic relationships, diet, and habitat type, based on examinations of the skull. Future studies will include examinations of integration and modularity of the jaw systems, as well as investigations of dentition patterns and biomechanical function across species.

Title: 46-9: Comparing axial versus appendicular change across secondarily aquatic amniotes

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Despite convergence in aquatic locomotory morphology in the derived members of secondarily aquatic clades, distinct functional and morphological differences separate these clades at the onset of their transitions, particularly between mammal and reptile groups. The presence and absence of certain bones, vertebral orientation and movement, and limb posture are differences

divided distinctly between mammals and reptiles. For example, marine mammals' lack of a coracoid and clavicle and having ancestrally upright posture with dorsoventral axial movement, as opposed to the complex pectoral girdles on marine reptiles and an ancestrally sprawling posture coupled with lateral axial movement. Yet, secondarily aquatic groups, both mammal and reptile evolved locomotor morphology suited to the aquatic realm via avenues in axial or appendicular-driven swimming. This study examines the degree by which secondarily aquatic clades change in their axial vs. appendicular skeletons relative to one another to determine if there any linkages between ancestral terrestrial state and swimming style. Early transitioning members of secondarily aquatic amniote clades were selected-- cetacea, pinnipedomorpha, lutrinae, mosasauroidea, sauropterygia, thalattosauria, and various individual semi-aquatic taxa like the Platypus and *Castorocauda*. Combinations of relevant skeletal measurements in fossil and extant taxa, used as functional proxies, allowed me to directly compare the manner in which these clades transitioned to aquatic environments and determined similar evolutionary patterns in groups which share ancestral terrestrial morphology and/or swimming style.

Title: 34-1: Odonto-seq: using shark developmental transcriptomics to define a tooth

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Sharks and their relatives are typically covered in highly specialized skin appendages called dermal denticles; ancient tooth-like units (odontodes) composed of dentine and enamel-like tissues embedded in the skin. These 'skin teeth' are incredibly similar to oral teeth of vertebrates, and share comparable morphological and genetic signatures. Recently, we have collected transcriptome data from embryonic sharks to uncover a core gene regulatory network (GRN) that appears to unite all tooth-like elements (odontodes), including teeth and skin denticles in sharks. We show how similar and disparate derived tooth-like structures are in modern sharks. These observations are based on differentially expressed genes (DEGs) recovered from our developmental transcriptome (odonto-seq) of both the regenerative teeth and emerging skin denticles from the small-spotted catshark (*Scyliorhinus canicula*). We ask what defines a tooth at both the molecular and morphological level. Our insights provide a framework to understand how nature makes, replaces and evolves a vast array of odontodes, and how much of this diversity is present in the same species.

Title: 31-5: The morphological-functional-ecological diversity of damselfishes (Pomacentridae) is tightly linked to a ligament

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Reef fishes have diversified into thousands of species that fill various types of ecological niches, contributing to the tremendous biodiversity of reef ecosystems. Interestingly, the morpho-functional disparity in teleost reef fish taxa is quite unbalanced and various factors may explain this uneven distribution among families. Most of my works focus on the evolution of one major radiation of reef fishes, the damselfishes (Pomacentridae), and, here, I aim to highlight the uniqueness of this family among teleosts according to their cephalic morphology and their associated diversity. One synapomorphic trait of damselfish is the cerato-mandibular ligament (c-md) that joins the ceratohyal of the hyoid bar to the lower jaw, at the level of the coronoid process. We first showed that this ligament is involved in two major functions of damselfish behavior: sound production and feeding. Both behaviors are based on the same principle: the c-md allows rapidly closing the lower jaws in a few milliseconds, without the help of the *adductor mandibulae* muscles. Consequently, the damselfishes possess two mouth-closing systems. Then we demonstrated that this functional duplication enabled grazing damselfishes to have a forceful and extremely fast bite, challenging thus the trade-off between force and velocity. Finally, by combining eco-morphological data with phylogenetic comparative methods, we provided evidence that the c-md would have operated as a fundamental key to the process of diversification in damselfishes.

Title: P4-18: Body-support-dependency of the torsional stiffness in the forearm of Asian black bear (Ursus thibetanus)

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Carnivoran mammals (e.g., lion and bear) utilize their forelimb as locomotor and a manipulator depending on situations. These multi-functional behaviors are realized by coordination patterns between the shoulder, elbow, and wrist joint in the sagittal plane and the radioulnar joint, i.e., intralimb coordination in the forelimb. Previous anatomical studies have revealed that shapes of the radius represent the potential of the manipulator capability of mammals, e.g., the straight radius in horses for more locomotor function and the curved radius in monkeys for more manipulator function. However, it is unclear whether the carnivoran mammals' morphology of the forelimb contributes to both locomotor and manipulator behaviors, depending on the situation. To this end, this study aims to understand the effects of the forelimb's morphology in carnivoran mammals on interlocking mechanisms for intralimb coordination for locomotor and manipulator behaviors. To address interference between locomotor and manipulator functions, we measure a torsional stiffness in the radioulnar joint of an Asian black bear (*Ursus thibetanus*) during the forelimb supporting body weight. As a result, we revealed that the torsional stiffness

would increase as the supporting body weight increases. Furthermore, the absence of flexor digitorum muscles reduces the load dependency in the torsional stiffness in the radioulnar joint.

Title: 4-3: Evolution of scapula size and shape in Carnivora

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Despite the large morphological diversity of the carnivoran scapula, the causes of this variation remain unclear. Furthermore, well-preserved fossil scapulae are rare, so little is known about its morphological evolution. Here we address both topics using 3D geometric morphometrics.

We digitized 34 landmarks in 475 scapulae from 225 carnivoran species (92% extant genera) to cover the broadest possible range of morphological, taxonomic and functional diversity. We used phylomorphospaces to explore scapula shape variation, and quantified its relationship different factors (size, phylogeny, locomotor function). Then, we inferred scapula shape evolution by reconstructing theoretical scapula shapes for all internal nodes in carnivoran phylogeny, and interpreting the ecomorphological ramifications of the resulting shape transitions.

A significant portion of scapula shape variation was explained by shared evolutionary history, with carnivoran families occupying discrete regions of the PC1-PC2 phylomorphospace. Size also had a significant effect, but its magnitude halved if pinnipeds were not included in the sample. Finally, several functional trends were highlighted in our analyses, such as the different strategies for both swimming and terrestrial locomotion in phocids and otariids, arboreal carnivorans developing more rounded scapular blades with curved spines and enlarged acromial processes, or running specialists converging into more triangular blades with straight spines and a reduced acromion. Based on these trends, we hypothesize that the carnivoran ancestor was mostly terrestrial but had very good climbing skills.

Title: P3-17: Quantifying mammalian locomotion using cluster analysis

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Describing locomotor habits using qualitative categories is a staple of studies on mammalian locomotion. However, there are several issues associated with this, such as an information loss on behavioral repertoire related to assigning a single category to each species, and different levels of subjectivity throughout the assignment process (category definition, number of

categories used, species assignment to each category, etc.). Additionally, how many and which categories will be included in the study needs to be decided (also subjectively) prior to starting the assignment process.

We provide a novel method for defining and assigning locomotor categories which is based in quantitative data, minimizes subjectivity, and preserves more information on behavioral repertoire. Particularly, our method relies on creating numerical axes defining proficiency in each locomotor habit (climbing, swimming, running, etc.), assigning each species a score in each axis, and then using Ward's hierarchical clustering on the resulting data matrix to group species into a biologically informative number of categories (the number of which can be optimized using clustering validation methods). Subjectivity is thus reduced to the scoring step but, since the locomotor habit axes have been designed to increase reproducibility, assignment subjectivity is minimized.

Here, we present a preliminary use of our method on 202 mammalian species, representing every mammalian order, and provide statistical quantification of interobserver subjectivity.

Title: P3-6: Tweaking the chicken beak: Investigating the shape and development of the chicken (Gallus gallus) beak from embryo to adult

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The chicken (*Gallus gallus*) has been the model organism for investigating beak development for the past century. Despite this, few studies have assessed how the shape of the beak may change from when it initially forms in embryogenesis to the final postnatal and adult beak shape. Here we perform this analysis in light of the power cascade model of growth. The power cascade is a log-log linear relationship that describes the growth of the beak radius from the tip to the base. We specifically focused on the ontogenetic shape change of the premaxilla, as it is the primary structure that shapes the upper beak tip. We measured the overall shape of the chicken premaxilla from embryonic (stages HH 30 to HH 45) to postnatal (one day postnatal to adulthood) stages according to the power cascade model. We also used accompanying whole-mount and histological preparations to assess shape change in the bone and cartilage of the premaxillary region. We found that while the initial shape of the premaxilla, and therefore the beak tip, is established at early developmental stages, the shape is then remodeled later than expected. This finding challenges the assumption that embryonic and prenatal morphology may be predictive of the adult shape, and supports the notion that postnatal development is also a dynamic process that is important in fully understanding morphogenesis.

Title: Taking a step back: 3-D kinematic studies spark new perspectives on skeletal and footprint form

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During terrestrial locomotion, we and other limbed vertebrates transmit forces to the substrate with each step to support, propel, and maneuver our bodies. Yet today's thousands of species represent only a fraction of the anatomical and functional diversity that arose over more than 350 million years of tetrapod evolution. How can paleobiologists hope to reanimate extinct animals known only from static skeletons and footprints in the fossil record? Here, I advocate for motion as a key source of perspective for evaluating morphology. In our work, progress has accelerated as tools fostering 3-D visualization, animation, and simulation have unveiled previously hidden anatomy and movement in extant forms. Combining CT scanning with X-ray Reconstruction of Moving Morphology (XROMM) and discrete element method modeling has allowed us to explore the dynamic context in which morphologies interact among themselves (joints) and with the environment (tracks). I will present examples from kinematic analyses of living birds, crocodilians, and humans that fundamentally changed our interpretation of limbs and the substrate deformations they leave behind.

Title: 24-1: The evolution and development of the cetacean (whales, dolphins, porpoises) flukes

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Cetaceans (whales, dolphins, and porpoises) became obligately aquatic around 38 million years ago during the late Eocene. This shift in ecological niche is tracked in the fossil record via the reduction of the hindlimbs, uncoupling of the pelvis from the sacrum, and homogenization of the post-lumbar vertebrae for dorsoventral spinal undulation. The soft-tissue flukes of cetaceans, found at the distal end of the tail, are the main propulsive organ and have functionally replaced the hindlimbs. Fossil evidence suggests that flukes appear ~40 MYA, tractable via the presence of skeletal markers known to be associated with the soft-tissue flukes. The composition and biomechanics of the flukes have been studied, but little is known about their development and evolution. This study first investigated protein signaling in the developing flukes of an embryonic beluga whale, and second, used evidence based on dissections to morphologically differentiate tail and fluke vertebrae in bowhead and beluga whales and correlate these changes directly with the overlying soft tissue. Molecular results show protein signals involved in

vertebrate limb and fin development play a role in the developing fluke of cetaceans. Dissection results investigated the relationship of the established fluke skeletal traits with the overlying soft-tissue. Taken together, results suggest that the cetacean fluke is a modified, bilateral limb, with an evolutionary origin that can be inferred by the morphology of caudal vertebrae.

Title: 25-3: Universal or unique? Insights into morphological changes along the 'domestication continuum'

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Human-animal relationships come in various forms and span a wide range of intensities, from anthropophily, e.g. in urban wildlife, to intensive breeding, e.g., in domestic farm animals and pets. One common and central attribute among the populations on this 'domestication continuum' is a certain degree of tameness towards humans. However, whether there is a particular set of phenotypic traits apart from tameness that is shared by these populations in human proximity is intensively investigated and debated. In this talk, I synthesise some of our recent collaborative works that contribute to this debate, investigating phenotypic traits in different populations that are distributed along the length of the 'domestication continuum'. Specifically, these studies look into skull trait changes in urban birds, captive monkeys, and various domestic mammals, exploring shared – and unique – patterns of change in response to human proximity.

Title: 33-8: Connective Tissue and Lateral Stabilization of the Giraffe Cervical Vertebral Column

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In the giraffe (*Giraffa camelopardalis*), the strong elastic force of the nuchal ligament allows head elevation and support to be mostly passive. Large tensions along a series of articulated, rigid vertebrae, however, requires substantial stabilization to prevent collapse of the series. Here we give novel descriptions of soft connective tissues in the giraffe cervical vertebral column that we hypothesize play a significant role in lateral neck stabilization. Giraffe cervical vertebrae lack the lateral projecting portion of the transverse process. The thin bony shelf connecting the ipsilateral articular processes in typical artiodactyl cervical vertebrae is replaced with a thick, compound connective tissue sheet that serves in place of the transverse process as the attachment site for many muscles of lateral stabilization. The deep fascia covering the transversospinalis muscles is highly modified in a manner that produces significant resistance to dorso-ventral tension but high elasticity along the cranio-caudal axis. A robust tendon and thick fascia layer extend from the ventral lamina of the transverse process to the caudal end of the vertebral body, increasing the size of the attachment site for muscles that can stabilize the neck during

flexion. Insights into how these structures impact cervical stability not only inform giraffe biomechanics but serve as important models for including the connective tissues of the neck when investigating the mechanics of any long-neck form.

Title: 3-1: The Legacy of Susan W. Herring: A Giant in Her Field

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Susan Herring had a large influence on the Vertebrate Morphology Community. She impacted both the science of vertebrate morphology and the scientific community that is now the International Society of Vertebrate Morphologists. Her scientific contributions in functional morphology include bone stress, suture development and muscle function. She is also a leader in the work on mammalian feeding anatomy and function, with implications for other vertebrate feeding systems. Susan Herring is also one of the founders of the ISVM. She participated in the important first meetings in Giessen, Wien, and Antwerp. She was the organizer and convener of the 1994 in Chicago, USA. Those meetings led to the founding of the ISVM, of which she was the first president. Her contributions to many aspects of this field are, as is Sue, larger than life.

Title: 53-9: Buffered Lugol's Iodine Preserves DNA Fragment Lengths in Fixed Museum Specimens

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Contrast-enhanced X-ray computed tomography (CT) has expanded opportunities in vertebrate morphology research by allowing improved visualization of internal soft tissues. Museum collections have played a pivotal role in these advances because they preserve and record natural history and its variation. Yet, vouchered specimens could be at risk if staining techniques are destructive. For example, the pH of unbuffered Lugol's iodine (I_2KI) may be low enough to damage DNA. The extent of this risk is unknown due to a lack of rigorous evaluation of differences in DNA quality between control and experimental samples. In this study, we used formalin-fixed mouse samples to document differences in DNA concentration and fragment length between non-stained, ethanol-preserved controls and three iodine-based staining preparations: (i) 1.25% weight-by-volume (w/v) alcoholic iodine (I_2E); (ii) 3.75% w/v I_2KI; and (iii) 3.75% w/v buffered I_2KI. We tested the null hypothesis that there is no significant difference in DNA concentration and fragment length between unstained specimens and those stained with

unbuffered and buffered iodine solutions. We found that DNA concentration decreases because of staining. Fragment lengths, however, were significantly higher for buffered I_2KI and control samples, which were not, themselves, significantly different. Our results implicate buffered I_2KI as the appropriate choice for contrast-enhanced CT imaging of museum wet collections to safely maximize their potential for understanding phenotypic diversity.

Title: 50-2: Functional regionalization of the backbone along the land-to-water transition in mammals

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Mammals have reinvaded the aquatic realm numerous times throughout their evolutionary history, resulting in various aquatic adaptions and associated swimming modes. Along the land-water continuum, there is a trend from limb-driven to backbone-driven locomotion. The most terrestrial species (e.g., muskrat) use limb-driven quadrupedal or bipedal paddling, semiaquatic species (e.g., seals) use a combination of limb and body-driven movements, and fully aquatic species rely solely on backbone oscillations (e.g., cetaceans). Evolution of these diverse swimming modes was supported by reorganization of the 'typical' mammalian skeleton. While past efforts have focused on documenting changes to the limbs, few studies have detailed the morphofunctional transformation of the backbone during the land-to-water transition, despite the backbone being central to aquatic locomotion. Here, we investigated the biomechanical properties of the vertebral column of several terrestrial, semiaquatic and aquatic mammals. Using static intervertebral joint bending experiments, we quantified the range of motion and compliance of each joint along the spine. More terrestrially-adapted species show greater functional disparity in the presacral vertebral column, while fully aquatic species have functionally homogeneous anterior vertebrae and higher biomechanical variability in the caudal (tail) region. These results highlight the large-scale functional changes of the backbone during the land-to-water transition and the importance of the caudal skeleton to fully aquatic mammalian locomotion.

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Title: P4-12: The Olfactory Anatomy of the Archaic Oligocene Odontocete, Archaeodelphis

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Extant odontocetes have lost the cranial osteological features associated with an ability to detect airborne odors. The loss of olfaction came in part as a result of the evolution of their ability to echolocate. Echolocation put the squeeze on olfaction. Bony features associated with olfaction were lost in different lineages of odontocetes at different times during the Miocene epoch. In stark contrast, the most stem-ward odontocetes, those from the older Oligocene epoch within the family Xenorophidae, had all the osteological features required to support a well-developed sense of smell. These features are similar in many ways to those seen in both archaeocetes and extant mysticetes. CT scans of the type partial skull of the xenorophid *Archaeodelphis patrius* show that it had prominent nasal passages, a nasal septum, dorsal nasal meatuses and ethmoturbinates within an olfactory recess. Further posteriorly, a cribriform plate, olfactory bulb recesses and an olfactory tract are also preserved. Although xenorophids had the ability to echolocate at this early stage in odontocete cranial telescoping, the novel osteological morphology associated with that ability had not yet started to impinge on the archaic morphology associated with their ability to detect airborne odorants. Over millions of years, posterior telescoping of the odontocete skull in association with the evolution of echolocation changed the orientation of the odontocete olfactory apparatus from horizontal to sub-vertical, prior to olfaction disappearing altogether.

Title: 40-2: MYTHBUSTERS: refining observations about anal fin variation in surfperches

Authors: Breana N. Goldman, Karen D. Crow

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Surfperches (Embiotocidae), exhibit novel, sexually dimorphic, anal fin modifications that are likely associated with internal fertilization, but their function is currently unknown. These structures have been loosely characterized, in taxonomic keys and papers from the last century, as bony hooks and serrated plates (Amphisticinae, Hubbs 1918), or enlarged fleshy protuberances (Embiotocinae, Tarp 1956). We characterized divergence between subfamilies, species, and sex that have not been previously described using clear and stain methods. We found several surprising discoveries including sexual dimorphism that is not fully penetrant but rather manifest as diminished character states in females, and both ancestral and derived fin ray modifications that are constrained to subfamilies as originally described. Finally, we demonstrate an anal fin modification that is specified by a novel HoxA13 expression domain via in situ hybridization. These results provide another example of how redeployment of HoxA13 is associated with a novel trait, and highlight the role of the 5' HoxA genes in the evolution and development of novel fin and limb morphologies.

Title: 28-2: Modelling nasal airflow and acoustics in The Greater Horseshoe Bat (Rhinolophus ferrumequinum)

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Nasal-emitting echolocating bats emit sound from their larynx and direct it through their nasal passages. The details on how nasal passage morphology attenuates and directs sound waves are poorly understood due to the small size of the nasal anatomy in bats.

We used computational fluid dynamics (CFD) to visualize airflow through the nasal passage of *Rhinolophus ferrumequinum* based on a diffusible iodine-based contrast enhanced computed tomography (diceCT) data set.

The nasal passage in *R. ferrumequinum* contains a "U" shaped nasal vestibule that opens into an enlarged cavum nasi proprium with a distinctly separated olfactory recess as determined by a well-developed lamina transversalis. A distinct nasal septum maintains separation of left and right nasal passages. Nasal turbinals reside largely in the olfactory recess. The two halves of the nasal passage join together at the caudal end of the nasopharyngeal duct.

Our visualised flow field found that air mostly bypassed the turbinals during exhalation, suggesting unidirectional airflow through these olfactory-focused structures. To test acoustic function of the nasal passage, we used a time-dependent transient CFD model to accurately capture the air field during exhalation.

This transient airflow model will be used as a scaffolding for acoustic wave modelling. Our approach will offer insight into how nasal passage geometry reflects and redirects sound waves, allowing these bats to shape their acoustic field for echolocation.

Title: 3-3: Modelling how suture morphology and complexity drives mammalian cranial evolution

Authors: Heather White[1], Yichen He[1], Abigail Tucker[2], Vincent Fernandez[3], Roberto Portela Miguez[4], Arkhat Abzhanov[5], Enrico Grisan[6], Alana Sharp[7], Anjali Goswami[8]

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Sutures provide active growth centres that facilitate cranial bone growth and support skull functioning, but they have received comparatively less attention in evolutionary analyses than cranial shape. Here, we use geometric morphometrics to analyse patterns of morphological

development for the skull and its sutures, as well as quantifying their interactions. Skull and suture morphology (shape, complexity, and fusion) were quantified in a comparative ontogenetic framework across Mammalia (22 species, 165 specimens), ranging from fetal to adult stages. Marsupials displayed fewer differences in the degree and pattern of suture fusion than placentals (marsupials: 71.36%; placentals: 76.63%), with cranial base sutures remaining open for longer. Suture complexity was greater for sutures adjacent to the underlying brain (coronal and sagittal sutures), suggesting a relationship between postnatal brain growth and suture morphological complexity. Ancestral state reconstructions of skull morphological development, suture fusion, and suture complexity identified clear differences between marsupials and placentals, specifically localising these differences as paedomorphic shifts on the marsupial lineage. Finally, an integrated pattern of morphological development was observed between skull shape and each cranial suture variable (shape, fusion, and complexity). Our current work expands upon these findings, using machine learning to quantify suture evolution across the synapsid to mammal transition, capturing key evolutionary innovations. With these novel approaches, we address the question: How have cranial sutures evolved to support the diverse functions of the mammal skull?

Title: From Development to Deep Time: Reconstructing the Evolution of Tetrapod Diversity with a Phenomic Approach

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What processes shape organismal diversity over large time scales? Approaches to this question can focus on many different factors, from ecology and life history to environmental change and extinction. Uniting these factors in a macroevolutionary framework is typically complicated by differences in the sources, types and scale of data collected, but open access 3D datasets have transformed this field in recent years. Here, I will discuss the patterns of and influences on cranial evolution across Tetrapoda using a vast 3D phenomic dataset that spans >300 million years of evolution. While most large-scale studies of morphological evolution utilise relatively limited descriptors of morphology, surface sliding semi-landmark analysis allows for detailed quantification of complex 3D shapes, even across highly disparate taxa. We analysed morphological evolution using a dense dataset of landmarks and sliding semi-landmarks for over 1500 species of living and extinct limbed vertebrates. Patterns of cranial organisation are generally conserved within large clades, but clear shifts are evident across. Comparing patterns across the diversity of living and extinct tetrapods, I will discuss differences in the relative effect sizes of developmental and ecological factors on skull shape variation and rate of evolution, as well as temporal trends in shape evolution. A unified approach to data collection allows direct comparison of disparate taxa, and demonstrates that ecology, life history, extinction events, and climate are all significant influences on cranial shape, though the magnitudes of their effects vary markedly across different vertebrate classes.

Title: 53-3: No scalpel required: using diffusible iodine-based contrast-enhanced Computed Tomography for high-throughput imaging of the anatomy of natural history specimens in 3D

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Each specimen housed within a natural history collection represents a treasure trove of anatomical knowledge waiting to be uncovered. To reveal soft tissues inside fluid-preserved specimens, diffusible iodine-based contrast-enhanced CT (diceCT) is a commonly used method that involves staining a specimen with an iodine solution, increasing the radiopacity of soft tissues so that they can be imaged using X-ray CT. The recent diceCT effort at the Florida Museum of Natural history is one of the largest and most taxonomically broad soft tissue imaging efforts in the world, with over 300 datasets produced covering fishes, amphibians, reptiles, birds, and mammals. As part of the openVertebrate (oVert) Thematic Collections Network, these datasets are freely available via MorphoSource for research, education, art, and other purposes. Furthermore, we have refined methods for the application of diceCT for natural history collections, and we explore best practices informed by recent work in the field. We present recommendations including predictions for staining duration, suggestions for optimal staining techniques, and recommendations for scanning and post-processing. The recently funded NoCTURN network also provides opportunities for collaboration with other diceCT researchers to fine-tune our methods. As diceCT continues to be a widely employed method for non-destructively documenting the internal soft anatomy of alcohol-preserved museum specimens, we hope that these datasets and methods will contribute towards the growing stock of digital anatomy in online repositories.

Title: 24-6: The developmental mechanisms underlying the evolution of the avian pelvis

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The highly derived avian pelvis evolved via a stepwise transition that is well-documented by an excellent fossil record. We have recently shown that this transformation is paralleled during the early ontogeny of living birds, with embryonic pelves initially possessing several ancestral dinosaurian/archosaurian character states (e.g., anteroposteriorly short ilium, anteriorly directed pubis, pubic 'boot') that transform to their derived condition across roughly two days of *in ovo* development. This transient presence of early archosaur, dinosaur, and stem-bird pelvic anatomy serves as an excellent study system to investigate the developmental mechanisms underlying this major morphological transition. The expression of key skeletal patterning genes like PAX1, EMX2, and IHH occurs during this same critical developmental window. By combining a modified CLARITY protocol to clear embryonic tissues with new techniques for fluorescent *in situ* hybridization and confocal microscopy, we will quantify the three-dimensional expression patterns of these important genes and directly compare them with the ontogeny of pelvic form.

Next we will use experimental techniques (e.g., small molecule inhibitors, RCAS vectors) to manipulate the expression of these genes, assess the resultant changes in anatomy, and determine which developmental factors underlie key characteristics of the avian pelvis. This will all contribute to testing hypothetical evolutionary modifications to ancestral developmental pattern and constraining the mechanisms underlying the changes that occurred along the avian stem.

Title: P4-13: Developmental morphology of squamate lungs, with special reference to the bizarre lungs of chameleons

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Squamate reptiles (i.e. lizards and snakes) exhibit diverse lung morphologies, which are distinct from mammals and birds. Development of the lungs of the brown anole (*Anolis sagrei*) is characterized by pulmonary mesenchyme differentiating into a derived smooth muscle mesh. This mesh, in tandem with lumenal pressure in the pulmonary epithelium, generates the final honeycombed faveolar morphology of *A. sagrei*. Chameleons, which are also iguanian lizards, exhibit a more complex lung morphology, including additional chambers and distinct finger-shaped diverticulae in the dorso-posterior portion of the lung. To understand the origins of this derivation, we compared the development of veiled chameleon (*Chamaeleo calyptratus*) lungs and other lizards. We aimed to polarize the likely ancestral state of squamate lung development and to explore the developmental processes that gave rise to the bizarre pulmonary morphology of chameleons. We reveal that chameleon lungs, as well as other lizards, exhibit the characteristic smooth muscle mesh illustrated in *A. sagrei*, suggesting this is an ancestral condition for squamates. We also show the developing lungs of *C. calyptratus* exhibit derived patterns of chamber morphogenesis and diverticula outgrowth. Taken together, we set the foundation for studying pulmonary diversity in reptiles.

Title: 49-5: Setal morphology of Sphaerodactylus geckos: Microscopic diversity in some of the smallest amniotes

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Adhesive toe pads have evolved independently in lizards at least 16 times, primarily in geckos. Toe pads are composed of either one or many modified scales, called scansors, that exhibit

thousands of hypertrophied epidermal structures (i.e. setae). The size and shape of setae varies among gecko species allowing the toe pad to passively cling to smooth surfaces either vertically or even upside down. Although setal morphology has been a topic of interest for over a century, no one has investigated variation across a single radiation of closely related taxa. Using scanning electron microscopy, we investigated setae of Puerto Rican *Sphaerodactylus* geckos. *Sphaerodactylus* are primarily found in the Caribbean where they likely experienced an adaptive radiation. By sampling all seven species occurring on mainland Puerto Rico, we found setal morphologies distinct from any previous descriptions of gecko setae. Setal diversity within the Puerto Rican radiation of *Sphaerodactylus* seems to be associated with habitat preference. Taken together, we lay a foundation for studying *Sphaerodactylus* locomotor morphology in the context of an adaptive radiation.

Title: 39-1: On the cusp of adaptive change: the tempos and modes of molar evolution during the phyllostomid bat radiation

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Adaptive radiations generate biodiversity and are key to understanding ecomorphological diversification. Yet, there remains considerable uncertainty about their macroevolutionary dynamics, such as whether they are commonly marked by an early burst in phenotypic diversification. Phyllostomid bats radiated extensively in craniodental adaptations for diverse diets, and we use their molars to investigate the factors that influence macroevolutionary change. We quantify the three-dimensional shapes of first lower molars of 120 species of Noctilionoidea (Phyllostomidae and close relatives) and find that different diet groups occupy unique regions of morphospace. Additional comparative analyses reveal a striking pattern: each dietary group exhibits distinct tempos and modes of evolution. Faunivores have ancestral molar morphologies, relatively low morphological disparity, slow evolutionary rates, and a constrained, Ornstein-Uhlenbeck evolutionary process. In contrast, frugivores and nectarivores both exhibit greater within-group disparity, fast evolutionary rates, and evidence of a Brownian motion evolutionary process. Frugivores also exhibit some evidence of an early burst. Sanguivores have extremely derived dentitions and represent another morphotype that diverged from the ancestral morphology. These unique tempos and modes of evolution among diet groups likely reflect variation in functional constraints associated with different types of mastication. We posit that strong selective pressures related to shifts to derived diets were necessary to 'free' molar morphologies from the ancestral morphotype and functional constraints, but once free, molars exhibited considerable evolvability, diversifying morphologically in-step with diet.

Title: P4-14: Structural specialization of nuchal ligament in American bison and gaur

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The nuchal ligament, located on the dorsal region of the neck, is particularly well-developed in ungulates. It is noted to possess a greater proportion of elastic fibers in comparison to other ligaments in the body, thus exhibiting strong rubber-like characteristics. The passive tension generated by this ligament plays a crucial role in elevating the head and neck against gravity, thereby maintaining an upright posture. Previous studies have reported that the structure of the nuchal ligament can be specialized in species with notably massive heads. Therefore, in this study, we dissected 20 species of ungulates and compared the macroscopic structure of the nuchal ligament. The results revealed that in American bison (*Bison bison*) and gaur (*Bos gaurus*), the nuchal ligament originates from a more posterior location than in other species, bifurcating to the left and right and running lateral to the spinous process of the thoracic vertebrae. When the amount of strain of the nuchal ligament during dorsoventral neck movement was measured, there was little difference between American bison with bifurcated nuchal ligaments and other species with nuchal ligaments of common structure. It is suggested that the natural length of the ligament increases as its origin is shifted posteriorly, and the amount of strain of the ligament increases accordingly, which may have resulted in a structure that does not interfere with neck movement.

Title: 43-3: An osteological description of the rostrum in billfishes through development (Xiphiidae and Istiophoridae)

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Billfishes are characterized by elongation of the upper jaw into a bill or rostrum. Although this is the major structure characterizing this group, its anatomical components continue to be debated. Furthermore, a thorough description of the major osteological differences and their developmental timeline among species is still lacking. The goal of this study was to describe the osteological composition and ontogeny of the rostrum in the two families that represent this group, Istiophoridae and Xiphiidae. Comparisons of cleared and stained billfish larvae at different developmental stages were made along with other techniques such as histology and CT images of adult specimens. Our results show cogent differences between specific osteological components, ossification times and overall morphology that is mirrored in the adults. The rostrum in xiphiids comprises mostly the premaxillae and their ascending processes, but in istiophorids distinctive prenasal bones, are also present. Despite these differences between the two families, rostra construction seems to follow a common developmental pathway, in which an early, horizontally oriented rostral cartilage acts as the major supportive structure. Overall

differences in osteology and morphology of the feeding apparatus in billfishes will be further discussed in a form-functional context.

Title: 44-5: Mechanical Anisotropy of Shark Skin

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Shark skin is hypothesized to behave as an exotendon, providing mechanical advantage during locomotion and improving swimming performance. In shark skin, dermal denticles are embedded in the dermis and collagen fibers form an elastic meshwork. During swimming, this network experiences stress along two distinct axes (longitudinal and hoop) as forces are transmitted along the body. Previous research found that shark skin behaves anisotropically, stiffening in the hoop axis and extending greater longitudinally, and that mechanical behavior is impacted by both denticle density and collagen fiber arrangement. We quantified the mechanical properties of shark skin, the collagen fiber network, and dermal denticle density variation to test the structural impacts on the anisotropic behavior in a comparative context. We dissected skin from 19 shark species (6 families). We quantified the denticle density and fiber angles for each sample. Skin samples oriented along the longitudinal and hoop axes were tested in uniaxial tension to failure at 2 mm/s strain rate. We generated stress-strain curves for each test and calculated the mechanical properties. We found that skin tested along the hoop axis was significantly stiffer than the longitudinal axis. Stiffness also correlated negatively with denticle density and positively with fork-length (FL). These comparative data support the exotendon hypothesis by showing skin behaves anisotropically generating mechanical advantage in both axes. This work was supported by the United States National Science Foundation (IOS award 194713).

Title: What are they good for: Morphological variations of Pre-Pelvic Claspers across Holocephalans

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Male cartilaginous fishes exhibit a modification to their pelvic fins called claspers that are used during copulation. Comparatively, male Holocephalans exhibit several additional reproductive structures adorned with hook-like dermal denticles that facilitate mating, including a head clasper (tenaculum), and another paired structure anterior to the pelvic fins called pre-pelvic claspers (PPCs) that are unique to this group. Here we visualize the morphology of the pelvic girdle and associated copulatory organs (PPCs and claspers) via micro computed tomography (μCT) scans. Specimens representing three *Hydrolagus* species (Chimaeridae), and one representative of the Callorhinchidae and Rhinochimaeridae specimens were imaged. After μCT

scanning the internal cartilaginous structures, the *Hydrolagus colliei* specimen was stored in a 3% Phosphotungstic acid solution to contrast stain the soft tissue, we then re-scanned the specimen which allowed us to reconstruct the soft tissue paddle of the PPC. Finally, we used a Scanning Electron Microscope to visualize the PPCs across development. PPCs are ornamented with multiple hook-like or plate-like dermal denticles on the medial side for grasping the female. These denticles are much larger than the small denticles covering the surface of the posterior claspers. Interestingly, we found that species with long gracile claspers and lack dermal denticles covering the claspers, exhibit denticle-covered PPCs, suggesting a trade-off between the relative size of the PPCs vs. pelvic claspers and the presence of small numerous denticles.

Title: 5-5: What to do when mammalian forelimb muscles don't divide into dorsal and ventral groups: the special case of panniculus carnosus

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Developmentally and evolutionarily, muscles of the limbs and muscles of the trunk are distinct anatomically. Muscles of the trunk are serially innervated in strips, with each spinal nerve contribution innervating just a portion of the muscle. Conversely, muscles of the forelimb are innervated via a complex braided nervous exchange called the brachial plexus. M. panniculus carnosus is located and acts on the trunk in domesticated mammals; it is therefore considered a trunk muscle functionally and is often referred to as "m. cutaneous trunci" for that reason. However, it is innervated via a branch of the brachial plexus. In this study we dissected 15 individuals from from five different orders of mammals, including Marsupalia, Afrotheria, Carnivora, Artiodactyla, and Primates, to follow the innervation of panniculus carnosus. We discovered that m. panniculus carnosus is consistently innervated from the brachial plexus, and also that it is joined via innervation to the ventrally located pectoralis muscle group as well as the dorsally located m. latissimus dorsi. Long standing anatomical cannon states that the brachial plexus, while derived entirely from ventral rami, is divided into dorsal and ventral divisions. Here we suggest that mm. pectoralis, m. latissimus dorsi, and m. cutaneous trunci are ancestrally derived from a laterally positioned common muscular sling and do not fit into the dorsal and ventral divisions categories.

Title: 9-8: Evolution and Anatomy of Gizzards in Fishes

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Gut morphology is tied to the food organisms can digest. Gizzards are specialized organs of the gut found in archosaurs and fishes which mechanically reduce food and thereby aid digestion. Gizzards are thought to compensate for edentulism, and/or provide an advantage when consuming small, tough food items (e.g., phytoplankton, algae). It is unknown how widespread gizzards are in fishes and how similar these structures are among different lineages. Here, we investigate the distribution of gizzards across bony fishes to 1) describe gizzard tissue composition in multiple lineages, 2) determine if aspects of gut morphology are associated with the presence of a gizzard, and 3) estimate how many times gizzards have evolved in bony fishes. According to our analyses, gizzards are rare across bony fishes, evolving only five times in a broad taxonomic sampling of 45 species, and gizzard presence is not clearly correlated with factors like gut length or dentition. We find that gizzard morphology varies widely among lineages where one is present, both macroscopically (presence of a crop) and microscopically (varying tissue types). We conclude that gizzards in fishes likely aid in mechanical reduction of food, but their relative scarcity suggests they are just one of many possible solutions for processing a nutrient-poor diet.

Title: 2-1: Body size shifts in color polymorphic salamanders in response to climate change

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Animals with discrete color polymorphisms offer a unique opportunity to examine the effects of climate change on intra- and inter-specific morphological variation. Color morphs have correlated trait complexes, and, therefore, morphs may exhibit divergent adaptative responses to changing environmental conditions. Here, we examine spatiotemporal body size shifts in *Plethodon* salamanders, which has a widespread striped/unstriped color polymorphism. Recently, we demonstrated that a single, commonly studied species has experienced rapid body size shifts in less than 50 years. In total, there are ten species within the genus *Plethodon* that display the striped/unstriped color polymorphism, and non-polymorphic closely related species are typically fixed for either phenotype. We know little about these other polymorphic *Plethodon* species and whether they also show similar, divergent body size changes in response to shifting climate. Using historical museum collections, we categorized color morphology and measured body size of *Plethodon* salamanders. We use a phylogenetic generalized linear modeling framework that includes information about spatial population structure to examine how body size varies with climate, elevation, and over time. With use of historical biological collections, this work provides essential data for understanding the evolution of color morphs and whether species or morphs respond concordantly to changing environmental conditions.

Title: 18-2: A myological approach to gape and bite force reconstruction in Smilodon

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How *Smilodon* used its hypertrophic canine has been the subject of debate since its first fossils were described; animals need to be able to open their mouths wide enough to eat, and yet the elongated canines of many sabertooths (for which there are no good living analogues) make it hard to understand how they achieved this. While many have used osteological and engineering approaches to explore this, for the first time, we present a myological approach to quantify gape in *Smilodon*. We dissected 11 extant felids spanning the size range of the family, and quantified the fascicle length (FL) and physiological cross-sectional area (PCSA) of each masticatory muscles. We also assessed the correlation of osteological proxies for these variables to reconstruct them in *Smilodon*. As previously hypothesized in publications, the best proxies of bite force suggest that *Smilodon* was relatively weak. However, contrary to previously published hypotheses, for most osteological predictors, *Smilodon* appears to have had relatively *shorter* FLs, suggesting that their muscles had less stretch than those of extant felids. Since *Smilodon* probably had to open its jaws fairly widely, this finding suggests that the architecture of their masticatory muscles was different than that of extant felids which means that *Smilodon* potentially had even weaker bite forces than previously predicted – even further deepening the mysteries of how sabertooth felids used their jaws.

Title: 25-6: Setting the tempo of morphological change: Osteological shape diversity in domestic pigs over 100 generations of intensive human directed selection

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While archaeologists have begun to clarify the locations and timings of multiple animal domestications, including horses, dogs and pigs, it is still unclear how quickly these domestic organisms changed from their wild predecessors into domesticated forms and if there is a uniform morphological signal that can be attributed to animals raised within the structures of human directed selection regimes. Furthermore, it is also unclear if phenotypic change occurs in domestic animals at a similar rate to their wild cousins. The Sus 100 project evaluated the biological effects of human driven selection pressures upon an ideal model organism, the domesticated pig. Specimens from two distinct pig breeds, the Edelschwein and the Landschwein, were compared with wild boar remains from both modern and historic periods, covering approximately 100 generations, in order to investigate the speed and uniformity of morphological variation. Both the skull and selected postcranial elements were analysed with 3D geometric morphometric methods, allowing for an insight into the responsiveness of *Sus scrofa* to living in human controlled environments, adding another piece to the puzzle to understanding the complex pathway of animal domestication.

Title: 17-4: The helmeted hornbill's hammer: complex anatomy and impact-resistant structural design of the casque

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The critically endangered helmeted hornbill (*Rhinoplax vigil*) is the only species of hornbill with a solid casque, an anterior protrusion above the beak. As a result, these birds are poached across their range, their casques traded illegally, carved, and made into ornaments. Casques function in sexual selection, acoustic resonance, as a digging tool, and in a rare defensive behaviour called 'aerial jousting', where they collide casques mid-flight, in a display that can be heard for ≤100m. Previous X-ray imaging revealed dense bone trabeculation in a cavity between the casque and the braincase. However, it is unknown how this is structured to sustain such extreme impact. We characterised the structural relationship between skull and casque internal anatomy using microCT, digital network analysis and material characterization. We found that although the casque is homogenous keratin, around 8 times thicker than its beak keratin, the trabeculae form a complex anisotropic network, most dense between the dorsal casque and anterior braincase and converging on particular skull regions (e.g., the craniofacial hinge and the gap between the nasal passages). In some specimens, we found bullets within the trabeculae, their entry trajectories surrounded by tissue masses, suggesting potential for tissue regeneration within this cavity. The combination of casque and trabeculae therefore represent a complex architectural composite, with implications for the species ecology and biology, but also biomimetic lightweight structural design.

Title: 53-6: A Deep Learning pipeline to quantify cranial suture morphology from 3D scans

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Cranial suture plays an important part in brain development and skull functioning. With rapidly increasing access to 3D imaging tools, high-resolution 3D skull scans are readily available and provide researchers with non-invasive means to quantify sutures with unprecedented detail. However, measuring sutures manually, for example placing large numbers of semi-landmarks on scans, is highly time-consuming. Thus, to quantify sutures across a wide range of species, a key challenge is finding high-throughput methods to capture suture morphology directly from scans.

Deep learning has become the state-of-the-art of many computer vision tasks, and it has been used to predict accurate phenotypic measurements on many biological datasets, which brings significant potential in identifying sutures automatically. Here we present our work developing a new pipeline using Deep Learning to automatically extract suture morphology from skulls. We used Deep Learning to segment sutures on micro-CT scans of mammal skulls for 21 extant species As the suture region is very small on the slices, we tried a variety of approaches to design our Deep Learning models to tackle this challenge. We then evaluated the performance of different models. Finally, we show how we can transfer segmentations into morphological information relevant to suture function and development. With these initial trials, we will ultimately build a flexible pipeline that allows researchers to use Deep Learning to measure sutures accurately and efficiently from scans.

Title: 11-5: The consequences of calcium: investigating intracortical reproductive signals in the American Alligator for sex determination.

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Identifying sex in extinct archosaurs has proven difficult due, in part, to low sample sizes, preservation biases, and methodology. While previous studies have largely focused on dimorphic morphological traits, here we investigate osteohistological signals of egg-shelling in modern alligators. Egg shelling requires large mobilizations of calcium reserves. Aves utilize medullary tissue as a calcium reserve, while crocodylians appear to mobilize calcium from cortical bone or osteoderms. Thus, egg-shelling events should be detectable in female crocodylian cortical bone by analyzing artifacts of resorptive processes required for calcium mobilization. We examined undecalcified mid-diaphyseal *Alligator mississippiensis* femoral bone cross sections for cortical signals of reproduction. Cortical thickness, secondary resorption, and medullary cavity area were measured in femoral cross sections from captive raised male (n=10) and female (n=29) *A. mississippiensis* of 26-27 years at age of death. Data was analyzed by pairwise t-tests between sex and captivity status. A reproductive signal was undetectable in this study and any quantifiable differences between sexes appears to be driven by size dimorphism. Results of the present study indicate reproductive signals in long bone cortices are not reliable indicators of sex in *A. mississippiensis*, but future study of dimorphic signals would benefit from more extensive sampling and limiting of confounding variables. If present in extinct archosaurs, utilization of structural bone as a calcium reserve is undetectable based on the current study.

Title: 43-2: Sample size and two-dimensional geometric morphometrics impact the evaluation of morphological variation in three species of Louisiana bat

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Although geometric morphometrics has had a profound impact on our understanding of morphological evolution, factors such as sample size and views selected for two-dimensional geometric morphometric (2DGM) analyses are often dictated by specimen availability and time rather than study design. We assessed morphological variation in skull shape in three bat species in Louisiana, *Lasiurus borealis*, *L. seminolus*, and *Nycticeius humeralis*, using 2DGM. Leveraging our large intraspecific sample sizes, we evaluate the impact of sample size on calculations of mean shape and shape variance, and the concordance of multiple 2D views. We found that shape differences were not consistent across views, and the views were not all strongly associated with one another. Additionally, reducing sample size affected mean shape and increased shape variance intraspecifically. These results underscore the importance of selecting appropriate sample sizes and 2D views for each hypothesis. Further, these species are sympatric in Louisiana and have substantial dietary overlap. We found that the two lasiurid species overlap in shape space but are separate from *Nycticeius*, and that there were subtle but statistically significant differences in shape between *L. borealis* and *L. seminolus*. These results suggest that phylogeny rather than function drives shape differences between our selected taxa.

Title: 54-4: The subpectoral diverticulum in Buteo: not just another air sac

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Emerging from the respiratory system of birds is an array of secondary diverticula that weave around the joints, between muscles, under the skin, and variably pneumatize the postcranial skeletal tissues. While avian air sacs drive ventilation through the gas-exchanging lung, both the sacs and diverticula have been demonstrated to play a role in secondary non-ventilatory functions including visual displays and vocalization. Here we evaluate the non-ventilatory function of the subpectoral diverticulum in the red-tailed hawk (*Buteo jamaicensis*) and Swainson's hawk (*Buteo swainsoni*) using dissection, microCT, 3D segmentation, and 3D multibody dynamics (MDA) biomechanical models. The subpectoral diverticulum is a structure emerging from the interclavicular air sac in the axillary region that extends towards the sternal keel between the thoracic fibers of m. supracoracoideus and m. pectoralis. When inflated (both during sedated ventilation and in deceased specimens), the thoracic fibers of m. pectoralis are displaced ventrally, independent of the movement of the sternal keel. MDA models indicate that

when fully inflated in some specimens, the diverticulum can increase the moment arm of the more caudal pectoral fibers by up to 113%. CT images of sedated individuals, indicate that they can inflate the diverticula in a bilaterally asymmetric manner and shift inflation levels during an individual breath cycle. These data suggest that this diverticulum may impact pectoralis muscle function during flapping movements.

Title: 45-4: On the relationship between retinal and visual field topography in vertebrates

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In 1977, Hughes published a highly influential synthesis of comparative optics, retinal morphology and ecologically relevant behavior to describe the functionality and utility of the binocular and peripheral components of the visual field across mammals (Handbook of Sensory Physiology 5:613-756). Hughes argued that the advantages of binocular vision and stereopsis were positioned far closer within an animal's visual field than was properly appreciated. Since this publication, advancements in our understanding of natural scene statistics, ecological optics, comparative retinal morphology and physiology as well as neural components contributing to ethologically relevant behaviors, such as locomotor planning and execution, have been made. Here I use optimization and information theory approaches to model the volumes, types, and rates of visual information collected from visual fields for vertebrates inhabiting various environments and possessing differing visual field sizes and specializations for resolution. These models include light environments, such as photopic (abundant light), mesopic (intermediate light levels), and scotopic (light-limited), as well as the locations of retinal specializations for resolution within visual fields. The results of these models suggest that more visual information is available and gathered in mesopic light conditions, especially in the binocular field, than has previously been suggested, at least for mammals. However, much as Hughes anticipated, the benefits of this additional information in the binocular field is largely restricted in space to a region close to the animal, not much beyond arms reach.

Title: P1-16: Comparative functional morphology of the pharyngeal musculature in invasive Asian Carp

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Since their first releases into U.S. rivers half a century ago, Asian carp have threatened freshwater ecosystems from the Mississippi River basin through the Great Lakes. Silver, bighead, grass, and black carp all feed on different prey, from extremely small particles to aquatic plants and hard-shelled molluscs. While individual aspects of the trophic anatomy of these fishes have been studied, this is the first study to describe and compare pharyngeal

musculature across these invasive species. Here we describe the pharyngeal bones and muscular architecture of each species, compare relative muscle masses, investigate fiber types, and compare morphological features using CT data. We use dissection and computed tomography to compare bony and muscular elements, as well as histological techniques to further characterize pharyngeal muscles. The following muscles were dissected out and weighed: levator arcus branchialis 5, retractors os pharyngeus inferior and superior, transversus ventralis, and pharyngocleithrals internus posterior and externus. We found that the levator was the largest pharyngeal muscle by relative mass in most species, while the inferior retractor was the largest in black carp. Interestingly, previous work indicated that this latter muscle is also largest in common carp, suggesting that this architecture may be better suited for generalized diets. We examine these differences in a functional context to determine the role of pharyngeal anatomy in these fishes' status as successful invaders.

Title: 9-1: Is that a fish tongue?: Comparative morphology of the cypriniform palatal organ

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Cypriniform fishes, which make up roughly 25% of the world's freshwater fishes, are characterized by many feeding novelties including the palatal organ, a large tongue-like, muscular mass on the roof of the mouth. The palatal organ has only been described in a few species although it characterizes nearly all cypriniform fishes. Composed of a complex mesh of differently-sized muscle fibers of various lengths and diameters it is covered by an epithelium studded with taste buds. In goldfish, this structure functions as a muscular hydrostat forming protrusions that trap particles against the floor of the pharyngeal cavity. Such processing is neurologically costly with the vagal lobe comprising roughly 20% of the brain. However, it is unknown what feeding role this structure may play in other fishes. Here we describe the anatomy of this muscular pad in the major clades of Cypriniformes, identifying some major differences in muscle architecture in the two major cypriniform lineages. Notably, even in *Paedocypris*, a greatly miniaturized cyprinid, the palatal organ takes up a significant portion of the buccal cavity. It is unlikely that a miniaturized species would retain expensive muscular tissue that is not functional. Moreover, the palatal organ of this miniaturized species shows some of the greatest underlying organization. Our comparative data show that it is only in the algae-scraping *Gyrinocheilus* that the palatal organ has lost most muscular tissue.

Title: 41-3: Form and function of lizard cranial osteoderms

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Dermal bony plates also known as osteoderms (ODs) are present in several distantly related vertebrate taxa and they are particularly common and diverse among extant lizards. Lizard osteoderms have classically been considered to be protective elements against predator attacks. However, empirical data supporting this hypothesis are scant. We instrumented temporal osteoderms with a rectangular rosette strain gauge and 1) loaded different areas of their head to better understand the mechanical responses of osteoderms to loading in preserved specimens, 2) loaded frozen of live anesthetized specimens to test whether results were similar, 3) evaluated loading during transducer biting as well as feeding and 4) evaluated whether osteoderm size and shape are constrained by bite force and may in term constrain locomotor performance in cordylifom lizards. We show that loading generates large strains, that the relative stiffness is similar in preserved versus fresh specimens, that loading increase with bite force in most species and that during feeding osteoderms show significant deformation. Finally, we detected relationships between osteoderm size and shape and performance traits in cordyliform lizards. These results suggest that osteoderms play a role in cranial biomechanics and may co-evolve with fitness-relevant performance traits.

Title: P1-2: Pug-nosed Pigs—What Goes Wrong?

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Yucatan minipigs represent an extreme along the spectrum of snout shape in *Sus scrofa*. Whereas wild boar and feral swine have long, narrow snouts, domestic breeds have shorter, broader faces. This tendency is exaggerated in Yucatans, which have short upper jaws accompanied by malocclusion. Since growth of the midface involves both bone (sutural surfaces) and cartilage (nasal septum), we investigated these structures in Yucatan and standard pigs. Heads (n=84, 0-12 months) were examined by dissection, computed tomography and/or histomorphology. Coronal and nasofrontal sutures were not fused in growing Yucatans, but compared to standard pigs, were simpler and narrower, with disorganized ligaments and more osteoblasts. The nasal septum was more affected, notably in the endochondral ossification of its caudal end. Neonatal Yucatan septa were over 17% bone, whereas neonatal standard pig septa were under 13% (p=0.03). The discrepancy increased with further growth, and multiple regression indicated that ossification percentage was a negative predictor of snout length. The cartilaginous growth plates at the ossifying border disappeared earlier in Yucatans, with the ventral area, usually the most active in growth, the most affected. In conclusion, poor growth and early ossification of the caudal nasal septum are probably the primary cause of Yucatan short-snoutedness, with the sutural changes either a secondary consequence or another

manifestation of heightened osteogenesis. Supported by NICDR F30DE028183 and R21DE024814.

Title: 21-2: A tool for testing aeroelastic links in bird wings: Blocking feather muscle activity in vivo in fowl (Gallus gallus) with 6-hydroxydopamine.

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Birds possess a network of dermal smooth muscles that influence feather position. These muscles are innervated by noradrenergic autonomic nerves, and have been suggested to contribute to thermoregulation, display, and aeroelastic behavior of the wing in flight. Despite their functional importance, experimental investigations have been hampered by difficulties in measuring and manipulating smooth muscle *in vivo*, especially when compared to skeletal muscle. Our goal in the present study was to improve understanding of smooth muscle function in determining external wing morphology. We have adapted an existing approach using 6-hydroxydopamine to block noradrenergic signaling as a novel means of knocking down smooth muscle function in the expansor secondariorum, a smooth muscle belly that runs to the proximal secondary flight feathers. Across a varying range of time courses and doses (n = 9 individuals), we found a single 9 mg/kg intramuscular dose was sufficient to block feather movement elicited by direct nerve stimulation. In contrast repeatable feather movements were exhibited in contralateral sham injection controls. The effect was localized to an ≈1 cm radius, as evidenced by continued response from adjacent feather muscles on the treatment side. This approach provides a means to conduct localized loss-of-function experiments to uncover the roles of autonomic feather position control in avian biology.

Title: 24-5: Revisiting the homology of the therian premaxilla

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The homology of the marginal jaw bones has rarely been questioned among bony-jawed vertebrates. However, the topographical relationships of the therian premaxillae (incisive bones) are unique. They locate lateral to the external nostrils, although the premaxilla of most non-therian tetrapods is found in the medial. To reconcile this inconsistency, we conducted comparative morphological analyses in the various tetrapod embryos (e.g., mice, goats, echidnas, chickens, lizards, and frogs) and the fossil record and showed that the rostralmost upper jaw region was highly reconstituted during mammalian evolution. Namely, the main body of the therian premaxilla should be homologous with the septomaxilla, and the palatine part should be assigned as a part of the vomerine bones. The cell-lineage tracing using *Dlx1*-CreER^{T2} mice

demonstrated the premaxillary region of non-therian tetrapods diverted as the protruded nose in the therian mammals, semi-independent from the upper jaw. Almost the entire upper jaw, including the main body of the therian premaxilla, is from the maxillary prominence. Although protruding noses are also found in non-therian tetrapods such as the soft-shelled turtle, our embryological analyses have shown that they retained the ancestral facial patterns of the tetrapods and differed from the therians. Thus, the mammalian face is an evolutionary novelty established through the reconstitution of the ancestral facial constraints, and its transition is a unique event during the evolutionary history of the tetrapods.

Title: 54-7: The key innovation of the mammalian respiratory system

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In the mammalian lineage, the evolutionary origin of the skeletal muscle sheet separating the pleural and peritoneal cavities, or the diaphragm, preceded acquisitions of mammalian characteristics including the low-compliance bronchoalveolar lung, distinct lumbar region, and possibly fixation of the cervical vertebral number to seven. From the viewpoint of evolutionary developmental biology, an identity of each skeletal muscle is determined depending on extrinsic cues during development, and limb muscles, for example, can develop from somites at variable positions in different lineages. The myocytes of the diaphragm are derived from the migratory muscle precursor cells destined to the forelimb field (*sensu Tbx5*-expressing lateral plate mesoderm) like forelimb muscles of the mammals and the other tetrapods. On the other hand, the homology of the diaphragm is elusive when features shared with the diaphragm or the phrenic motor column in the spinal cord is sought solely in the same mammalian body, since the ancestral condition can be inferred only by outgroup comparison. Therefore, we have conducted outgroup comparisons, and found that the diaphragm likely evolved from the forelimb muscle group, in particular a shoulder muscle. The key innovation that brought about the evolution of the diaphragm would have occurred at the base of the limb bud in embryos of a certain mammalian ancestor.

Title: P3-13: Evolutionary developmental perspective for the early evolution of the pectoral fin

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The origin and early evolution of the pectoral fin represent an example of acquisitions of new motile organs whose movements deviated from the axial and pharyngeal movements in the ancestral vertebrates. Stem gnathostomes would hold the key to understanding how such a new motile organ evolved, because their pectoral girdles with articular fossae and neurovascular foramina could be preserved in the fossil record. However, data about the anatomy and

development of the pectoral appendages in the extant gnathostomes are still insufficient to compare with these fossils. To overcome this problem, we collected data about developmental processes of the pectoral appendages in a chondrichthyan (cloudy catshark *Scyliorhinus torazame*) and sarcopterygians (mainly Mexican axolotl *Ambystoma mexicanum* and for reference, Australian lungfish *Neoceratodus forsteri*), focusing on the vascular systems and spinal nerves. Whereas vascular plexi were initially formed widely in body walls alongside fin/limb buds, during subsequent remodelings of the vascular plexi, blood vessels of the fin/limb bud were restricted in proximities of the common cardinal veins, in both the chondrichthyan and sarcopterygian developments. It is in contrast with spinal nerve axons that independently invaded the fin/limb buds. According to the fossil record, positions of vascular canals relative to the articular fossae on girdle skeletons were variable in basal "placoderms", unlike crown gnathostomes, and it possibly reflected difference in positional relationships between the heart and pectoral fin.

Title: 35-2: Effects of history on ecomorphological convergence across planktivorous fishes

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Planktivory is a distinct type of foraging that has evolved repeatedly among coral reef fishes. Most reef fish planktivores feed by visually selecting and capturing microscopic plankters that are often transparent and evasive. This foraging mode is widely associated with a suite of morphological specializations hypothesized to converge across disparate clades. However, clade-specific differences in morphology, form-function relationships, or adaptive history can constrain ecomorphological convergence. Indeed, ancestral effects may explain the inconsistencies in morphological changes following transitions to selective planktivory among clades studied to date. Here we use a phylogenetic framework to describe morphological trends associated with selective planktivory across 1,812 marine acanthomorphs and comparatively assess the effects of ancestral morphology and foraging condition on corresponding trajectories of morphological change. Reconstructions of foraging history reveal more than 30 independent transitions to selective planktivory, providing many replicates for testing morphological convergence. By comparing a series of evolutionary models, we find strong effects of history across most morphological traits, but also some evidence of convergence among traits that describe general body shape. Pattern-based analyses confirm these results, and further reveal the effects of ancestral foraging condition on morphological changes following transitions to selective planktivory. Overall, our findings highlight the importance of ancestral effects in shaping

patterns of morphological convergence despite the seemingly uniform functional demands of selective planktivory. Funding from the National Science Foundation DEB 1556953/1830127.

Title: P3-19: A preliminary analyze of cranial variations in three Amphisbaenia species

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Amphisbaenia is a fossorial group of Reptiles. They display morphological adaptations to burrowing, namelly, a cylindrical and elongated body, a tendency to lack legs, and a strongly ossified and compacted skull. Regarding the skull four morphotypes can be assumed: round-headed, spade-headed, keel-headed, and shovel -headed, beeing the snout region the main cranial variation. The intermediate region of the skull and the occipital zone are more constant in the different species of the group. However, it is worth mentioning that these skull regions are particularlly related to many aspects of their life, such as excavation activity and related bite force, for example. We hypothesize that there are significant variations in these skull regions between different species and that such variations may be related to their lifestyles. The main objective of our research was to analyze, in a preliminary way, cranial variations between three species of Amphisbaenia nameli, *Amphisbaena darwinii*, *Blanus cinereus* (both with a rounded skull), and *Leposternon microcephalum* (with a snout-headed skull). For this, computerized microtomography of four adult specimens of each species were analyzed using 3D Geometric Morphometrics, based on 22 landmarks describing the intermediate and occipital skull regions. Associated Principal Component Analyzes showed a clear difference between the three species studied.

Title: 16-4: ‘They’re just like football players’: Human ethics in animal research

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As the existence of this panel demonstrates, there is increasing recognition that traumatic brain injury (TBI), and the potential neurodegenerative effects thereof, is ‘not just for humans’. Understanding how TBI affects nonhumans—and how those animal brain injuries do and do not map onto human brain injuries—is a significant scientific endeavour involving scholars from diverse disciplinary backgrounds who deploy a wide range of methods and models. In this

presentation, I draw upon my anthropological research that has involved observations and interviews with scientists studying TBI in animals, as well analyses of various written sources, in order to better understand this emerging area of scientific research. In particular, I seek articulate how those investigating TBI in animals understand the ethical consequences of their work. I make two arguments in particular: First, scientists studying animal models of TBI draw frequent comparisons between the animals used in their research and humans, particularly American football players. Second, that the purpose of these comparisons is often to undergird ethical arguments about the appropriateness or otherwise of humans playing football. In making this argument I suggest that while pre-clinical animal studies exist at some distance from the highly contentious and politically fraught debates over concussion in sport, those debates continue to inform, and perhaps shape, research on animals.

Title: 8-4: The Ontogenetic Interface of Jaw-Muscle Leverage and Cranial Morphology in Capuchin Primates

Authors: Megan A. Holmes[1], Parker M. Taylor[2], Rocio Ramirez[3], Megan P. Solis[4], Mariana D. Fogaça[5], Janine Chalk-Wilayto[6], Claire Terhune[7], Myra Laird[8]

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Dr. Herring's work on the ontogeny of feeding cemented the importance of development in the mammalian masticatory system, inspiring a range of evolutionary biological analyses, including our ongoing research on capuchin feeding ontogeny. Juvenile *Sapajus* is known to feed on mechanically challenging foods in contrast to their sister-taxa, *Cebus*. Previously, we reported that skull shape and jaw leverages varied with age and differed between the two genera. Mechanical advantage was consistently greater in *Sapajus,* presumably due to developmentally early exploitation of mechanically challenging foods. Now, we predict that *Sapajus* skull shape correlates significantly with jaw leverage at the anterior and premolar dentition across ontogeny, reflecting the need for functional competence in the masticatory complex early in development. Three-dimensional landmarks were placed on the skull and dentition in an ontogenetic sample of *Sapajus* (n=33), capturing both skull shape and jaw leverage for the masticatory muscles. Two-Block Partial Least Squares were conducted to test for correlations in specimens with deciduous or permanent dentition. No significant correlation was found between skull shape and leverages at the deciduous dentition, yet a correlation was present ($p<0.05$) at permanent bite-points (i.e. temporalis leverage at anterior dentition/ masseter leverage at premolar dentition). Results do not fully support our prediction but likely reflect the growing importance of masticatory functional

competence post-weaning and the varying leverage each jaw-closing muscle has at different bite-points.

Title: P2-16: The current state of the field in using continuous shape data for phylogenetic reconstruction: A systematic review

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Discrete morphological data are often important in traditional systematic methods for phylogenetic reconstruction and are crucial for merging fossils into the tree of life, calibrating molecular dating and enhancing accuracy in phylogenetic inference. However, a major limitation of discrete morphological data is subjectivity in character and character state definition which can introduce biases and mislead inferences and divergence time estimations. Quantitative data e.g., geometric morphometric (GMM; shape) data can allow for more objective integration of morphology into phylogenetic inference. This review describes the current state of the field in using continuous shape data for phylogenetic reconstruction, and offers pathways for approaching this task with GMM, using the PRISMA-EcoEvo v1.0. reporting guideline. A comprehensive search string yielded 106 phylogenetic studies published in English up to Dec 2022 in the Web of Science database. Title/abstract screening removed 97 articles and full-text screening was performed for 55 articles. Support values (i.e., bootstrap, jackknife) for topologies reconstructed using GMM were compared to those using discrete morphological data. Articles were independently screened by two authors to determine final inclusion and quality assessment. Most phylogenies showed increased support and resolution with the inclusion of continuous data, either as continuous-only datasets, or integrated into discrete datasets, despite the ongoing rarity of such studies. Improved methods for the application of quantitative data to phylogenetic inference remain crucial to the advancement of morphological phylogenetics.

Title: 31-2: The functional morphospace of fish skulls is constrained by evolutionarily rigid, ubiquitous bounds

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Lineages that enter ecologically available “adaptive zones” often undergo rapid morphological evolution which leads to their adaptation to these zones. Such lineages accumulate disparity until they fill the functionally available morphospace, and their rate of morphological evolution

decelerates. However, it is unclear which mechanisms set the bounds of the morphospace, and how stable these bounds are throughout evolution. Here, we characterized the tempo and mode of evolution of muscle-skeletal traits in fish skulls across 13 fish radiations, featuring age ranges of 0.1-50 Myrs, and a diversity of trophic strategies and ecologies. We used traits for which a functional link with feeding performance is established, so that variation in trait values can be mechanistically linked to variation in feeding performance. We found that the bounds (i.e. min and max value) and ranges for size-corrected functional traits were remarkably consistent across the 13 radiations, and did not expand with the age of the radiation. For most of the traits, a model of bounded Brownian motion was overwhelmingly favored over other models of trait evolution. Disparity through time analysis indicated that 50% of the disparity was reached within ~10 Myrs, and then plateaued. We suggest that constraints on the design of bones and muscles bound the functional morphospace during adaptive evolution. While the functional morphospace initially fills rapidly, diversity is ultimately maintained through revisiting previously utilized morphospace regions.

Title: 51-1: Walter J. Bock 1933-2022: Evolutionary Biologist, Functional Morphologist, and Science Organizer

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Walter J. Bock (WJB) significantly influenced biology through his publications and lectures and his work as a visionary science organizer. As a “compleat” evolutionary biologist, he seminally contributed to the empirical basis, analytical methodology, and theoretical underpinnings of functional, ecological and evolutionary morphology. Through over 300 publications, WJB laid the foundations for a holistic approach towards understanding evolutionary processes involving morphological transformations in adaptation to changing environmental conditions based on principles of physics. He explored long-standing issues by generating functional-morphological data, clarifying systematics and evolutionary theory, and reconstructing the evolutionary history of birds. His work has influenced numerous research areas and has only grown in relevance with the recent increased attention to functional aspects in phylogenetic studies. Generations of students, post-docs, and colleagues remember WJB as a generous mentor at Columbia University, the American Museum of Natural History, and numerous international meetings, universities and institutes. WJB was a committed servant to science as a reviewer of over 100 books; an editor of journals and book series; a sought-after member of editorial and institutional review boards; a promoter of increased scientific participation and recognition of colleagues from underrepresented groups throughout the world; the Secretary General (1978-1998) and President (1998-2002) of the International Ornithological Congresses; and a founding member of the organizing committees of the European Ornithologists’ Union (1997) and the International Society of Vertebrate Morphologists (1994).

Title: 27-2: Evolution of asymmetric dentition in Asian snail-eating snakes

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Bilaterians can be characterized by a roughly equal number of paired organs on the left and right sides. However, the mandibular teeth of Asian snail-eating snakes are a remarkable exception. Sakes of the family Pareidae are regarded as dietary specialists of terrestrial snails and slugs. A common ancestor of the pareid snakes evolved the asymmetric dentition with different numbers of teeth on the left and right sides as a special adaptation to efficiently prey on the dextral majority of snails. How did this evolutionary novelty, which clearly deviates from the normal morphogenesis of bilaterians, become possible? In this talk, I will present the research that has been conducted to date to elucidate the evolution and developmental basis of this asymmetric dentition.

Title: 13-4: How trabecular bone adapts to biomechanical constraints associated with high body weight in limb long bones

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While the long bones of most terrestrial taxa tend to show a tubular structure in their diaphysis, with a compact cortex surrounding a relatively large medullary area, this organization differs in heavy amniotes. Their long bones are indeed characterized by a thickening of the cortex and an extension of the trabecular bone into the medullary area. However, this tissue can strongly differ, along a bone and between bones, individuals, and taxa, in the number, thickness, orientation, and connectivity of the various osseous trabeculae. The detailed qualitative and quantitative 3D analysis of the trabecular bone of rhinoceros limb long bones allowed us to show the differences in compactness (bone volume fraction) and orientation (anisotropy) of the trabeculae along these bones. From the conception of a musculoskeletal model of the forces applied to these bones, these microanatomical differences could be associated to the various stresses in tension and compression going through the bones. This allowed us to better characterize the form-function characteristics of trabecular bone in long bones and, more specifically, to highlight the adaptive features of trabecular bone in response to high body weight in rhinos. Further comparisons with other massive mammals will provide a better understanding of how bones jointly adapt their external and internal structures to heavy weight support and locomotion and allow for better inference of the locomotor capabilities of fossil taxa.

Title: 10-2: Climbing kinematics and ecomorphology of Aneides salamanders

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North America is home to a genus of climbing salamanders (*Aneides*), which includes species that live in trees. Many salamanders are capable of adhering to steep surfaces and climbing short distances using mucous adhesion. However, some *Aneides* climb redwood trees as high as 88 ft (27 m) – a dangerous feat for the ill-equipped. To facilitate safer and more effective climbing on inclined surfaces, we hypothesize that arboreal species modulate their locomotor behaviors and possess morphological adaptations. *Aneides* salamanders lack the claws and toe pads found in arboreal frogs and lizards, but do have large feet and expanded toe tips that may prevent slippage. To test our hypothesis, we captured 3D kinematics of the semi-arboreal Aneides aeneus walking on flat surfaces at 0, 45, and 90 degree inclines. Our preliminary data suggest that *A. aeneus* adopts a more crouched posture, different gait, and slower locomotor speed on steeper inclines. We plan to compare the limb joint angles between *A. aeneus* and other salamander species that differ in their scansorial tendencies. To investigate whether arboreal species have morphological adaptations for climbing, we will compare the foot and toe morphology of diverse salamander species along the terrestrial-arboreal gradient. We expect to find that arboreal species move faster and exhibit a wider range-of-motion on steeper inclines than terrestrial species, and that kinematic differences are facilitated by morphological adaptations.

Title: P1-19: Cutting corners: a tool for measuring Functional Homodonty in 3D Slicer

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Binning vertebrate dentitions as morphologically homodont or heterodont based on similar or dissimilar tooth shapes and sizes, hides nuances in dental variation that ultimately misinforms our understanding of tooth function. Similar teeth do not always perform the same. The functional homodonty method quantitatively assesses the functional diversity of teeth by calculating the stress a tooth can transmit to prey based on its surface area and position along the jaw. Variation in stress reveals a functional homodont-heterodont continuum that can be studied across species and analyzed in an evolutionary framework. With the growing availability of CT scans, studying tooth shape across vertebrates has never been easier. Here we present a new tool for measuring functional homodonty in 3D slicer, an open-access program for processing CT scans. The functional homodonty module in Slicer semi-automatically estimates the stress values from segmented teeth that can be easily exported and analyzed in R using open-source code from GitHub. To demonstrate the power of the functional homodonty method and the new tool, we plan to investigate evolutionary changes in salamander dentitions across habitat types and feeding modes. By increasing the accessibility of the functional homodonty method we hope to encourage diverse use cases and further theoretical development.

Title: 21-1: Elucidating the ecological and life history drivers of Galloanserae skull evolution using high density 3D geometric morphometrics

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Our research aims to elucidate the drivers of Galloanserae (ducks, chickens, and relatives) skull evolution. We created and analysed a comprehensive 3D dataset of skull morphology for >240 species, including key extinct lineages, to uncover the extent of morphological variation exhibited by Galloanserae as well as quantifying the factors driving this skull shape variation. Extant Galloanserae only represent a fraction of the remarkable morphological and ecological diversity they attained over ~67 million years of evolution, spanning from pseudotoothed Pelagornis to the giant flightless Gastornis. We tested the hypothesis that extinct Galloanserae will exhibit distinct cranial forms unrepresented in extant taxa. Additionally, we isolated the relative influences of phylogeny, ecology, diet, habitat density, developmental mode, and migration on skull shape variation and evolutionary rates. Principal Component Analysis (PCA) revealed that extinct clades greatly expand the breadth of Galloanserae morphospace occupation beyond what could be inferred from extant taxa alone. Preliminary analyses show significant relationships between Galloanserae skull shape and ecology ($P = 0.039$), habitat density ($P = 0.001$), and migration ($P = 0.0016$). Preliminary rate analyses demonstrate heterogenous rates of evolution for different character states within habitat density, migration, diet, and developmental mode. Our results indicate that ecology, habitat density, migration, diet, and developmental mode are key factors influencing the skull evolution of Galloanserae and highlight the importance of fossils to inform estimates of phenotypic disparity.

Title: P1-1: Locomotor biomechanics of the early dinosaur relative *Lagosuchus lilloensis*

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The Late Triassic archosaur *Lagosuchus lilloensis* (= *Marasuchus*) occupies a pivotal phylogenetic position in between outgroups to dinosaurs (e.g., pterosaurs) and true dinosaurs. Indeed, it is close to expectations for the general form and function of an ancestral dinosaur, such as having long hindlimbs and presumably a bipedal stance. It thus has long been seen as pivotal for understanding the origin and early evolution of Dinosauria. However, the functional consequences of its osteology have only been studied qualitatively. We micro-CT scanned all known specimens in Argentina and reconstructed a 3D digital composite skeleton from the best-preserved bones. In this process, we identified some bones that do not pertain to this taxon, and others that resolve or contribute to controversies regarding its anatomy. We used the digital model in biomechanics software to reconstruct the hindlimb musculature and the body shape (e.g., centre of mass). Using biomechanical simulation, we then analyse how well it ran, and

compare these results to those of others for bipedal early archosaurs. Our findings illuminate how the dinosauriform *Lagosuchus lilloensis* may have moved, and (via comparisons to results from modelling other archosaurs) contribute to debates over if, or how, locomotor function impacted the survival of dinosaurs vs. other taxa across the Triassic-Jurassic mass extinction.

Title: 50-4: Evolution of intervertebral joint function in Crocodylomorpha assessed via automated digital methods

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Extant Crocodylia are unusual in having procoelous trunk vertebrae surmounted by a dual row of osteoderms, important in lateral and dorsoventral motions. The stiffness and mobility of the intervertebral joints have been empirically quantified before. Digital estimates of mobility in five extinct taxa have been quantified via manual methods, addressing how axial morphology formed a "bracing system" whose functions evolved across Crocodylomorpha. However, the effects of osteoderms on mobility have only been empirically assessed; not gauged with these digital methods or in fossils. Here we use the new, automated "AutoBend" digital modelling approach, which has been empirically evaluated in lizards and mammals, to estimate joint mobility and stiffness across Crocodylomorpha. We apply the method, which was validated using existing data, to trunk vertebrae from fossil Crocodylomorpha across representative points along the phylogeny. We thereby test if (1) more extensive osteoderms decrease mobility and increase stiffness of the vertebral column; and (2) ancestral, apparently more mobile, amphicoelous intervertebral joints were functionally replaced by derived, procoelous joints, whilst preserving overall mobility and stiffness. Our findings provide a new, more rigorous assessment of the evolution of vertebral mobility and stiffness in this clade, which also justifies applying it to other archosaurs with similar axial morphology (e.g., Pseudosuchia). These assessments have important implications for the evolution of locomotion across Archosauria.

Title: P1-9: Postcanine tooth morphology of Arctic seals and its relation to their zooplankton reliance

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Tooth morphology relates to diet in many animals. Previous studies of Antarctic seals suggest that jagged post-canine teeth (PC) function as a sieve, retaining small prey in the mouth while expelling water. However, in seals, previous studies are biased toward Antarctic species, and

seals of Northern Hemisphere are poorly studied. In this study, we investigated the relationship between PC morphology and contribution of zooplankton in diets in Phocidae family. Our study consisted of three parts: (1) comparison of PC morphology within *Pusa* (Arctic seal) species, (2) comparision of PC morphology including *Phoca* (Arctic seal) species which are relatives of *Pusa*, (3) analysis of PC morphology and contribution of zooplankton in all Phocidae. We found that PC morphology is highly distinctive between *Pusa* and *Phoca*, but one of *Pusa* species, the Baikal seal was an exception. PC of Baikal seal displayed hallmarks of both *Pusa* and *Phoca*, with highly jagged PC and limited tooth spacing. In addition, we showed that species with intermediate tooth spacing tends to rely more on zooplankton, and PC morphology with high jaggedness would be beneficial for feeding on zooplankton. This research reveals the strong relationship between PC morphology and the reliance on zooplankton, in addition to contributing valuable information on Arctic seal tooth morphologies.

Title: 43-8: On the development of the nasal turbinals and homology in laurasiatherians, with special reference to pangolins

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The nasal capsule is the rostral part of the chondrocranium, constructed during cranium development. This nasal capsule eventually becomes the nose. Multiple corrugated structures are formed within the nasal capsule of the chondrocranium, developing into turbinals and laminae. During fetal and postnatal ontogeny in mammals, turbinals and laminae change the structure by branching off and scrolling, hindering homologization among species. Hence, tracing the ontogenetic process from fetal to adult is essential to resolve this issue. Adult pangolins have complex nasal cavity structures. They have not been compared to laurasiatherian species, and their turbinal homology remains unresolved. We studied the development of the nasal capsule in pangolins and other laurasiatherian species, combing DiceCT images. As a result, in all laurasiatherians, the maxilloturbinal has a complex branched structure. The lamina horizontalis separates the frontoturbinal recess and the maxillary recess. The ethmoturbinal (ET) I branches into the rostral and caudal sides. No sign of interspecific differences in turbinals and laminae were observed in pangolins with four ETs, well-developed ET I branching rostrally and caudally, and long and heavily branched interturbinals. Previous investigators erroneously indicated that pangolins have up to seven ETs; well-developed ET I was identified as multiple ETs, and heavily branched interturbinals were identified as ETs, which led to the misidentification of the overall number of ETs.

Title: 6-5: How artificial selection can inform the study of brain evolution

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Comparisons across species are the primary means of studying brain evolution, but identifying the selective pressures that cause evolutionary changes in the brain remains challenging. An alternative approach is to select for specific traits within a species, so that confounding variables are more effectively controlled. Although selection experiments have proven useful in this context, the selection for specific behavioural or physical traits that gave rise to domesticated breeds is a potentially powerful tool in the study of brain evolution. For example, homing pigeons have been selected for centuries for navigation ability, providing an effective test of how selection for a specific behaviour can cause changes in the brain, especially the size and composition of the hippocampus. Contrary to predictions, homing pigeons do not differ in relative hippocampus size from other pigeon breeds. Instead, homing pigeons have smaller hippocampal neurons at higher density than other breeds, which likely provides some computational advantages for long-distance navigation. Homing pigeons did not differ from other breeds in the relative size or neuron density of several other brain regions, but other breeds did, suggesting that different selection regimes can affect the brain differently. The way that artificial selection for breed specific traits affects brain anatomy parallels some of the patterns observed across species, which demonstrates that inter-breed comparisons can play a significant role in understanding how the brain evolves.

Title: 22-8: Who was the real sabertooth: Thylacosmilus or Thylacoleo?

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This might seem to be a silly question. Both were marsupials, rather than placental feloid carnivorans like most sabertoothed mammals: *Thylacosmilus* had famously hypertrophied and mediolaterally compressed canines while *Thylacoleo* had merely minuscule canine remnants. But the question also addresses the issue: "What is the sabertooth ecomorph?" Sabertoothed carnivores are generally considered to have been powerful ambush predators, possibly capable of tackling prey alone bigger than themselves. *Thylacoleo* was clearly such a carnivore: although its enlarged, supposedly caniniform, incisors were blunt rather than sharp, and may have been for holding prey while it was dispatched with the enlarged claw on the pollux, its cheek teeth were specialized for flesh eating, dominated by an enlarged carnassial-like premolar with pronounced shearing wear, and it had a powerful bite. In contrast, *Thylacosmilus* had few features of feloid sabertooths apart from enlarged canines: it lacked incisors and a bony jaw symphysis, its postcanine teeth were small and showed blunted rather than shearing wear, and it lacked the cranial anatomy conducive to the proposed sabertooth headstrike, but rather FEA analyses show it to have been stronger in pull-back action. It seems likely that *Thylacosmilus* was a specialized scavenger rather than an active predator. So, the question remains: What makes a saber tooth — is it the canines, or is it the type of predatory lifestyle?

Title: P2-3: Sthenurine kangaroos break the CREA rule of facial allometry

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The facial lengths of many mammalian lineages follow the CREA (Cranial Evolutionary Allometry) rule of positive allometry. Extant kangaroos (Macropodinae) are a classic example, but the extinct kangaroo subfamily Sthenurinae contains many notably short-faced species, especially the later (Plio-Pleistocene) ones. Do sthenurines also follow the CREA rule, despite their absolutely shorter faces? As complete skulls are unavailable for most sthenurine taxa we used lower jaw measurements as a proxy for both body size (molar row length) and face length (length of the jaw anterior to the molar/premolar boundary). We found that while macropodine face lengths scale with positive allometry (exponent of 1.18), slightly more positive (exponent of 1.24) if larger extinct taxa are included, sthenurine face lengths show strong overall negative allometry (exponent of 0.67), with three different trends. The Miocene taxa plot close to the macropodine regression line, while the Plio-Pleistocene taxa plot with stronger negative allometry to the general sthenurine exponent in two different ways: the relatively longer-faced *Sthenurus* lineage with a less negative exponent (0.54) than the relatively shorter-faced *Procoptodon* lineage (exponent of 0.32). Thus the Plio-Pleistocene sthenurines definitively break the CREA rule. The specialized hands and forelimbs of sthenurines, hypothesized to be used in foraging, may allow for these kangaroos to have a shorter face, as their muzzles would not be constrained in length by the demands of food selection.

Title: 46-4: Reconstruction undulatory swimming in the first secondarily aquatic amniote

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Secondary adaptation to life in water represents one of the most striking cases of convergence in the evolutionary history of amniotes. One of the most notable examples, the mesosaur *Mesosaurus tenuidens* was the first amniote to have shifted to an aquatic lifestyle. Yet, debates regarding its locomotory abilities are still ongoing and currently lack robust biomechanical testing. Here, we developed a novel combination of range of motion analysis and mathematical model to quantify the undulatory swimming capabilities of mesosaurs. We compared the results to the spectrum of undulatory swimming modes observed in modern taxa. In parallel, we validate our analysis from a blind anatomical perspective using the extant marine iguana. We find that the vertebral column of *M. tenuidens* was remarkably flexible in the 3D-space, in particular in the caudal region. This flexibility allowed for a wide spectrum of lateral undulations, ranging from a slight movement of the tail tip to full body undulation. However, our results show that extreme case of anguilliformy was not possible. These findings suggest that mesosaurs would have been

able to adopt various swimming speeds. We propose that a wider spectrum of undulation modes may represent a plesiomorphic condition within a secondarily aquatic amniote lineage, which would have become more constrained as more derived taxa adopt a more pelagic existence. Funded by the Innovation Fund of the Museum für Naturkunde.

Title: 29-6: Sheep and Goat: Comparison of 8000 years of evolution of two morphologically close domesticated species

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Within the Caprini tribe, *Capra* and *Ovis* genus diverged 5 to 7 million years ago. Within these genus, two species have been domesticated: the sheep (*Ovis aries*) and the goat (*Capra hircus*). While the two species are morphologically close and are difficult to disentangle in bioarchaeology and especially isolated teeth, they are found in large number within archaeological records since the Neolithic. The two species possess different ecological preferences and human uses but are found within the same archaeozoological assemblages. In order to study their respective evolution over the last 8 millenia, we first develop a 2D landmark and sliding-landmark approach based on geometric morphometric protocol to quantify the size and shape of the 3rd lower molar. We explored differences between modern references before exploring the long-term diachronic evolution of the two species in the North Western Mediterranean basin, outside their initial domestic center. The morphometric variation was contrasted with climatic and cultural changes through time. A total of 4700 teeth from more than 225 sites in Catalonia and South of France covering the last 8000 years, that came in addition to ~900 modern specimens from multiple breeds. This study is part of the ERC granted DEMETER project aiming to assess ‘Eight millennia of changes in domestic plants and animals: understanding local adaptation under socio-economic and climatic fluctuation’, in collaboration with concern archaeozoologists and archaeologist.

Title: 42-5: The Parietal Eye in Fossil Amniotes

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The parietal foramen is an opening in the skull for the parietal eye, a photosensitive outpocketing of the brain that was previously hypothesized to have role in the regulation of circadian rhythm and thermoregulation. However, it has also been suggested that latitude has an effect on the presence or absence of the parietal foramen. Among tetrapods, the parietal foramen is lost in many amniotes today, with the exception of many squamates and *Sphenodon*, but this feature

was once widespread among tetrapods in the Paleozoic and the earliest phases of the Mesozoic. To explore the function of this organ in living lizards, we sampled *Anolis sagrei* (n=57) from three different localities at different latitudes. We found no statistical differences in the size of the parietal foramen across latitudes, allowing us to entertain the notion that behavior may play a greater role in the presence of this feature. Additionally, we surveyed the fossil record of pan-reptiles and pan-mammals from the Carboniferous through the Triassic to determine how the size of the parietal foramen has changed in these lineages over time. We found in several lineages, the parietal foramen decreases in size or disappears completely at the Permo-Triassic boundary, indicating unique behavioral shifts that may correlate with survivorship during the largest mass extinction in Earth's history.

Title: 45-9: Anatomy of the premaxilla of Tylosaurus nepaeolicus (Squamata: Mosasauroidea) and its implications in the sensoriality of aquatically adapted squamates

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Mosasauroidea represent a unique body plan within Squamata: elongated body with a modification of the pelvic girdle and reduction of limb bones to form paddle-like appendages. Adaptations of mosasaurs to aquatic environments have been mostly studied from the perspective of anatomical modifications at a postcranial level. In contrast, little is known about cranial adaptations, including skeletal and soft parts, which have been mostly focused on middle and inner ear. It is widely accepted that there is a relationship between the vestibular apparatus and functional aspects of the animal's biology, but other neurological and sensory aspects of the skeleton have not been studied in Mesozoic aquatic squamates. Here, we analysed the premaxilla of a juvenile *Tylosaurus nepaeolicus* from the Cretaceous of Kansas using mCT scanning. The obtained images show the correlation of the neurovascular system on the wall of the nasal cavity, in accordance with the high density of foramina observed in the external side of the premaxilla and maxillae. The relative development of different regions of the nasal cavity might affect the olfaction, respiration, and ultimately the thermoregulation of mosasauroids. Innervation and irrigation of the premaxilla are discussed in relation to possible sensory adaptations to the aquatic environment. The obtained anatomical information shed light on the sensory mechanisms in the evolution and success of one of the most specialised groups in the history of Squamata.

Title: 11-4: An examination into the palaeohistology of Thalattosuchia (Crocodylomorpha) from the Posidonia Shale Formation, Germany

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The Posidonienschiefer Formation (Jurassic: Toarcian) of Germany has yielded incredible fossil vertebrates, including thalattosuchian crocodylomorphs. The most notable and abundant thalattosuchian is the teleosauroid *Macrospondylus bollensis* (formerly '*Steneosaurus*'). Individual skull lengths range from 12 cm-100 cm, making it an ideal taxon for histological and ontogenetic studies. Previous work examining histology in thalattosuchians have been preliminary, aimed at providing a basic understanding of bone microstructure in teleosauroids, but lacking the taxonomic, stratigraphic, and ontogenetic control required to understand growth and palaeobiology within a species. We examined histological sections (three femora, one tibia, one dorsal osteoderm and one jaw section) from small, medium, and large specimens of *Macrospondylus*. We focused on growth rate, size at sexual maturity, and potential habitat-related microstructural markers. We found: (1) visible lines of arrested growth (LAGs) increasing in number with increasing femoral length; (2) a distinct external fundamental system (EFS) in the largest specimen, supporting osteological maturity; and (3) a tubular long bone structure with a dense cortex in the adult, consistent with Middle-Late Jurassic teleosauroids. In addition, the adult displayed heavy bone remodelling compared to the smaller individuals, creating a distinct difference in bone porosity and microanatomy through ontogeny. Our results complement our work relating to *Macrospondylus* growth by providing the age parameter needed to calculate growth rates, and offer insights into thalattosuchian ecology.

Title: 45-7: The Extraordinary Sensory Biology of the Silverjaw Minnow, Notropis buccatus

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The lateral line system (LL) of fishes, comprised of neuromast receptor organs found on the skin (superficial neuromasts, SNs) and within bony canals (canal neuromasts, CNs), detects water flows and mediates prey detection. Most species have one cranial LL canal phenotype, but *Notropis buccatus* has two - narrow canals above and behind the eye and widened canals ventral to the eye and on the mandible. In this study, multiple methods were used to describe the morphology and development of two canal phenotypes. Results show that the widened canals form earlier than the narrow canals. CNs in all canals are similar in size upon canal enclosure, but CNs in widened canals change shape and increase dramatically in size *after* enclosure, unlike in other species. Additionally, many SNs were found on the skin over the widened canals accompanied by hundreds of external taste buds (also found in other cypriniforms). This suggests multimodal integration of gustation with flow-sensing, which has been hypothesized to mediate benthic prey detection in species with widened canals. Preliminary feeding experiments (under light/dark conditions with an intact or antibiotic-ablated LL) suggest that the LL is not the only modality mediating benthic prey detection. This work has revealed LL developmental patterns of the divergence of two canal phenotypes within a species and will facilitate the design of integrated studies of sensory development, behavior, and ecology.

Title: 54-6: Thoracic cage morphology coadapts with aerobic capacity in artificially selected High Runner mice

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Cursoriality, fast and sustained running, is a highly-specialized locomotor behavior that has evolved numerous times in mammals. However, it can be very challenging to disentangle skeletal adaptations for running behavior from other potentially correlated factors, such as diet, habitat, body size, or phylogenetic history. The High Runner (HR) project is a long-term experiment in which mice were selected based on voluntary wheel running, resulting in 4 replicate lines that run three times further per day than 4 unselected control lines. These mice have myriad adaptations, including increased endurance and maximal oxygen consumption during forced exercise (VO2max). However, the role of thoracic morphology in facilitating this increased VO2max of the HR lines is unclear. Here, we examine thoracic cage morphology in HR mice for the first time, and test the hypothesis of increased rib cage volume relative to controls. We postulate that ventilatory capacity may be increased via increased thoracic count (adding ribs) or increasing rib curvature. Thoracic count and rib shape (using 3D geometric morphometrics) were compared between HR and control lines. We find that two of the four HR lines have increased thoracic count via homeotic addition of a rib or pair of ribs, suggesting these skeletal changes may contribute to sustained, endurance-running ability. For future studies, selection experiments can provide a unique opportunity to test adaptive hypotheses in the mammalian ventilatory evolution.

Title: P2-8: Musculoskeletal constraints on hopping in the distal hindlimbs of giant extinct kangaroos

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The largest kangaroos today achieve masses of up to 90 kg; however, various extinct kangaroo species greatly exceeded this, with the largest likely exceeding 200 kg. In predicting the hopping abilities of these giant kangaroos, studies have to date primarily focussed on the allometry of tendon safety factors in the hindlimbs. Unfortunately, large errors can be associated with estimates derived from extrapolating scaling patterns beyond the body mass range of extant species. This issue may be ameliorated by synthesising multiple scaling analyses based upon different morphological measures. Here, in order to improve our understanding of the mechanical limitations faced by giant kangaroos during locomotion, we compare several methods for estimating size constraints on hopping locomotion, based on various musculoskeletal elements of the kangaroo hindlimb. Our results suggest that the hindlimb bones of giant kangaroos could withstand the forces involved in hopping, and that their ankle extensor muscles would likely be able to produce the forces required to resist ground reaction forces when hopping. However, we find that ankle extensor tendon diameter is the limiting factor in the giant species Sthenurus stirlingi and Macropus cf. M. titan, in agreement with prior conclusions. This

study demonstrates how different musculoskeletal elements may provide differing interpretations of the limits of locomotion in extinct species, and thus the importance of integrating both soft and hard tissue evidence into such interpretations.

Title: 54-2: Origin and evolution of lung and gas bladder ventilation in air-breathing fish

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Air breathing has a rich evolutionary history, both in the tetrapod lineage and in the rest of Osteichthyes. Air breathing and lungs evolved in the common ancestor of Osteichthyes tens of millions of years before the water-to-land transition, and approximately 50 fish species breathe air using lungs or a gas bladder today. Within the context of aquatic air-breathing species, there remain long-standing questions about the function of air breathing for buoyancy, the origin of air breathing behavior, and its later diversification. For aquatic species, air breathing inherently provides both respiration and buoyancy, but little work has been done to examine how ventilation is modified to regulate buoyancy. I present data demonstrating that royal knifefish (*Chitala blanci*) use a 4-stroke breath expiration-inspiration breath in response to depleted oxygen and use an inspiration-only breath in response to depleted buoyancy. I discuss evidence suggesting that inspiration-only breaths are used by both sarcopterygian and actinopterygian species, and the implications of this to our understanding of the early evolution of air breathing. I hypothesize that inspiration-only breaths are ancestral to Osteichthyes and thus are the precursor to both sarcopterygian 2-stroke breaths and actinopterygian 4-stroke breaths. Within Sarcopterygii and Actinopterygii, the breath types and mechanisms of ventilation have diversified, and I discuss how this diversity informs our understanding of air-breathing evolution.

Title: P4-16: First description of the air-breathing behaviors of Australian lungfish (Neoceratodus forsteri)

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Although there was a single origin of lungs and air breathing in the common ancestor of Osteichthyes, ancestral state reconstruction of its descendants (sarcopterygians and actinopterygians) indicates that they used different ancestral breath types: 2-stroke and 4-stroke breaths, respectively. How these two breath types evolved from a common origin is still unclear. 2-stroke and 4-stroke breaths have distinct skeletal motion and airflow patterns, and a 2-stroke breath is not simply a subset of a 4-stroke breath. The phylogenetic distribution of species that use 2-stroke and 4-stroke breaths informs our hypotheses about the evolutionary history and transitions between these breath types. While there is a remarkably consistent division—2-stroke breaths in sarcopterygians and 4-stroke breaths in actinopterygians—there are some exceptions.

Two sarcopterygians *Amphiuma tridactylum* (an aquatic salamander) and *Xenopus laevis* (an aquatic frog) use 4-stroke breaths, and *Neoceratodus forsteri* (Australian lungfish) has been suggested to use 4-stroke breaths. Although it is known and expected that African lungfishes and South American lungfishes use 2-stroke breaths, the air-breathing behavior of Australian lungfish has not been described. To determine which breath type *Neoceratodus* uses, we recorded X-ray video of their air breaths. We found that they use 2-stroke breaths, often followed by an additional inspiration. This data is consistent with what is observed in other lungfishes and with the hypothesis that 2-stroke breaths are ancestral to sarcopterygians.

Title: 24-9: Evolution of the naso-palatal complex in Lepidosauria – insights from comparative embryology

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The naso-palatal complex of amniotes contains developmentally-related soft-tissue structures, including the peripheral parts of both vertebrate olfactory systems, the nasal cavity and vomeronasal organ. In squamates, the vomeronasal organ is well-developed and enters the oral cavity exclusively. The nasal cavity contains a single concha, and its lumen is well-separated from the oral cavity due to the formation of the choanal groove. In contrast, the naso-palatal complex of *Sphenodon*, the only living member of the squamate sister group, is characterized by the following characteristics: two nasal conchae, the connection of the vomeronasal organ with the nasal cavity, and long choanae providing an extensive communication of the nasal cavity and the oral cavity. Here we prepared 3D reconstructions of the anterior snout of *Sphenodon* embryos based on histological serial sections and compared obtained results to our previous morphological studies on lizards, utilizing both X-ray microtomography and light microscopy. Our analysis shows an evolutionary shift from *Sphenodon*-like ancestors to squamates concerning differences in morphology of the vomeronasal organ and rearrangement of the anterior concha, which, at least in part, participates in the separation of the nasal cavity from the oral cavity in lizards and snakes. We also found some similarities between Gekkota and *Sphenodon*, which might indirectly support the controversial molecular view of squamate phylogeny in which Gekkota, not Iguania, is the earliest-evolving crown group.

Title: P3-12: Craniofacial malformations in squamate embryos

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A vertebrate head is a complex anatomical part of the body. Modifications of its shape are of fundamental importance in an evolutionary process. The diverse craniofacial morphology of amniotes evolves as an adaptation to the environment through modifications related to food intake or the formation of specialized sensory organs. The fusion of the facial prominences, and thus differentiation of the primary palate, upper jaw and nasal cavities, is an important event in the amniote head development. This process requires a proper shape and position of the prominences. If it is disturbed in some way, various types of craniofacial clefts or other malformations may occur. Here we analyzed embryos of squamates with head dysmorphia observed under a stereomicroscope. Morphological analysis was performed on three species of lizards: *Anolis sagrei*, *Lepidodactylus lugubris* and *Lacerta agilis*. Developmental abnormalities ranged from minor changes in facial structure to significant disturbances in both, the snout and brain. In numerous embryos, craniofacial malformations co-occurred with abnormalities in other body parts, e.g., limbs and tail. In such cases, the analysis in the scanning electron microscope was performed. Three brachycephalic, “short-snouted”, embryos were embedded in the paraffin and serially cut to perform anatomical and histological analysis, including 3D reconstructions of the snout. Described malformations occurred spontaneously, without any laboratory intervention, such as extremely high incubation temperature.

Title: 49-6: Relationship between skull roof bone microanatomy and ecological traits in rodents

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With a considerable variation in habitat, lifestyle, and diet, rodents have the potential to reveal important insights into the evolution and adaption of cranial bone microanatomy. However, no study has examined the variability of their skull roof`s inner morphology to date. Here, we addressed the question of how the internal bony structure of the rodent skull roof is adapted to different environments and how it is affected by body size.

Micro CT scans of 106 skulls belonging to 64 species from 23 rodent families were analysed. First, a defined area of the skull roof was selected, and compactness (C), cross-sectional area (CSA), and thickness (Th) were measured. Then the correlation of these parameters with skull size, locomotion and diet was examined.

The strongest differences in CSA and Th were found between semi-aquatic rodents and the less specialised generalists. A semi-aquatic lifestyle is mainly found among the larger taxa in this study. And because of the strong correlation of CSA, Th and C with skull size, the larger CSA and Th in semi-aquatic species can probably be attributed less to lifestyle and more to size.

The present study could neither reveal lifestyle, diet, nor phylogeny as a primary evolutionary driver of the inner morphology of the skull roof in rodents. Nonetheless, our results suggest a strong relationship between size and rodent skull roof microanatomy.

Title: 39-5: Fantastic filters: comparative morphology of rorqual baleen

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Mysticete whales are a group of gigantic filter-feeders defined by their fringed baleen and are divided into two groups: balaenids and rorquals. Baleen is a keratinous oral tissue that hangs from the roof of the mouth in bi-laterally symmetrical racks, with larger plates positioned labially and smaller plates positioned lingually. The edges of the baleen plate fray into fringes that interlock, creating a dense mat. While recent studies have shown that balaenids likely feed using a cross-flow filtration mechanism, it is unclear how filtering is achieved in the lunge-filter feeding rorquals (Balaenopteridae). We used a multimodal approach, including micro-computed tomography (μCT) and scanning electron microscopy (SEM), to visualize and describe the variability in baleen anatomy across five species of rorquals. We also aimed to estimate the pore size, an imperative first step to determining the filtration mechanism, which has yet to be established due to the dynamic nature of the filter. For most morphological measurements, larger whales exhibited hypoallometry relative to body length. μCT and SEM revealed that the major and minor plates break away from the mineralized fringes at variable distances from the gums. Using an equation for spherical filter media, we modeled the effective pore size and found that pore size is likely not a proxy for prey size but instead, may reflect changes in resistance through the filter that affect fluid flow.

Title: 52-5: Shape differences in the hemipenes of rattlesnakes in a hybrid zone

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The oldest hypothesis to explain the evolution of diverse genitalia is the “lock and key” hypothesis, where male intromittent organs are proposed to act as “keys” that fit into specific female “locks”, thereby reinforcing speciation by preventing mating between incipient species. However, when put to the test, the “lock and key” hypothesis has received little support,

even though it has been assumed to be the most likely explanation for morphological diversity in snake hemipenes. Here we examine hemipene shape in a rattlesnake hybrid zone between Mojave rattlesnakes and their hybrids with Prairie rattlesnakes using 3D morphometrics and automated landmarking. We used Auto3dgm with 3000 semilandmarks to compare 35 specimens, 20 Mojave rattlesnakes, 9 Prairie and 6 hybrids. The main axis of shape variation along PC1 explained 53% of the variance, with positive values showing widely bifurcated hemipenes and negative values showing less bifurcation between hemipene lobes. Three of the hybrids fell out in the positive PC1 region, though an ANOVA between hemipene shape and species was not significant ($p = 0.054$). Future work will examine Prairie rattlesnakes, as well as female genitalia in all species and hybrids, to test if assumptions of the "lock and key" hypothesis can explain genital diversity in this system.

Title: P2-5: Looking into the future of migratory parrots: assessing the vision of iconic species to assist conservation planning

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The world's only long-distance migratory parrots, the Swift (*Lathamus discolor*), Orange-Bellied (*Neophema chrysogaster*), and Blue-winged (*Neophema chrysostoma*) parrots, are endemic Australian species. All three species are facing population decline, two are critically endangered. In other avian orders, migratory behaviour has been linked to reduced visual and cognitive abilities which may increase their risk to collisions, pollution, and habitat changes. For this study, we test if qualities of the eyes and brains of migratory parrots have diverged from their non-migratory relatives and if they share similarities with other migratory species. To achieve this, we use μCT scans of specimens to measure the visual pathways and brain regions which are evident in skulls. Preliminary results from a captive Swift parrot indicate that this specimen does not share the same neuroanatomical adaptations which are typically present in migratory birds of other avian orders. Instead, the anatomy measured in this individual does not substantially differ from the non-migratory relatives in this study. Due to this being a singular captive specimen, however, the results cannot be interpreted with confidence. Nonetheless, there are captive breeding programs for the conservation of these birds, knowing how captivity influences these species may assist with planning for potential limitations. Because of this, measurements from both wild and captive specimens of all migratory parrots will be collected to determine if the neuroanatomy of these parrots co-vary.

Title: 52-1: Reproductive impacts of differential extensibility of cloacal and vaginal wall tissues in the American alligator

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In female American alligators (*Alligator mississippiensis*), successful reproduction depends upon the expansion of cloacal and vaginal tissues to accommodate and orient both the male phallus during copulation and eggs descending from the oviducts during oviposition. Both tissues may also have roles in cryptic postcopulatory female choice, as the highly innervated clitoris is integrated into the part of the cloacal wall of the proximal proctodeum where pressure from male glans inflation occurs during copulation, and the distal ends of the paired vaginas are arranged in tight coils that could restrict semen entry and control fertilization success. Materials testing shows that vaginal tissue is about equally extensible circumferentially and along its long axis, suggesting that its cross-sectional shape can change freely in response to egg passage. In contrast, cloacal wall tissue is more extensible circumferentially than along its long axis, suggesting that the microanatomical organization of the tissue preferentially allows dorsoventral and lateral expansion of the cloaca. Because dense tissues around the cloaca wall also limit expansion dorsally and laterally, the interaction of male and female tissues during copulation should preferentially displace female tissues ventrally and laterally, creating an open space at the level of the vaginal openings adjacent to the terminus of the sulcus spermaticus without extending along its long axis, thus maintaining the glans position relative to the clitoris.

Title: P2-18: Effects of cursoriality on mammalian semicircular canal morphology

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The semicircular canals detect head angular accelerations, facilitating balance and gaze stabilization during movement. Semicircular canal morphology indicative of canal sensitivity has been correlated with categorical locomotor agility in mammals. However, this correlation loses statistical significance once variation in the demands placed on the vestibular system by the visual system are accounted for in models of canal morphology. Because locomotion is the source of most head movements that must be compensated for by the vestibular reflexes to stabilize gaze, it remains likely that aspects of locomotion other than those captured by agility scores may influence the evolution of canal sensitivity. This study tests the hypothesis that evolutionary changes in maximum locomotor speed and cursorial specialization are correlated with increases in canal sensitivity by comparing morphological proxies of vestibular sensitivity across five pairs of closely related species that differ in their maximum running speeds and degree of postcranial cursorial specialization. Canal dimensions were measured from micro-CT scans (n=50) of ten species and compared across species pairs while statistically controlling for the influence of body mass and visual acuity. Preliminary analyses of a subsample indicate that more cursorial species have a greater average canal radius of curvature relative to body size than less cursorial species. Results from the complete sample and analysis of additional canal metrics will be discussed.

Title: 12-2: Dentofacial adaptations to masticatory muscle function

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Over the years there has been a need to study the influence of masticatory muscle function on craniofacial growth because the knowledge of the mechanisms behind both normal and abnormal craniofacial growth is a prerequisite for adequate treatment of craniofacial anomalies, including dental malocclusions.

In this presentation, we will view the influence of the masticatory muscle function on craniofacial growth as it has been recorded in a series of animal experimental and clinical studies. The common characteristic of these investigations is that the elevator muscles of the mandible influence the transversal and the vertical dimensions of the face. The decreased loading of the jaws due to masticatory muscle hypofunction may lead to decreased sutural growth and bone apposition, resulting in turn in an decreased transversal growth of the maxilla and narrower bone bases for the dental arches. Furthermore, an increase in the function of the masticatory muscles is associated with anterior growth rotation pattern of the mandible, with well-developed angular, coronoid, and condylar processes, as well as more dense internal bone structures of the alveolar bone.

Title: 52-3: Female Reproductive Organ Anatomy and CRISPR Gene Editing in the Brown Anole

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Reproduction modes across vertebrates are diverse. However, reproductive tract organs across vertebrates have a similar overall structure. In mammals, the reproductive tract develops from paired epithelial tubes called the Wolffian and Müllerian ducts. The Wolffian ducts contribute to the male reproductive tract organs (vas deferens, epididmys, seminal vesicles) whereas the Müllerian ducts contribute to the female reproductive tract organs (oviduct, uterus). During embryonic development, the Wolffian and Müllerian ducts form in both sexes; however, anti-Müllerian Hormone (AMH) secreted by the fetal testis induces the regression of the Müllerian ducts and testosterone induces the differentiation of the Wolffian ducts. The absence of AMH in female fetuses leads to retention of the Müllerian ducts and subsequent development of the female reproductive tract. Knowledge of these processes in other vertebrate lineages is limited. Here, we present data from the brown anole exploring the development and adult architecture of the female reproductive system. We show that the adult oviduct is divided into three regions that each have a unique morphology, histology, and transcriptome signature. We have used CRISPR to mutate genes in major hormone signaling pathways and we present data on the role of these genes in reptilian reproductive system development. Our data extend histological studies of

reproductive organ morphology in reptiles and expand our understanding of the genetic requirements for the development of the reproductive system across vertebrates.

Title: Regional variation of epiphyseal fusion and trabecular architecture in cetacean vertebrae

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Modern cetaceans (whales, dolphins, and porpoises) from terrestrial mammals adapted to an aquatic environment after significant skeletal transformation. Cetacean skeletons have vertebrae comprised of compact and trabecular bone, and epiphyses are fused on the cranio-caudal ends of the vertebral body. Epiphyseal fusion is highly variable across cetacean species, and factors influencing fusion rate are unclear. Trabecular bone responds to mechanical loading, and plate fusion may respond to stress along the vertebral column. Here, we hypothesize that trabecular structure will vary with epiphyseal fusion state in response to loading. We predict that vertebrae with fused epiphyseal plates will have increased structure. Utilizing eight species of stranded cetaceans and museum archives, we selected three thoracic, lumbar, and caudal vertebrae and documented epiphyseal fusion state. We CT scanned samples and calculated data for a suite of variables within a region of interest at the middle of each vertebra and adjacent to the epiphyseal plate. We found that vertebrae with fused plates had higher bone volume fraction, and caudal vertebrae had more trabeculae adjacent to the epiphyseal plate. These results suggest trabecular structure in caudal vertebrae may respond to mechanical loading during swimming because cetaceans swim using dorso-ventral oscillations of the posterior body. This work was supported by the Tomography for Scientific Advancement's Jim Elliot Award and Florida Atlantic University's Newell Doctoral Fellowship.

Title: 43-4: Modularity, biomechanics and bmp4 expression integrate developmental plasticity in fish novel head morphotypes.

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The adaptive potential of plastic responses relies on integrated developmental responses encompassing different levels. We investigated how manipulation of developmental conditions in *Megaleporinus macrocephalus* fish induces plastic responses at phenotypic and molecular levels. We evaluated three complementary dimensions of epigenetic processes that released new complex phenotypes: 1) functional modularity of skull bones, 2) biomechanical properties of the

chondrocranium and 3) expression levels of *bmp4*, a gene involved in the evolutionary diversification of trophic phenotypes in vertebrates that has been previously hypothesized as a candidate for genetic accommodation of plastic responses. Results suggest that developmental plasticity can expand a morphospace without changing the modular architecture of the skull. Chondrocranium plastic responses encompass differences in mechanical stress magnitude, which seems restricted to certain chondrocranium regions. Specifically, we identified a 'mechanical unit' encompassing three bones, related to changes in mouth position induced by foraging mode. Differences in *bmp4* expression levels between morphotypes from Bottom and Surface environments suggest plastic responses at the molecular level related to cryptic developmental plasticity in *M. macrocephalus*. Our results offer an integrative perspective of epigenetic factors shaping plastic responses at different levels, expanding our knowledge about the mechanisms of developmental plasticity that originate novel complex phenotypes.

Title: 9-7: A pound of flesh, a pint of blood - ectoparasitic fishes as a model system for understanding evolutionary novelty & diversity

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Plagues, pestilence, and parasites inspire revulsion, and dread, while serving undeniable roles in structuring populations and altering energy transfer in ecological systems. Ectoparasitic vertebrates make compelling, accessible systems for examining the form/function relationships between parasites, hosts, and their communities, and the ways ectoparasites exploit food webs. We will discuss the evolutionary history and adaptations that fishes and other vertebrates use to feed, and even graze, on animal hosts. From piranhas that crop fish fins to catfishes that burrow deep into others to feed on blood and slime - we estimate that ectoparasitism has evolved some 15-20 times in Neotropical freshwater fishes alone. Scale eating, a form of grazing, is particularly interesting on several fronts. Some fishes do it with little modification, others are wildly different from close relatives. The strategy requires gaining a thin layer of nutrients along with an indigestible wad of minerals. This 'narrow' niche is occupied by ectoparasites with a diversity of feeding morphologies and behavior. Ectoparasitic lineages, evolving from drastically disparate bauplans, do not converge on limited optimal phenotypes. Instead they serve as a reminder that a tool shaped for one task can, with little modification, serve radically different roles.

Title: 15-3: Extant anamniotes as models of how feeding influences terrestrialization events

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Studies of transformations in terrestrializing vertebrates often evaluate changes to locomotion (fins-to-limbs), and ventilation (gills-to-lungs) as factors constraining these critical evolutionary

events. However, maintaining feeding abilities moving from water to air is potentially problematic but much less studied. I present kinematics, muscle strain, and EMG data from extant anamniotes (*Protopterus*, *Necturus*, *Amphiuma*, and *Ambystoma*) that differ in their terrestrialization propensity and the robustness of their hyobranchial morphology, which can influence intraoral behaviors. These data enable me to test the idea that intraoral feeding biomechanics pose significant constraints to terrestrialization. Whereas transport cycles consistently (and unsurprisingly) involve caudad tongue and food movements during jaw depression, we see repeated changes across the sample in the pattern of coordination of tongue three-dimensional movements and jaw kinematics during chewing. Aquatic chewing involves tongue retraction during jaw depression, likely to generate suction and avoid food escape, whereas terrestrial chewing involves the pattern so familiar in amniotes of tongue protraction during jaw depression, to position food in occlusion. The ability of several taxa to, ontogenetically or behaviorally, alter their tongue and jaw coordination pattern when transitioning from aquatic to terrestrial chewing provides the first evidence to suggest that feeding, and particularly chewing poses a significant constraint upon terrestrialization in vertebrates. This finding should now be confirmed in a broad comparative framework, capitalizing on the many extant anamniotes that terrestrialize.

Title: 32-4: Embryonic evidence uncovers convergent origins of laryngeal echolocation in bats

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Bats are the second most speciose group of mammals, comprising 20% of species diversity today. Their global explosion, representing one of the greatest adaptive radiations in mammalian history, is largely attributed to their ability of laryngeal echolocation and powered flight, which enabled them to conquer the night sky, a vast and hitherto unoccupied ecological niche. While there is consensus that powered flight evolved only once in the lineage, whether laryngeal echolocation has a single origin in bats or evolved multiple times independently remains disputed. Here, using prenatal ontogenetic series of a wide range of bat species, we present morphogenetic and transcriptomic evidence in support of laryngeal echolocation having multiple

origins in bats. Our comparative embryological investigations found that there is no developmental difference in the hearing apparatus between non-laryngeal echolocating bats (pteropodids) and terrestrial non-bat mammals. In contrast, the echolocation system is developed heterotopically, heterochronically, and transcriptomically in the two phylogenetically distant laryngeal echolocating bats (rhinolophoids and yangochiropterans), providing evidence that laryngeal echolocation system evolved independently in these bats.

Title: 19-4: Unique agenesis of third molars in a wild sika deer population impacts longevity

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In herbivorous mammals, molars are essential for shearing fibrous vegetation. The third molars (M3) erupt last in ruminants and need to tolerate lifelong wear, which results in an evolutionary trend to become larger and more high-crowned (hypsodont). Here, we report unique dental anomalies found in the Japanese sika deer from the Boso Peninsula, showing a complete lack of the third molar (M3 agenesis). M3 agenesis has never been reported for wild ruminants and offers a rare opportunity to quantify the importance of M3 by comparing deer with M3 agenesis to normal ones. We examined 2,547 mandibles to quantify the frequencies of M3 agenesis and other anomalies and took morphometric measurements. The overall frequency of M3 agenesis was 7.0% (179 individuals), with significant sex differences (Fisher exact test, P=0.001). The frequency was higher in females, suggesting that responsible gene(s) might be located on the X-chromosome. Deer with M3 agenesis had significantly smaller M1 and M2 than normal individuals, implying that gene mutations affect molar morphogenesis. M1 wear was not faster in M3 agenesis dentitions, partially due to the absence of senescent individuals: no M3 agenesis deer lived longer than 11 years. Survival analysis (Kaplan-Meier method) revealed a lower survival rate in M3 agenesis deer, suggesting a possible negative effect of M3 agenesis on life expectancy. Funding: Grant-in-aid (16K18615 and 20F20325) from JSPS for MOK and DEW, respectively.

Title: 39-3:Temporal dietary shift toward more abrasive food among Cretaceous ornithopod dinosaurs

Authors: Tai Kubo[1], Mugino O. Kubo[2], Manabu Sakamoto[3], Daniela E. Winkler[4], Masateru Shibata[5], Wenjie Zheng[6], Xingsheng Jin[6], Hai-Lu You[7]

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Dinosaurs were the dominant mega-herbivores during the Cretaceous, when angiosperms, flowering plants, emerged and diversified. How herbivorous dinosaurs responded to increasing angiosperm diversity was largely unknown due to the lack of a method that can infer the diet of herbivorous dinosaurs directly from their body fossils. We applied dental microwear texture analysis (DMTA), which evaluates microscopic level three-dimensional tooth surface texture, on 12 ornithopod dinosaurs of the Late Jurassic and Cretaceous. We found that Late Cretaceous ornithopods have rougher dental microwear texture compared to pre-Late Cretaceous ornithopods, with a phylogenetic model of evolution supporting a temporal trend toward rougher dental microwear, indicating a dietary shift towards more abrasive food. Phylogenetic modelling also showed that dietary variation reflected in dental microwear texture increased in hadrosaurids, the derived Late Cretaceous ornithopod clade. These changes were likely due to the ingestion of more phytoliths, which are more concentrated in angiosperms than other major plant groups. Our results show that, when applied to the occlusal enamel surface, DMTA can reconstruct the diet of herbivorous dinosaurs with a resolution superior to conventional methods. Its application to other herbivorous dinosaur clades will reveal how different dinosaur clades reacted against the diversification of angiosperms.

Title: 47-1: On the evolution and recapitulation of the vertebral column

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Among vertebrates, mammals exhibit the most regionalized differentiated vertebral column and serve as a good model for understanding segmental metamerism and positional-value-based metamorphosis. In mammals, the occipital, cervical, thoracic, lumbar, sacral, and caudal vertebrae are well differentiated. The number of vertebrae in each modules, or the "vertebral formula", is variable in different lineages of mammals, and can be arranged as an order of variation on a phylogenetic tree. In other words, the change in vertebral formula itself represents a derived trait. From this perspective, we discovered that the afrotherian clade, whose morphological synapomorphy had remained unknown, has increased thoracolumbar vertebrae in common. It is easy to imagine that changes in Hox gene regulation are involved in this evolutionary background. Nevertheless, it is necessary to carefully examine in which hierarchy of taxa the homologous specification by Hox gene expression is shared. For example, in many amniotes, the boundary between cervical and thoracic vertebrae is specificized by Hoxc6, but in turtles, there is a discrepancy according to a recent analysis: a redefinition dependent on Hox gene homology may be necessary. Finally, it should also be emphasized that the developmental establishment of the Hox code does not exhibit Haeckelian recapitulation. The evolution of vertebral formulae would have occurred as a shift in developmental program during early development, which corresponds to a type of heterochrony, Sewertzoff's Archallaxis.

Title: P1-3: Glide-reflection symmetry, homology of body sides, and evolution of gastrulation in deuterostomes

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The arrangement of segmental structures with alternation of the left and the right antimeres, known as the glide-reflection symmetry, as opposed to the perfect bilateral symmetry, was found in a number of deuterostomes. The glide-reflection symmetry occurs in both somitomeric and branchiomeric organs. The distribution of the glide-reflection symmetry among deuterostome taxa (echinoderms, enteropneusts, cephalochordates, ascidians, hagfishes, chimaeras) suggests its ancestral nature. This feature could be inherited from Precambrian dickinsoniids. Where known, all cases of the glide-reflection symmetry among deuterostomes are characterized by spatial and/or temporal lead of the left anterior-most segment relative to its right antimere. This suggests, with great confidence, intimate relationship between all these cases, implying left-to-left and right-to-right side homology across deuterostomes. This homology contradicts the widely accepted hypothesis of the whole-body dorsoventral inversion of chordates as compared to other deuterostomes. Instead, I suggest a hypothesis of peculiar transformation of the process of gastrulation which caused inversion of dorsoventral polarity of some parts of the body but did not affect the left-right polarity. This process involved the animal-vegetal extension of the blastopore over embryo's dorsal side in basal deuterostomes. It was continued by the shift of the left-right organizer from the dorsal lip of the blastopore to the anterior tip of archenteron in non-chordate deuterostomes, which caused inversion of the notochordal area of archenteron from the roof to the floor.

Title: 8-2: Ontogenetic changes in bite force and gape in tufted capuchins

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Bite force and gape are two important performance metrics of the primate feeding system, and these metrics are inversely related such that the feeding system cannot simultaneously maximize both bite force and gape without specific muscular adaptations. How developing primates navigate these competing needs is largely unknown. Here we quantify *in vivo* bite forces and gapes across ontogeny and examine these data in relation to body mass and cranial measurements in tufted capuchins, *Sapajus* spp. Bite forces and gapes were also compared to geometric and mechanical properties of mechanically challenging foods to address the relationships between bite forces, gapes, and food accessibility (defined here as the ability to breach shelled nuts).

We collected data from an ontogenetic series of 20 captive tufted capuchins at the Tufted Capuchin Monkey Procreation Center in Araçatuba, Brazil. Bite force-gape and behavior data were paired with body mass, photogrammetric measures of jaw length and facial width, and food geometric and material properties. Tufted capuchins with larger body masses had absolutely higher *in vivo* bite forces and gapes, and animals with wider faces had absolutely higher bite forces. Juveniles had smaller bite forces and gapes compared to subadults and adults. Our findings indicate bite force and gape relate to food accessibility and highlight differences in *in vivo* measures of performance compared to those derived solely from skeletal morphology or muscle architecture.

Title: 45-5: Aging and the senses

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There has been much recent interest in assessing the sensory abilities of varied vertebrate species. This has offered an ever-increasing understanding of the breadth and depth of vertebrate abilities and their intersection with cognition and appreciation of the surrounding environments. Most studies, however, have viewed such sensory abilities as static throughout a lifespan, rarely considering the often-profound effects of aging. This overview, drawing largely from recent, extensive investigations of humans and human diseases, has shown that a species sensory range changes considerably during its lifespan, with marked alterations during adult aging. Here we discuss briefly theories on organismal and cellular aging and then focus on current assessments of the anatomical substrates and functional correlates of sensory deterioration/change in aspects of olfaction, taste, vision, balance, and sound generation/hearing. We draw particularly from data charting presbyphonia (age-related changes that affect an individuals' voice) and presbycusis (age-related hearing loss), conditions that draw from our own studies on the comparative biology of the mammalian vocal tract and inner ear. Our observations support the findings that, at least as relates to sensory abilities, species should be viewed as "longitudinal" rather than static entities, acknowledging the enormity of change/alteration/diminution of acuity brought on by the aging process. Such an understanding will enable a more realistic assessment of the diversity inherent in a species sensory portfolio.

Title: 40-1:Comparative and evolutionary perspectives on the ontogeny of post-cranial skeletal pneumaticity

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Post-cranial skeletal pneumaticity (PSP) is an important anatomical characteristic of most modern birds, and has been one of several extinct non-avian dinosaurs. There are numerous *a posteriori* explanations of its advantages, mostly related to the density-reducing lightweight construction and traits such as active flight or gigantism, but the evolutionary origin of PSP remains shrouded in mystery. Part of this is due to an incomplete understanding of the mechanism that generates these air-filled bones. We histologically examined the developing humeral PSP in Lohman Selected Leghorn chickens from day 1 after hatching (dph), showing no pneumaticity, up to 50 dph, at which the humerus is largely pneumatized. For comparison we studied selected age samples of quails (*Coturnix japonica*), in which pneumatization sets on slightly later in life. Yet another comparison was built upon a developmental series of the vertebrae of the butterflyfish *Pantodon buchholzi*, whose parapophyses become "pneumatized" by its swimbladder. The two avian examples studied displayed a congruent series of tissue dynamics, starting with a cartilaginous precursor that becomes replaced by a marrow-filled bone, and an eventual resorption of the marrow and epithelial lining. The development of the unambiguously convergent piscine case of PSP showed numerous deviations from this avian sequence, but agreed in a conspicuous presence of a fatty intermediate tissue. The potential role of fat for the evolutionary origin of PSP will be discussed.

Title: 15-1: Is there a veggie option? Dietary adaptation and feeding mechanics in dinosaurs

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The ability to eat plants (herbivory) is considered a key innovation in vertebrate evolution. It allows access to previously unavailable food sources, leading to increased species richness and morphological variability. A textbook example of convergent evolution, herbivory has independently evolved over 25 times in the history of terrestrial vertebrates resulting in similar skull and jaw shapes. In particular in dinosaurs, the adaptation to herbivory has led to a range of different morphofunctional solutions to similar ecological requirements.

Here, I will give an overview of the anatomical and functional adaptations to diet in the crania and mandibles of different dinosaur groups and species: (1) Within theropods, herbivory has evolved several times. Biomechanical analyses show a general trend towards structural strengthening of the mandible in different groups. This was achieved by modifications of the mandible to reduce feeding-induced stresses and to increase bite efficiency. (2) Within ornithischian dinosaurs, several clades had adapted to high-fibre herbivory. Despite similar

demands, the functional convergence was low among different clades with each instead achieving comparable performance through different adaptations of the feeding apparatus. (3) An investigation into the relevance of individual morphological characters using actual and theoretical models demonstrates a variable influence of these characters (and combinations thereof) on feeding performance. For example, orbit shape, coronoid height, and dentary morphology were found to mitigate feeding-induced stresses.

Title: 4-1: Evolutionary convergence and integration among carnivoran skeletal systems

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Morphological diversity is often attributed to adaptations to distinct ecological traits. Although the adaptive evolution of skulls, limbs, and, to a lesser extent, vertebrae are well studied in carnivorans and other vertebrate clades, how ecological traits also influence the overall body plan remains unclear across macroevolutionary scales. For example, are patterns of ecomorphological convergence similar between the overall skeleton and each individual skeletal system? Here, we test the hypothesis that extant carnivorans with similar ecologies will exhibit convergence in the skeleton. This would suggest that skeletons are functional and ecological factors lead to common morphologies on the whole skeleton level and/or that the three skeletal systems are tightly integrated with each other due to intrinsic factors. Alternatively, non-convergence of the entire skeleton among species with similar ecologies but convergence in cranial, axial, and/or appendicular skeletons would suggest that individual components of the overall body plan can adapt to particular functional and ecological factors independently from each other.

Title: 25-4: Phenomics Of Goldfish Domestication

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Goldfish domestication has led to a broad diversity in integumentary and skeletal morphology. Anatomical studies of goldfishes can serve to investigate the morphological evolvability of a single species and the differential effects of extensive artificial selection. We combined discrete and continuous trait exploration to decipher the phenotypic diversification of goldfish breeds, including the wild type, within the cyprinids (n =84 species). Our primary data comes from both

extensive high resolution computer tomography scanning and access to available data for other cyprinids. Our discrete features approach documented variation in phylomorphospace via several morphological traits (e.g., vertebral numbers, integument, fin diversity). Principal component analysis revealed a clustering of breeds based on body shape and fin configuration. Selection for a globular body shape, as detected in goldfishes, led to great changes in the vertebral column and in swim bladder size and shape. The latter, associated with the Weberian apparatus, led us to suggest that globular breeds are the most divergent from the wild type. Changes in the Weberian ossicles are in the shape and relative length of some processes. Analyzes of neurocranial morphological variation using 3D geometric morphometrics demonstrate much variation in goldfish compared to the wild form, with a general trend towards shorter neurocranium and larger orbit. Goldfish diversification includes occupation of morphospace void of any living species among cyprinids.

Title: 10-1: Comparative analysis of musculoskeletal anatomy in relation to locomotor mode in frogs

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Amphibians exhibit complex anatomical features of the pelvis and limbs which enable them to employ a range of locomotor styles in a variety of environments, making them ideal organisms for investigating the relationship between morphology, function, ecology, and evolution. By digitally dissecting micro-CT scans, we investigate the link between skeletal and soft-tissue anatomy and locomotor mode, shedding new light on how functional demands impact morphology. Skeletal measurements for 164 taxa from all 56 recognised anuran families indicate that hindlimb proportions differ significantly between species utilizing different locomotor modes, suggesting that each segment performs discrete functions. Skeletal morphology is also highly conserved in jumpers, regardless of habitat type, while broader anatomical solutions are found for swimmers, burrowers, and walkers. This is reflected by the morphology of semi-aquatic taxa, which is shaped more by requirements to jump than to swim. Additionally, we show how pelvic morphology, a key predictor of locomotor mode in anurans, should be considered along a morphological continuum rather than as discrete types. Comparative analyses of muscle anatomy from a subset of 20 representative species show various trends between muscle size and locomotor mode. By combining this anatomical data with biomechanical models, we will obtain direct mechanical evidence for how variations in limb anatomy influence locomotor multi-functionality across the frog phylogeny. Ultimately, this work contributes towards constructing a workflow for inferring the locomotor behaviours of extinct taxa using fossil measurements.

Title: 30-3: The hidden complexity of reptilian enamel

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Reptile teeth are often morphologically simpler than their mammalian counterparts and have less complex enamel coating their tooth crowns. However, we present two exceptions to this classic dichotomy and highlight their importance in understanding the evolution of structurally and chemically complex dental enamel. The first is the convergent evolution of mammal-like prismatic enamel in squamates and extinct rhynchocephalians. Through comparative histological analysis, we demonstrate that the combined selection for abrasive-resistant teeth and the phylogenetic constraint of a loss of tooth replacement in some reptiles has resulted in the repeated evolution of more complex prismatic enamel in reptiles.

The second exception is the surprising discovery of chemical and structural reinforcement of the cutting edges in carnivorous reptile teeth. Despite having extremely thin enamel, the serrated teeth of Komodo dragons (*Varanus komodoensis*) are iron-coated. Iron-pigmented enamel is elsewhere seen in mammalian enamel and is associated with adaptative wear-resistance. Whereas this coating manifests as orange tooth tips and serrations in Komodo dragons, we recently discovered similar coatings in extant crocodylian teeth that are otherwise invisible to the naked eye. Through detailed structural and elemental imaging, we characterize this unusual adaptation, discuss its effect on the mechanical properties of enamel, and compare this with the serrated teeth of theropod dinosaurs to assess the prevalence of this adaptation across extinct carnivorous reptiles.

Title: 10-3: Size and locomotor influences on hindlimb bone cross-sectional properties in saltatory rodents, marsupials, and primates

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Species of extant rodents, marsupials, and primates have independently evolved bipedal, saltatory forms of locomotion including terrestrial hopping and arboreal leaping. Given the differences in substrate reaction forces incurred during quadrupedalism versus saltation, hindlimb bone cross-sectional properties (CSP) should differ according to locomotor mode. Here we examine functional convergence in CSP of the femur and tibia in a comparative sample of 41

mammalian species including rodents, marsupials, and primates. We predict that, within and among taxonomic groups, saltatory species have greater cortical bone strength properties compared to quadrupeds. Using micro-CT scans of the femur and tibia, we calculated estimates of bending strength (Z_p), torsional strength (J), compressive strength (cortical area), and cortical bone distribution (I_{max}/I_{min}) at diaphyseal midshaft. CSP were scaled, log-transformed, and compared between saltatory and quadrupedal taxa 1) within and among mammalian groups and 2) within and among bone using ANOVA. Relationships among body size, CSP, and locomotion were explored using generalized linear models. Some, but not all, of our predictions were supported. For example, contrary to predictions, for some CSP (e.g., scaled femoral cortical area and J), quadrupeds exhibit significantly larger values than saltators. Body size is consistently a significant effect on scaled CSP in linear models. Our results suggest that both within and among Orders, body size may have a greater influence on CSP than locomotor mode.

Title: 23-5: Lessons from really big fish : integrating incomplete data in parametric modelling of coherent skeletal model

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Basking sharks filter-feed by widely opening their mouths and gill slits, causing gill arch cartilages and associated gill rakers to change positions and shapes. This, however, is hard to capture using conventional video or tomography methods, due to these animals' size, elusiveness, and CITES-status and the rarity of well-preserved specimens.

To overcome these extreme challenges to anatomy and physiology study of basking shark feeding and reconstruct coherent 3D skeletal models, we split the problem into three levels, integrating digital design and computer imaging approaches: generation of a simplified line scaffold, meshing of cartilages, and setting of parametric variables to accommodate assumptions.

The feeding apparatus was segmented from CT scans of intact shark heads using Amira-Avizo and abstracted by a set of points, polylines and curves (representing skeletal joints, medial cartilage axes and rakers roots, respectively).

3d models of open mouths were generated from diver videos using photogrammetry. Silhouettes of open arches and rakers were rebuilt into a second set of points and curves approximating feeding position. CT data were converted to mesh and parametrically mapped onto medial curves and joint points were moved from resting- to feeding-landmark locations, creating a 'digital

puppet' to capture the dynamic process of feeding and estimate anatomical movements of cartilages and rakers.

These results demonstrate the power of integrative and interdisciplinary approaches for the study of large and elusive wildlife.

Title: P1-13: Morphological diversity and functional adaptations of the non-avian maniraptoran manual claws and indication of their ecological niche shifts

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Maniraptora means 'hand snatchers', but the hands of maniraptorans in fact had various functions beyond grasping and diverse morphologies. We choose through ungual to investigate morphological specialisation and functional evolution in maniraptoran hands. Main reasons include the unguals exhibit the most distinctive morphologies among all manus elements, the unguals are located at the end of the forelimb mechanical systems, and therefore bear high stress in applications. By implementing the newly developed method of Deakin et al. (2021), we generated theoretical morphologies and build the functional performance surface and the adaptive landscape based on 274 manual claw shapes from 130 maniraptorans. We measured mechanical advantages (MA) and radiational efficiency (RE) to indicate the speed of claws, and simulate von Mises stress (VMS) distribution by finite element analyses (FEA) to represent the strength of claws during piercing, scratch-digging, and scooping. The speed and strength of claws formed a trade-off. To evaluate the pleiomorphic digging, scooping and capturing prey ability, we calculated the Pareto optimality of the trade-off based on the MA, RE and different VMS. Phylomorpho-functional spaces were generated to explore the morphological diversity via functional adaptations across maniraptoran phylogeny. Our findings support several independent grasping function losing events in Mesozoic maniraptorans, some may cause by degradation of forelimbs, while some adapted other functions like digging. Grasping abilities also re-emerged in some lineages, e.g., the late-branching dromaeosaurids.

Title: 12-3: Characteristics of Obstructive Sleep Apnea in Obese Minipigs

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Four obese and three non-obese minipigs(8.5-months to 6.5-years). The approaches included: 1) Sleep monitoring to identify OSA during natural/sedated sleep; 2) Sonometric technique to quantify 3D respiratory deformational changes of the tongue base(TB) and soft palate(SF); 3) Fat-weighted MRI and ultrasound elastography(EUS) to calculate fat deposition and tissue strain in TB, SF, and pharyngeal wall; 4) Sleep videofluoroscopy(SVF) to trace respiratory movements of SF and TB; 5) MRI to quantify pharyngeal spaces, and computational flow dynamic(CFD) to

modeling airflow dynamics. Results indicated**:** 1) The respiratory parameters of sedated sleep were similar to those of natural sleep, and the majority of OSA episodes occurred during rapid-eye-movement stage in obese minipigs; 2) significantly extended respiratory deformations of TB and SF were seen in obese/OSA minipigs; 3) The fat deposition of TB increased from rostral to caudal and reached the highest in TB. Higher TB strains were seen in obese/OSA minipigs; 4) Larger ranges of respiratory movements of TB and SF were seen in obese/OSA minipigs; 5) Lower inspiratory tidal volume and slow inspiratory airflow speed were seen with decreased airway dimensions and volumes in obese/OSA minipigs, and CFD confirmed that the decreased airflow speed occurred in the transitional region of nasal to oral pharynx. Therefore, OSA in obese minipigs presents similar characteristics to those of human, making obese minipig an ideal large animal model for OSA study.

Title: 30-1: Microstructure, biomechanics and chemical composition of teeth in seals

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Similar to other aquatic mammals, seals have evolved teeth with simplified morphology; they lack the carnassial tooth of most Carnivora. This is likely a consequence of aquatic feeding habits relying more on biting, grasping and tearing, reducing dental functional demands. This study investigated the microstructure, biomechanics and chemical composition of seal (Phocidae) teeth. Incisor, canine and post-canine teeth of Bearded, Greenland, Grey and Harbour seals were embedded in epoxy, sectioned, polished, etched and surface-coated for SEM, nanoindentation and EDX analyses. The overall organization of the enamel is similar in all tooth types sampled. The enamel in seals was prismatic, composed of transversely oriented undulating Hunter-Schreger bands (HSB) from the enamel-dentine junction (EDJ) to the outer surface, with prism decussation not prominent. The enamel layer was thin, commonly ranging from 80-200 µm, and open prisms predominated. The EDJ was sharp, with evidence of biomechanical structures such as enamel lamellae and tufts. Hardness and elastic modulus values were higher in enamel than in dentine. CaO and P_2O_5 were the main chemical components identified in enamel and dentine, with F, Na_2O, MgO, Cl and SrO identified in minor amounts. Despite simplification in morphology, teeth in seals retained complex enamel with HSB which is plesiomorphic in Carnivora. Feeding ecology and breeding biology have likely influenced enamel microstructure and biomechanical properties of teeth in seals.

Title: 6-6: Understanding the endocranial morphological diversity of modern bats (Mammalia: Chiroptera)

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Bats are the second-most diverse extant mammal group, showing high magnitudes of phenotypic diversity. Modern bat diversity derives from the unique combination of traits they exhibit, including flight, echolocation, and their remarkable dietary diversity. A variety of morphological adaptations have been associated with this set of traits, providing a robust understanding of the form-to-function link that relates phenotype and ecology in the evolution of bats. However, the nature of the relationship between this impressive diversity and related cognitive demands remains understudied. Here, using CT scans we quantified the diversity in the shape of the endocranial cavity in bats, as a proxy for the form of the brain. We assembled a dataset of over 140 species, representing over 10% of all species, all major groups, and a wide range of ecological adaptations. We also gathered data on species' body size, diet, echolocation strategy and phylogenetic relationships, to further explore factors that could explain patterns of endocranial morphological variation. We estimated the volume and surface area of the endocranial cavity, and of subsections representing different brain regions. We implemented phylogenetic comparative methods and regression modelling to decompose the differential effects of evolutionary relatedness and ecological adaptations in endocranial morphological diversity. Our results show multiple factors correlate with the endocranial diversity found in modern bats, indicating multifaceted patterns of variation that differ across bat groups and ecological

Title: 48-1: Combination of qualitative and quantitative data reveals unique patterns in the post cranial anatomy and taxonomy of Sphenacodontidae (Synapsida::Sphenacodontidae)

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An exemplar sphenacodontid 'pelycosaur' synapsid, the sail-backed *Dimetrodon,* is one of the most iconic members of the Paleozoic fauna of the American west. Although virtually every skeletal element is known, size and stratigraphic occurrence remain key factors in differentiating most sphenacodontid species. 2D geometric morphometric analysis was conducted on a sample of sphenacodontid humeri and femora. The morphological data was associated with a range of categorical data, such as locality and geologic context. This dataset subsequently underwent a Gower dissimilarity analysis to create a corrected distance matrix and a secondary Principal coordinates analysis. This creates a new "trait" matrix representing a combination of the morphometric PC scores and the classification data. As such, the analysis considers how the quantitative shape data is correlated with the qualitative data in determining specimen placement in tangent space. This analysis provides insights into areas of *Dimetrodon* taxonomy that are deserving of reassessment. For example, these results show an inability to differentiate *D.natalis* from *D.booneorum* and suggests an over splitting of these taxa. Further, results point to examples of biases in collecting and taxonomic assignment by pinpointing redundancies in the morphology and paleobiogeography of these animals. This work suggests features like size and location play an outsized role in the group's taxonomy, hindering work on macroevolutionary trends despite the existence of large collections in many major American natural history museums.

Title: 48-3: Endocast morphology differs significantly within North American river otters

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Interspecific variation in mammalian endocranial size and morphology has been attributed to multiple selective pressures, including diet, environment, and sociality, as well as constraints on both brain and skull development. While the relationship between these variables has been tested among species, we lack a fundamental understanding of intraspecific variation in endocranial and skull size and morphology in most taxa. Using the relatively large brained, and geographically wide-spread *Lontra canadensis* as a model, we quantified population variation in endocast volume and shape, as well as skull size and shape from microCT data from ecologically distinct regions of North America (AK, AR, FL, TN, WA) (n=25 individuals). Results show covariation between brain volume and latitude (r2=0.31), with the largest relative volumes found in Alaskan populations. Arkansas specimens differ significantly from all other populations in brain shape ($p<0.01$), with shorter and shallower lateral and entolateral sulci than higher latitude populations, as well as more rostrally-angled cruciate sulci than Floridian specimens. Skull shape differs significantly between all population ($p<0.01$), particularly in the palate width and infraorbital foramen position. Our results suggest that climatic factors may contribute to the variation in otter endocast size and morphology, with cold-climate populations developing larger brains with increased gyrification. The comparatively low variation in neurocranial shape suggests that the relationship between skull and brain development may be conserved among populations.

Title: P4-4: Directional Asymmetry in Limb Bone Shape of the North American River Otter

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Many species exhibit limb side dominance, which affects behaviors such as grasping, locomotion, or prey capture. This preference is then often reflected in the underlying musculoskeletal anatomy, with bone size and shape being altered due to these asymmetric pressures over an individual's lifetime. However, relatively little data exists on the limb asymmetry of non-primates. Focusing on a species that uses limbs to locomote in both terrestrial and aquatic environments, we evaluated the North American river otter (*Lontra canadensis)* to distinguish if directional asymmetry exists within bone size and shape (n=28 individuals). We quantified directional asymmetry through a variety of length and width measurements, as well as

3D geometric morphometrics in the humerus, ulna, radius, femur, fibula, and tibia from four different populations ranging from Alaska, Florida, Tennessee, and Washington. Using a t-test, we found non-significant ($p>.05$) differences in the length and width measures of the left and right limb elements. However, results of an ANOVA on Procrustes aligned shape coordinates indicate significant ($p<.05$) differences in bone shape. Our results suggest that the shape of left and right limb elements in both the forelimb and hindlimb illustrate directional asymmetry. Future research will provide insight as to whether this shape asymmetry is a product of handedness or other environmental factors.

Title: 10-6: A Permian burrow of stem lepidosaurs and the Paleozoic origin of extant reptile diversity

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Reptiles, including birds, are the most diverse group of living terrestrial vertebrates. Yet, their early evolutionary history remains obscure due to the scarcity of well-preserved transitional fossils capable of connecting the deep histories of the major extant reptile lineages. Here, we use micro-computed tomography (μCT) to describe a new fossil reptile based on an assemblage of four skeletons preserved together in a fine-grained structure interpreted as a burrow infill from the early Upper Permian (~256.8-258 million years ago) of the Karoo Basin, South Africa. The new taxon possesses numerous features, including an enlarged alar process, subpleurodont dentition, presence of a quadratojugal foramen, and absence of a lacrimal, that support it as the oldest known member of the clade pan-Lepidosauria, which includes lizards, snakes, and the Tuatara. The exceptionally preserved anatomy of the new taxon reveals the convoluted early evolution of the lepidosaur posterior skull and palate, which has long confounded anatomists. When included in phylogenetic analyses, the new taxon helps resolve several important conflicts in morphological and molecular phylogenies surrounding the relationships of crown lepidosaurs and turtles. The age of the new taxon confirms a Paleozoic origin for the reptile crown clade and adds lepidosaurs to the growing list of modern lineages that may well owe their survival of the Permian-Triassic mass extinction event to a burrowing ecology.

Title: 37-5: Avoiding the edge of failure: a strength-based perspective to explain equid digit reduction

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The evolution of the limbs of equids has fascinated scholars and laymen alike for generations. Several ideas have been proposed to explain the evolution of the monodactyl (one-toed) condition in modern (and many extinct) equid limbs. Ideas such as maximal speed, stability, body mass, inertial load, and distance transport propose different selective pressures which drove the evolution of monodactyly in Equus-line equids. Here, we have taken a biomechanically-rooted second glance at the equid locomotor transition. Over 90% of equid genera exhibited a non-monodactyl distal limb condition (either tetradactyl or tridactyl), yet survived for approximately 40 million years before monodactyl species emerged. It therefore seems highly unlikely that tridactyl or tetradactyl equids were operating on the edge of failure. Building on this evidence, we demonstrate considerable reductions in distal limb mass would have been possible by reducing digit number from three to one. Our perspective – 'equal strength synthesis' – treats intrinsic bone strength as the starting point for the evolution of monodactyly in equids, and combines the biomechanical and habitual aspects of previous explanations (e.g. body mass, distance transport). This synthesis presents a rigorous biomechanical revision to an age-old conundrum, bringing us one step closer to truly understanding one of the great transitions in vertebrate evolution. Moreover, our synthesis is not limited to equid evolution, but can be applied across a multitude of vertebrate clades.

Title: P2-7: The anomalous form of the tapir scapula (Perissodactyla: Tapiridae), with new insights from dissection and 3D imaging

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The gross shoulder anatomy of many ungulates can be inferred from veterinary textbooks, with uniformity in muscle arrangements and attachment sites. Recent studies of Malayan tapir (*Tapirus indicus*) forelimb anatomy indicate a unique shoulder muscle arrangement: the infraspinatus muscle wraps around the scapular spine, rather than occupying the infraspinous fossa as in other ungulates. In this study, I investigated the muscular and osteological anatomy of three modern tapirs via dissection (*T. indicus, T. terrestris, T. pinchaque*), and inspected the scapulae of extinct tapiroids using two- and three-dimensional imaging. Dissection results suggest that the infraspinatus muscle of modern tapir species originates from both supraspinous and infraspinous fossae, with the infraspinatus lying on both sides of the scapular spine. The fascial border between the supraspinatus and infraspinatus origins on the supraspinous fossa is marked by an ossified ridge, extending almost the full length of the scapular spine. This 'supraspinous ridge' is clearly visible on the scapular surface of both modern and extinct *Tapirus* scapulae. However, the ridge exhibits a clearly distinct morphology in *T. indicus,* divergent from all other *Tapirus* examined; the ridge does not appear present in any non-*Tapirus* tapiroids examined (e.g. *Nexuotapirus*). The presence/absence and morphology of the supraspinous ridge may be beneficial for phylogenetic analyses of tapiroids; however, any functional locomotor benefit of the infraspinatus straddling the scapular spine remains unclear.

Title: P4-7: Comparative anatomy of pelvic girdles in climbing fish

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Many teleosts that exhibit waterfall-climbing behavior use their anatomical specializations manifested in paired fins to negotiate surfaces, with which they make direct contact, and support their bodies in resisting external forces that are projected downward (gravity and hydrodynamic drag), during climbing. Climbing fishes typically propel themselves forward (or upward) by using either pectoral fins and/or their caudal fin while other parts of the body provide anchorage as seen in *Garra* spp. of the family Cyprinidae and *Lentipes* spp. and *Rhinogobius* spp. of the family Gobiidae. However, in some cases, the highly mobile pelvic girdle endows some species with an additional propulsive mechanism, enabling them to move and climb in inching motion, with alternating oral suction and pelvic adhesion, as seen in *Sicyopterus* spp. of the family Gobiidae and *Astroblepus* spp. of the family Astroblepidae. In this study, two pairs of longitudinal muscles, protractor ischii and retractor ischii, that actuate the motion of the pelvic girdles of these fishes are examined for the degree of locomotor specialization. These muscles are also compared with those of other climbing and non-climbing teleost species.

Title: 47-2: The control of transitions during vertebrate body formation

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A large part of the anatomical diversity among vertebrates derives from differential control of events associated with developmental transitions. Relevant to the lay out of the body plan are the transition from head to trunk and from trunk to tail development during formation of the main body axis. In addition, somite development undergoes a transition between two distinct and sequential phases, normally known as primaxial and abaxial, during formation of the body wall. I will discuss recent findings from my laboratory relative to the control of the different transitions during formation of the vertebrate body and how changes in their regulatory interactions can generate major changes in body anatomy.

Title: 20-3: Transcriptomic Characterization of neuronal damage markers in the dolphin cortex

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Traumatic Brain Injury (TBI) research has relied heavily on rodent models to understand pathology. Recently, there has been a call to expand comparative studies in novel species to better understand the factors underlying human TBI. As cognitively advanced long-lived mammals with high encephalization and gyrification, cetacean brains recapitulate many features of the human brain not seen in laboratory experiments. Further, as these are taxonomically distant taxa that converged on these features, a better understanding of the shared neurobiology in these species could elucidate the evolutionary restrictions which put them at risk for TBI. For direct comparison of specific markers with humans, it is first necessary to establish baseline expression patterns. Using an RNA-Sequencing approach in fresh frozen samples from a neonate with no indication of traumatic injury, this study generated the first cortical transcriptome for the bottlenose dolphin. Optimizing the opportunistic nature of stranding sample collection, well-established human markers of both chronic and acute inflammation were imaged in animals across life stages to assess the accumulation of neuronal damage with age using Fluorescent In Situ Hybridization (FISH) techniques. Additionally, to control for the adaptation to a hypoxia in marine environment, transcriptomic markers of neuroprotection were directly compared to human cortical samples. This cross-sectional study is a vital first step in establishing cetaceans as a viable model of neuronal damage in an intelligent species.

Title: 14-3: Extreme long-axis rotation: the functional consequences of fibular reduction in theropod dinosaurs

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Reduction of the fibula – one of two bones comprising the tetrapod crus – has been thoroughly documented in theropod dinosaurs. In at least three distinct theropod lineages, the once robust and tubular fibula became increasingly gracile and splint-like, ultimately losing its distal articulation with the ankle. We propose the previously unexplored hypothesis that fibular reduction enabled extreme long-axis rotation (LAR) at the theropod knee joint. Although centuries of paleontologists and zoologists assumed that birds and other dinosaurs have hinge-like knees capable of only simple flexion-extension, 3-D studies of avian kinematics have demonstrated that the tibiotarsus LARs nearly 70 degrees on the femur during locomotion. This additional degree of freedom is essential to avian locomotor control, allowing maneuvering by a limb with an otherwise sagittally restricted hip and ankle. Understanding how extreme knee LAR arose is thus essential to more fully understanding the evolution of theropod locomotor kinematics, agility, and performance. Here we present the results of a marker-based X-ray Reconstruction of Moving Morphology analysis of the avian knee joint with attention to the role of the reduced fibula. After describing the functional complex that facilitates extreme knee LAR in birds, we trace its assembly throughout theropod evolution and discuss the implications of this novel mobility for the behavior of dinosaurs able to exploit it.

Title: 39-2: A new Jurassic shuotheriid casts light on pseudotribosphenic tooth evolution and higher-level phylogeny of mammals

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Shuotherium dongi Chow and Rich, 1986 was named based on a partial dentary with some cheek teeth from the Middle Jurassic of Sichuan, China. The species was characterized by the lower molar with a 'pseudotalonid' positioned anterior to the trigonid, contrasting to the tribosphenic molar in which the talonid is posterior to the trigonid. Shuotheriids were later considered basal to Australosphenida that contain monotremes, although they have also been considered related to, or actually were, docodontans. A new shuotheriid species represented by two skeletal specimens with complete upper and lower dentitions in occlusion were discovered from Jurassic, China. Based on the serial homology and tooth occlusal relationship, it is clear that the protocone (or pseudoprotocone) is a cingular cusp, as interpreted for the development of the protocone in the tribosphenic molar. The new specimens also show that the 'trigonid' in shuotheriids is actually a 'pseudotrigonid' in which there is no cusp that is homologous to the paraconid of the tribosphenic molar (=cusp b of the triconodont molar). Instead, the molar pattern is similar to that of docodontans in which the mesiolingual cusp is cusp g, not the paraconid. This recognition would change the coding of many characters, result in new phylogenetic hypotheses of shuotheriids in relation to docodontans and Australosphenida, and affect the interpretation of the pseudotribosphenic and tribosphenic molar evolution.

Title: 23-1: Moving skulls: kinesis and sutures in feeding biomechanics of reptiles

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Cranial kinesis and movement at the joint between the upper and lower jaw are common in vertebrate species. The presence or the absence of cranial kinesis is usually linked to feeding: On one side, species that swallow preys or feed in the water via suction feeding often have very kinetic skulls implying many mobile joints. On the other side, species with a powerful chewing often have rigid skulls with lesser or directly no kinesis. Cranial bones are joined via sutures that can avoid or allow kinesis depending on how strong the connection between bones is. Therefore, when researchers build virtual models to test functional hypothesis by means of computational biomechanics, it is important to consider how kinesis and sutures can be modelled to understand how the skull moves during chewing. Reptiles are an excellent example to study moving skulls: Crocodilian and Testudines have akinetic skulls whereas Squamata have different types of kinetic skulls. However, the state-of-the-art in modelling them is far from being standardized. Using *Crocodylus niloticus* and *Gallotia stehlini* taxa, we present novel ways to model sutures and kinesis by means of non-linear and dynamic computational mechanics and how to integrate

them in finite element modelling. Our aim is showcase new computational tools that can be of interest for researchers that work in skull biomechanics and functional morphology in general.

Title: 50-1; Break-neck pace: analysing the interplay between integration and evolutionary rate in avian neck evolution

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The avian neck is a versatile and morphologically diverse appendage which operates as a surrogate forelimb, allowing birds to manipulate their surroundings despite lacking functional phalanges. Despite its clear functional significance, we lack an understanding of the tempo and mode of morphological evolution in the avian neck. Here we utilize a combination of 3D geometric morphometrics and phylogenetic comparative methods to investigate how morphological integration between the head, neck and forelimb has impacted morphological diversity and evolutionary rates across a broad sample of extant birds (112 species). We find strong integration between the neck and the forelimb, and weaker integration between the head and neck. The caudal-most cervical vertebra displays the highest degree of neck-forelimb integration, as well as the highest rate of morphological evolution. There are multiple bursts of rapid evolution at the base of ecologically and biomechanically specialized clades such as waterbirds and carnivorous birds. Within these specialized groups we observe significantly lower magnitude of neck-forelimb integration compared to other groups (e.g., Galloanserae, Passeriformes and Opisthocomiformes). Taken together, these results suggest that avian neck evolution is not constrained by head mass, as in many other vertebrates, but is closely linked to the evolution of the forelimb. Moreover, by weakening this neck-forelimb integration some bird clades have been able to adapt their necks to specialized niches such as aquatic and carnivorous feeding.

Title: 10-5: Anatomical Correlates of Cursoriality are Compromised by Body Size and Propensity to Burrow in a Group of Small Mammals (Lagomorpha)

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Highly cursorial animals are specialised for fast, sustained running via specific morphological adaptations, notably including changes in limb segment length and mechanical advantage.

Evaluating these adaptations in taxa whose members vary in cursorial ability often identifies anatomical trends correlated with a 'cursoriality gradient'; this is true of the Lagomorpha, wherein cursoriality is generally high in hares, intermediate in rabbits, and low in pikas. However, the phylogenetic sampling of such investigations has in past been limited to three American species (namely, *Lepus californicus*, *Sylvilagus bachmani*, and *Ochotona princeps*). Here, we expand the phylogenetic sample and body size range by including novel data from Australian samples of the European rabbit (*Oryctolagus cuniculus*) and European hare (*L. europaeus*), alongside unpublished data on the Eastern cottontail (*S. floridanus*). Using X-ray Computed Tomography and digital landmarking to capture appendicular skeletal proportions of ~40 specimens of each European species, we find the previously-identified morphological gradients associated with cursoriality are complicated when evaluated in a larger sample – relative length and joint velocity of limbs was lower than predicted in European rabbits and hares. Additionally, we present a novel assessment of morphological integration in the lagomorph appendicular skeleton, finding between-limb covariation patterns that are generally similar to those of other mammals. Broadly, these results suggest cursoriality is only one of many selective forces driving lagomorph skeletal evolution, potentially alongside body size and fossorial

Title: 33-4: Morphological disparity and integration in the vertebral column of pinnipeds (Mammalia, Carnivora)

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The vertebral column has a very important role in locomotion in aquatic mammals, such as pinnipeds. However, the mode of aquatic locomotion differs between pinniped groups. Otariids generate thrust with their forelimbs (pectoral rowing) while phocids move laterally the pelvic region (pelvic oscillation). Therefore, to explore differences between these groups can provide new clues about the evolution of the land-to-sea transition in pinnipeds. In this study, we explore the disparity and morphological integration of the presacral vertebrae of a set of living and extinct pinnipeds. The results obtained show that vertebral morphological disparity is higher in phocids than in otariids. In addition, disparity through time analyses indicate that, for most vertebrae, otariids subclades tend to explore different regions of the morphospace, whereas phocid lineages overlap within similar regions. Finally, the study of integration between vertebrae in otariids reveals an absence of a modular pattern along the spine, in contrast to the modular pattern found in phocids. These results suggest that adaptation to the aquatic environment in both groups follows two completely different pathways, probably associated with their mode of aquatic locomotion. Future studies on the biomechanics of the pinniped vertebral column may confirm the association of morphology and evolutionary patterns with locomotor performance.

Title: P4-5: Skull morphology variability in island Arctic foxes (Vulpes lagopus) are not correlated with ecology or development

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Island species are thought to be natural experiments of evolution, as they combine a series of features, such as fast evolution or traceable dispersion events, that make them excellent study cases. The Arctic fox (*Vulpes lagopus*) is one of these cases, as this species lives on the mainland and in different circumpolar islands. The ecology of this species varies among different populations, mainland ones live in the tundra and feed mainly on lemmings (lemming ecotype) and island ones live near the coast and feed on carrion, eggs and seabirds (coastal ecotype). Here, we use 3D geometric morphometrics to explore skull morphological variation among different island and mainland populations. Our results show that all lemming ecotype populations have a very similar skull morphology, whereas each coastal ecotype population has a different morphology. However, the patterns of fluctuating asymmetry, a proxy for developmental patterns, are very similar among all populations with the only exception of Mednyi island population. These results suggest that morphological variation of the skull in response of ecological adaptation can follow different paths regardless of the homogeneity of developmental patterns.

Title: 42-6: Mammalian olfaction, an integrative perspective

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The sense of olfaction is key to the survival of most vertebrates, as it is involved in the detection of potential food, mates and predators. In mammals, the importance of olfaction is evident both genetically and anatomically: olfactory receptor genes are the largest gene family, and olfactory structures such as the olfactory turbinals, the olfactory bulb, and the vomeronasal organ occupy a large volume in the mammalian skull. There is still a large gap in our understanding of how odorant perception and olfactory performance relates to the anatomical bases of olfaction, and whether and how olfactory genetics and morphology differentially covary among species that have different olfactory capabilities. Very few studies have attempted to relate genetic and morphological proxies of olfaction, and even fewer have tested the potential relation with olfactory capabilities. We CT-scanned and extracted the relative surface area and volume of olfactory turbinals and olfactory bulb endocasts in 18 mammalian species for which olfactory capabilities were previously tested. For these species we compiled results of olfactory sensitivity and discrimination tests as well as the number of functional olfactory receptor genes. We assessed the potential co-variation between all these proxies. Our results demonstrate that the relation between olfactory capabilities and the olfactory genetics and morphology is not straight-forward and that we may need to rethink the simplistic vision of olfactory performance and its proxies.

Title: 10-7: Functional morphology of the head and neck in a new cistecephalid dicynodont (Therapsida: Anomodontia) with implications for the evolution of fossoriality within the clade

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Cistecephalids are a late Permian clade of dicynodont therapsids known for specializations of the skull and postcranial skeleton hypothesized to be adapted for subterranean life. Features associated with fossoriality include spade-shaped skulls and robust pectoral girdles and forelimbs. Here we describe the cranium of a new cistecephalid dicynodont from the Mid-Zambezi Basin of Zambia. This specimen possesses an interparietal with a prominent nuchal crest and broad lateral edges, which are hypothesized to enhance atlanto-occipital muscle attachment sites. The specimen has a complex naso-frontal suture, similar to those reported throughout Cistecephalidae. Such characters align with hypotheses of cistecephalids engaging in head-lift digging. This new specimen shows a similarly complex suture where the parietal and interparietal meet, which may have provided additional resistance to compressive forces experienced when digging. CT data offers the opportunity for exploration of skull and neck morphology through segmentation and digital reconstruction. Combined with a comparative morphological study of other cistecephalids and a sample of extant head-lift burrowers, this work sheds light on the connection between anterior axial skeleton morphology and burrowing

ecology. This specimen displays a mosaicism in morphology that is increasingly recognized as a hallmark of cistecephalid evolutionary history. As possibly one of the earliest occurring cistecephalids, hypothesized to represent a stem-ward genus, we present the earliest example yet of derived burrowing ecomorphologies within the evolutionary history of Synapsida.

Title: P4-19: A physical model for reproducing the passive dynamics of limbs in walking and running horses

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We present a physical model for reproducing the passive dynamics of limbs in equine cadavers. We approximated the skeleton of a horse as a link structure and reproduced the eight major tendons in the limbs of a horse. It is known that multi-articular tendons in the equine leg passively interlock multiple joint angles. Based on the mechanical characteristics, we set the natural lengths of the tendons in the model to replicate the joint interlocking patterns measured by dissection. The mass of each part and the nonlinear elasticity of the tendons were modeled at 1/4 size based on the scaling laws. A legged robot equipped with the model can generate a gait with a joint angle profile similar to a horse by simply swinging the hip joint with a sinusoidal input. The robot can also generate walk, trot, and gallop-like gaits by changing the frequency and phase difference of the input. These experimental results suggest a large contribution of the passive dynamics of the equine leg, especially the interlocking of the joints, to the generation of walking and running.

Title: 16-2: TBI magnitude affects anxiety and dopaminergic signaling in fish

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Traumatic brain injury (TBI) is a public health issue with physically and emotionally debilitating effects. Studying human brain tissue is difficult, making it essential to explore the neurobiology of TBI using non-human animals. This study induced TBI via a weight-drop apparatus in mangrove rivulus fish, which can navigate land by jumping and often land forcefully on their heads. We employed a full-factorial design: three weights (0g, 0.3g, 0.6g), two frequencies (1 or 5 TBIs separated by 24h), two intervals between final treatment and euthanasia (1h, 24h). We quantified behavior in an open field and gene expression related to brain dopaminergic signaling (TH, DRD1, DRD2). We hypothesized that TBI would change behavior and alter dopaminergic signaling-associated gene expression (upregulated: DRD1, DRD2; downregulated: TH). TBI induced risk-prone behavior, a significant decrease in thigmotaxis post-TBI. Severity and frequency of TBI had a hormetic effect on DRD1 expression; animals concussed 5x with 0.3g (but not 0.6g) showed higher expression than all other groups. Animals concussed 5x with 0.3g had lower DRD2 expression than controls or those experiencing five 0.6g TBIs. Treatment alone did not affect TH expression but, only in the 0.3g group, the age-TH expression relationship at 1h (-) was reversed 24h post-TBI (+). This study contributes a unique model for TBI research and further elucidates neural processes and behaviors affected by concussions.

Title: 40-3: Turning a Skate into a Ray: The Genetic Basis of Modified Pectoral Fins in Manta Rays and their Relatives

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Batoids possess a unique body plan associated with a benthic lifestyle that includes dorsoventral compression and anteriorly expanded pectoral fins that fuse at the rostrum. Members of the family Myliobatidae, including manta, eagle, and cownose rays, exhibit further modifications to the standard batoid body plan that are associated with invasion of the pelagic environment, including redistribution of pectoral fin rays, a shifted center of mass, and a high aspect ratio, that facilitate underwater flight. Most notably, the pectoral fins are split into two discrete domains with independent functions--the anterior cephalic fins are used for feeding while the remainder is dedicated to oscillatory locomotion. Domain splitting during paired fin development is driven by an interruption of the AER around the fin margins that is maintained by *Wnt3/a*. *Dkk1* is a *Wnt* antagonist that is differentially expressed in the anterior pectoral fin of myliobatids. Here, we provide functional evidence that *Dkk1* is sufficient to initiate fin domain splitting. Agarose beads soaked in DKK1 protein were implanted in the pectoral fins of little skate (*Leucoraja erinacea*) embryos resulting in AER interruption compared to implantation of control beads. This disruption arrests fin ray outgrowth, creating a phenotype resembling that of a developing myliobatid. These results provide functional evidence for the underlying genetic pathway associated with the evolution of a novel paired fin/limb modification in manta rays and their relatives.

Title: 24-4: Developmental mechanisms of maxillary variation among bats and implications for craniofacial diversification in mammals

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Chiropteran craniofacial morphology is extremely diverse, which can be attributed to their diversity in echolocation abilities and specializations to various diet. Particularly in the maxillary bone, median, or bilateral cleft formation is observed as wild types in groups such as rhinolophoids and vespertilionids which resembles cleft palate, a recognized congenital disorder in humans. The development and mechanism of these aberrant morphologies found in bats is yet largely unclear, but understanding such factors have significant implications for resolving craniofacial anomalies in humans. In this study, embryonic series of various vespertilionid bats, which is found to form a median cleft jaw, and pteropodid bats which show normal craniofacial morphology, were compared. The results showed that in vespertilionids, the median maxillary cleft is caused by spatiotemporal control of the ossification site in the middle of the maxilla. Comparison with pteropodids revealed that this spatiotemporal regulation is caused by inhibition of ossification at specific sites. In previous studies, it was considered that cleft formation is caused by ossification inhibition along the fusion site of the palatine primordium. However, the present results show that premaxilla has multiple ossification centers, and that ossification control at each ossification center results in cleft formation. Furthermore, they occurred independently of the fusion of palatal primordia, indicating that previously proposed hypothesis warrants revision.

Title: P4-9: Insights into the brain-braincase relationship across the Sarcopterygii, Lissamphibia and Lepidosauria

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Although gross brain morphology is well understood across most vertebrates, the spatial relationship to the braincase has received less attention. The increasing access to non-destructive scanning technology permits measuring brain and braincase volume from a wider range of animals than ever before. Much of this recent work shows that this relationship can be highly

variable between species. Among birds and mammals the brain occupies the majority of the braincase and thus a similar volume. In contrast, among sarcopterygians (lobe-finned fish), amphibians and non-avian reptiles there can be great variation in brain and braincase volume. Here we quantify the brain-braincase relationship in several species from major clades across the vertebrate tree. We found that the volume of the brain within the braincase is highly variable among species: 30-80% Once quantified, we used 'heat maps' to illustrate the distance between the surface of the brain and the braincase. Critically, we find that the differences in volume relate to different brain regions in different taxa. This result builds on recent studies showing similar variability in the brain-braincase relationship between different taxa. These results also contribute to a greater understanding of brain-braincase spatial relationships among vertebrates and will prove useful for future work when interpreting fossil cranial endocasts of extinct vertebrates.

Title: 31-1: The feeding kinematics of a surgeonfish (Zebrasoma desjardinii) and the associated functional implications

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Benthic-feeding coral reef fishes display an impressive degree of morphological and functional adaptations. While the ecological outcomes of such feeding have been studied in detail, the morphological adaptations and mechanisms required to carry out these extractions, as well as how they are used during a bite, have only been sparsely studied. Here, we show how a surgeonfish (*Zebrasoma desjardinii*) uses its morphology (i.e., jaws, neurocranium, body) during different types of grazing (cropping and scraping) and we investigate how surface roughness influences scraping kinematics. We find that the upper and lower jaws interact differently with the benthos, suggesting a functional decoupling between the two. Furthermore, we found that most bites include two suction events, one just before the jaws make contact with the substratum, and once again post-jaw closure, when the fish re-opens its mouth to transport captured material for ingestion. Surface roughness impacts feeding kinematics, suggesting this property to potentially influence the choice of scraping locations on the reef. Overall, our results provide new insights to benthic-associated fish feeding, highlighting the diversity, and mechanical properties of, the different resources found on the benthos of coral reefs.

Title: 53-10: A Bayesian approach to dating the cetacean phylogenetic tree using correlated quantitative characters.

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Total Evidence Dating combining phylogenomic and discrete morphological data has been used to estimate species divergence times for numerous taxonomic groups, often using the Mk model. Yet, discrete data possesses several limitations including character choice subjectivity and limited available traits for certain (particularly fossil) taxa. Additionally, incorporating intraspecific morphological variation and trait correlations, two factors that affect divergence time estimates, can be computationally expensive using the Mk model. Quantitative morphological data avoids many of these limitations and can incorporate correlation and intraspecific variation in a Bayesian approach with comparatively low computational expense. We extend and test the scalability of such analyses for a much greater sample of species and morphometric data. We apply methods described in Alvarez-Carretero et al., 2019 to a dataset of 123 3D landmarks and 124 curves gathered from the crania of 201 species of extant and extinct cetaceans. Intraspecific variation is estimated using a sample of *Delphinus delphis*. Morphological evolution is modelled using Brownian diffusion, and preliminary results analysed under the independent rates model indicate an early estimate for the cetacean root at 59.5 Ma. Future work will develop these results with further model refinement and incorporation of molecular data for extant taxa. Combined, this approach is used to date the cetacean phylogenetic tree and assess the efficacy of Bayesian phylogenetic methods using high-dimensional morphometric data for large, comprehensively sampled datasets.

Title: 55-1: Genus at Work: Cranial shape diversity in a recent radiation of marsupial herbivores

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Rock-wallabies of the genus *Petrogale* recently radiated across all of mainland Australia. Seventeen recognised species now occupy discrete geographical pockets with surprisingly low sympatry. The genus therefore presents an excellent opportunity to examine influences of biological and geographical factors on morphological variation at the continental scale. Here, we present a geometric morphometrics analysis of cranial shape across ~400 specimens representing all seventeen species of *Petrogale* and the five subspecies of the *Petrogale lateralis* species complex. We find broad-scale shape variation among *Petrogale* crania is largely driven by evolutionary allometry aligning with Bergmann's Rule, whereby larger species are distributed further from the equator and exhibit size-related differences in cranial shape. This trend holds true with the exclusion of the two dwarf species from far Northern Australia. However, there is also a phylogenetic component involved, with contrasting evidence for Bergmann's Rule found within several monophyletic clades across the genus. Dominant shifts in cranial shape variation

across *Petrogale* therefore appear to be largely driven by phylogenetically constrained size diversity, with potential additional influences of size-mediated niche partitioning and regional shifts in food mechanical properties. Further analyses planned for this data will determine the impacts of climate and geography on cranial shape and feeding biomechanics, and covariation between morphology and genetics at both interspecific and intraspecific scales.

Title: 45-1: Whisked Away: synapsid sensory innovations and the evolution of facial musculature

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Facial muscles are a distinctive characteristic of extant mammals, but their evolutionary origins have long remained speculative. This superficial layer of muscle is intimately associated with the integument and unlikely to leave direct traces in the fossil record; however, Huber (1930) proposed a correlation between the emergence of facial muscles with expansion of the tactile sensory field innervated by the trigeminal nerve. We tested this hypothesis by examining the trigeminal nerve canals preserved in the upper and lower jaws within a phylogenetic sample encompassing both the synapsid line leading to modern mammals and non-synapsid outgroups. There is a pattern of change in trigeminal canal morphology unique to synapsids and suggestive of increasing tactile specialization. We hypothesize the derived state of the trigeminal canals appearing in the mid-Triassic period is an osteological correlate for the presence of facial muscle-mobilized mystacial whiskers. Furthermore, we demonstrate the derived state morphology consisting of a short infraorbital canal terminating in a single forward-facing foramen is functionally adaptive for reducing mechanical stress on the nerve exiting the bony canal to embed in the highly mobile whisker pad. The anatomical novelty of facial muscles evolved in concert with innovations in active gathering of sensory information and may have supported expansion into low-light and spatially-complex environments, as well as new feeding strategies involving tactile localization among our synapsid ancestors.

Title: P2-15: Telling Tails: Comparative muscular morphology and function of mammalian tails

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Tails have diversified alongside changes in locomotion as mammals radiated into the world's terrestrial, aquatic, and aerial environments. However, the intricate anatomy of the muscles and tendons comprising the tail has rendered this section of the axial skeleton relatively unexplored. We present a survey of tail muscular anatomy collected from dissections and diceCT scans in a phylogenetically and functionally diverse sample of mammals. We find intrinsic caudal musculature in bilateral dorsal and ventral tracts; however, dorsolateral and ventrolateral tracts consist of extrinsic muscles originating on the torso that rely on long tendons

spanning multiple joints to effect movement of distal caudal vertebrae. Anatomical data collected from dissection of unfixed specimens revealed an unusual morphology for the dorso- and ventrolateral muscles as a multi-tendinous sheet of fused muscle segments. We noted diversity in relative tail length, number of caudal vertebrae, relative integration of the caudal and hindlimb musculature, relative size and shape of the dorso- and ventrolateral muscles, and tendon branching patterns as a foundation for establishing potential form-function relationships. In addition, our anatomical investigation of Matschie's Tree Kangaroo (*Dendrolagus matschiei*) presents a case study for an ecological transition to arboreality from terrestrial ancestors and examination of the possible relationships between retained ancestral characteristics and adaptations to a different locomotor mode.

Title: 44-3: Mechanical properties of lizard osteoderms

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Osteoderms (OD) are mineralised structures forming directly within the skin, with or without physical contact with the skeleton and are thought to act primarily as body armour. The aim of this study was to characterise the mechanical properties of lizard ODs across several species. Representatives of several lizard groups were chosen for this study. At the macro scale, sheets of skin from cadaver tissues were characterised under tension and puncture experiments. At the nano scale, single ODs were extracted and characterised using nanoindentation technique. Results highlighted an unexpected level of diversity in the mechanical properties of lizard skin and ODs. Some, but not all, species develop an enamel-like capping tissue and the organisation of the bone matrix varies between species. Capping tissue have a similar elastic modulus as enamel while other sections of the ODs have similar elastic modulus as bone in other parts of the body. Macro scale deformation of the skin sheets is likely to be impacted by several factors including the morphology and distribution of the ODs as well as the presence or absence of the capping tissue within a single OD. The driving factors behind the diversity in lizards ODs remain unknown but this study advances our understanding of how nature modulates the stiffness of skin in lizards. This work was supported by the Human Frontier Science Program (RGP0039/2019).

Title: P4-17: Digitized endocasts and brains: measurements and analyses of the evolution of 172 fossil and extant vertebrate specimens

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This study considers brain evolution in vertebrates using 172 digitized endocasts of species spanning 80 million years. Three-dimensional (3D) models of 126 fossil endocasts, including Cenozoic mammals, Bathygenys, and dinosaurs, were quantified and compared with the endocasts and brains of extant species. Encephalization quotients and neocorticalization were calculated and are reported. For example, about 60 million years ago, mammalian neocorticalization averaged about 20%, which increased to a present average of 50%, and reached a maximum of about 80% in primates within the past 10 million years. Most importantly, this study sample (1) represents a culmination of the life's work of lead author Dr. Harry J. Jerison and (2) is largely now freely available to researchers on MorphoSource (https://www.morphosource.org/).

Title: P4-10: Assessing Morphological Variation in the Avian Quadrate Through 3D Geometric Morphometrics

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The quadrate is the driving force behind upper bill elevation in avian cranial kinesis, to the degree that the convention when describing cranial kinesis is to consider the quadrate as the starting point, and describe all movements as initiated from it. The morphology of the avian quadrate consistently includes a distinctive suite of morphologies, including an otic process and condyles, an orbital process, a pterygoid process, and a mandibular condyle, but is otherwise variable in shape. How this morphological variation relates to its function, or whether phylogenetics, dietary categories, or palatal morphology constrain quadrate disparity has not been previously tested, and may provide valuable insight into the morphofunctional evolution of the avian cranial kinetic system. This study aims to use 3D geometric morphometrics to explore and describe the morphological variation of the avian quadrate in taxa from every extant order of birds and examine it in its functional and ecological context. The results indicate that functional variables are the key driver of shape variation in the avian quadrate, such as in morphology of the orbital process, to which attaches the *protractor pterygoidei et quadrati*, and the shape of the mandibular condyle - both of which play key roles in the distinctive cranial kinesis utilised by avians.

Title: 24-8: Embryonic origins of amniote palate diversity

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The conformation and shape of the roof of the mouth, including the skeleton of the palate and associated soft tissues, is incredibly variable across living and extinct amniotes. This structure serves important ecological functions (e.g., feeding, respiration) and likely reflects constraints imposed by craniofacial development and evolution. However, the embryonic origins of amniote palate disparity have not been studied in either a quantitative or broadly comparative context. To assess the pre-skeletal origins of palate diversity, we used a combination of CLARITY, immunofluorescence, and confocal imaging to capture the three-dimensional (3D) form of embryonic tissues for a series of key stages of development in representative amniotes (*Alligator mississippiensis*, *Mus musculus*, *Gallus gallus*, and *Paroedura picta*). A series of antibodies (e.g., anti-Sox9, Runx2, Col I, Col II, Col IX, BSP II) traced the initial formation and progression of cartilage and bone development, which could be directly compared to subsequent skeletal ontogeny (μCT) using high-resolution 3D surface semi-landmark based geometric morphometrics. The total palate ontogeny morphospace revealed that many aspects of the 3D shape of the eventual cartilage and bone are fully realized by earlier protein expression patterns. Quantifying the differences between the trajectories of pre-skeletal tissue morphogenesis and the process of ossification may ultimately provide important insight into the mechanisms generating anatomical diversity, which appear to be predetermined by the onset of ossification.

Title: 10-4: Long bone loading during suspensory locomotion in brown-throated three-toed sloths (*Bradypus variegatus*)

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Long bone loading in upright animals has been well studied across many tetrapod taxa. Overall, these studies found that both proximal and distal limb segments experience greater bending loads than axial loads. However, few studies have evaluated bone loading in animals that employ below-branch arboreal locomotion. In contrast to upright taxa, tree sloths are among the rare mammalian taxa that demonstrate near obligatory suspensory habits as part of their arboreal

lifestyle. Consequentially, limb bone loading in tree sloths may then indicate higher levels of axial (i.e., tensile) loading and reduced levels of bending. To test this hypothesis, an inverse dynamics model was used to assess *in vivo* bone loading during suspensory walking in brown-throated three-toed sloths (*Bradypus variegatus*). Preliminary data show that proximal limb elements in both the forelimb (humerus) and hindlimb (femur) of three-toed sloths experience higher levels of bending, whereas distal elements (radius, ulna, tibia) experience higher axial loads. These findings suggest that distal limb loading patterns in suspensory species differ from those of upright mammalian taxa. Further material testing of tree sloth long bones is needed to verify how the structural properties of distal limb elements may adapt to this unusual loading regime.

Title: 37-4: Investigation of the convergent evolution of the prehensile tail among small-bodied rodents from the Hydromyini tribe

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Tails capable of grasping, also called prehensile tails, are considered as an adaptation to arboreality. Such capacities have appeared independently in at least six mammalian lineages. This trait, often considered as one of the least studied morphological adaptation of climbing species, has mainly been studied in new world primates and to a lesser extant carnivorans. Results have shown similar independently evolved features shared by prehensile species regarding bone, muscle and skin characteristics. However, these species tend to be relatively heavy tree-dwelling species. Hence, most hypotheses on the potential adaptive role of these morphological convergences have focused on the constraints associated with heavy-bodied species navigating a fragile and discontinuous environment. However, low-weight species have been largely overlooked. Here, we focus on a tribe of Australopapuan Murine Rodents, the Hydromyini, which present an important diversity of prehensile species distributed across nine genera and representing up to at least four independent origins of this trait. Based on a dataset composed of arboreal prehensile and non-prehensile species as well as their terrestrial relatives we examine the caudal vertebrae of these species using linear measurements. We first determine whether convergent patterns are observed between the prehensile species of this group and secondly determine if traits are convergent on those described for heavy-bodied primates and carnivores.

Title: 23-2: Evolutionary conserved mandibular exoskeleton structures in chewing insects

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Arthropods including insects have several feeding habits to adapt to their lifestyles. The hard insect exoskeletons are designed to perform feeding efficiently to satisfy their feeding strategies. We here present the chemical components within the hard exoskeleton of the mandibular part in chewing insects which is generated by the combination of chitin and melanin. To address how the hardness of the exoskeleton is generated, we use the two-spotted cricket *Gryllus bimaculatus* as a model insect because of its hard body, relatively large size and convenience to approach over the transcriptional manipulations. Melanization of insects proceeds by several enzymatic steps including *laccase 2*. The knockdown targeting *laccase 2* using RNA interference (RNAi) resulted in the soft and white-colored body whose mandible at mouthpart and tops of the tibial spina remained to be dark-colored. Energy dispersive X-ray analyses revealed the significant presence of Zinc (Zn) around these areas, eventually supporting to make the edge structures harder. The order to generate the exoskeleton is as follows; firstly, accumulation of Zn at the edge of mandibular teeth, then melanization occurs through each molting event. Finally, we will overview current knowledge of insects' exoskeleton-generating mechanisms.

Title: P1-8: Histomorphological indices to evaluate unique forelimb posture and digging strategy in moles (Eulipotyphla: Talpidae)

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Talpine moles (Eulipotyphla: Talpidae) are mammals that are highly specialized in burrowing using their forelimbs. Their shoulder girdles and forelimbs are adapted to hyper-abducted posture and humeral rotation digging, which is a unique digging strategy from the other diggers. This adaptation is considered to have been acquired for fossorial in mole evolution, however, the morphological indices to separately evaluate the forelimb posture and digging strategy are uncertain. By comparison among three moles (*Mogera wogura*, *M. imaizumii*, and *Urotrichus talpoides*: Talpidae) and an outgroup taxon (*Suncus murinus*: Soricidae), we found that histomorphological structures responding to mechanical loading may reflect hyper-abducted posture and humeral rotation digging, respectively. The scapulae of moles hardly responded to proximo-distal compression than those of *Suncus*. In contrast, the clavicles of moles responded to proximo-distal compression. Additionally, the microstructure of *Mogera* humeri responded to the torsional strain caused by humeral rotation digging. However, the humeri of *Urotrichus* did not show such responses as those of *Mogera*, although the digging performance and the growth rate need to be examined in *Urotrichus*, which may reflect the development of the microstructure. These histomorphological traits are expected to be clues to reveal the paleoecology of fossil moles, and to reveal when and how the moles have acquired the unique posture and digging strategy in their evolutionary history.

Title: 33-1: Sequential Scales: New perspectives on snake axial evolution

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Snakes have one of the most unique body plans, which has long been presumed uniform, despite immense variation in body form across the families. Diversity in the postcranial skeleton of snakes has likely been overlooked due to their lack of body markers (limbs, pelvis, etc.). Recently the heart has been proposed as a marker for the cervical-thoracic boundary, since *Hox* genes are known to have a major role in heart development. Heart position is also an important physiological trait shown to vary with ecology. Here we present a new perspective on this topic by investigating the vertebral column of two families, Elapidae and Colubridae, with known ecological transitions. We compared the number and size of vertebrae along the length of the axial skeleton using the heart as a boundary between the fore and hind body. We show relative heart position is achieved by sequential addition of vertebral to different body regions, and ecology underlies these observed differences in axial morphology. Focussing on the vertebral column provides greater understanding of snake body shape diversity and supplies a mechanism to explain how adaptation to new environments evolves.

Title: 6-2: Evolution of the cerebro-cerebellar system revealed by neuron counts

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The cerebellum has conserved circuitry and architecture across vertebrate taxa, despite enormous variation in its size and shape. It is therefore believed that it provides similar computations, namely predictive or feedforward control for telencephalic regions subserving sensorimotor and cognitive tasks. Abundant experimental and comparative evidence suggests a tight functional coupling and co-evolution of the cerebral cortex and cerebellum in mammals. Using the isotropic fractionator, here we investigate the evolution of the cerebro-cerebellar system in non-mammalian vertebrates by comparing numbers of telencephalic and cerebellar neurons in ~ 570 species of birds, non-avian reptiles, amphibians and fish. We demonstrate numerous cases of decoupling between the evolution of the telencephalon and the cerebellum. In basal ray-finned fishes, the cerebellum is small, but houses about 50% of all brain neurons. An enlarged cerebellum harboring a majority of brain neurons has evolved multiple times independently in teleost fishes, without an accompanying proportional enlargement of the telencephalon. By contrast, lungfish, amphibians, and squamate reptiles have small cerebella containing a small

fraction of brain neurons. An evolutionary trend of increasing cerebellar neuronal fraction is seen in turtles, crocodiles, and basal birds and gets reversed with the evolution of an enlarged telencephalon with high neuron packing densities in avian crown groups. These findings suggest that the coupling between neuron numbers in the telencephalon and the cerebellum is a derived characteristic of mammalian brains.

Title: 28-3: Pre- and postnatal morphogenesis of the hyolaryngeal apparatus in bats with evolutionary insights into the laryngeal echolocation.

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Laryngeal echolocation in bats is primarily driven by the hyolaryngeal apparatus, and the organ for the ultrasonic sound production is considerably divergent across species: nostrils in horseshoe and leaf-nosed bats; and an oral cavity in vespertilionid bats. The hyolaryngeal apparatus of laryngeal echolocating bats have undergone drastic morphological innovations such as the hypertrophied cricothyroid muscle. Despite the potential to be informative for the evolution of laryngeal echolocation, however, the morphological diversification of the hyolarynx remains unexplored. A recent study has clarified that the stylohyal and petrosal bone, both of which play crucial roles in the perception of the echolocation pulse, are ossified in a different way between nasal and oral echolocating lineages; thus, the embryonic development of the pulse-processing organ reflects the evolutionary signal for the laryngeal echolocation. Here, we conducted comparative analyses of the hyolaryngeal development to investigate the key morphological changes providing the bioacoustic diversity. The pre- and postnatal hyolaryngeal morphogenesis from three bats were three-dimensionally reconstructed using microCT and serial tissue sections. Our data show that laryngeal echolocating bats with different sound organs have substantially divergent hyoid components, the morphology of the laryngeal cartilages, and the laryngeal mineralization process. We demonstrate that the morphological features of the hyolaryngeal apparatus for the ultrasonic emission are likely non-homologous among bats, therefore corroborating the independent evolutionary origins of the laryngeal echolocation.

Title: 25-5: On the developmental origin of Araucana’s ear-tufts

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The Araucana chicken is a unique example of morphological changes under domestication. Among rumplessness and laying blue eggs, one of its most unique traits relates to structural particularities on the head. In addition to cranial variation, this breed shows facial epidermal appendages covered with feathers: the ear-tufts. Morphological descriptions and genetic studies have provided valuable information on the origin of these structures, suggesting candidate genes and abnormal pharyngeal arch fusion as a cause of the ear-tufts. However, the developmental process of these structures is still to be examined. Using lineage tracing, omics approaches, expression analysis, histological characterization and functional perturbation in well documented Araucana ontogenetic series, we work to shed new light on the developmental and molecular mechanisms that give rise to the ear-tufts in Araucanas. We provide new candidate genes and analyze the expression patterns of known candidates involved in the formation of ear-tufts (TBX1), ultimately identifying the molecular control of skin regional specificity in birds.

Title: Evolutionary morphology of the neck-to-trunk boundary in artiodactyls and the iconic case of the looong neck of giraffes

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Exemplified by the iconic long neck of giraffes, artiodactyls exhibit strikingly variable neck lengths while maintaining the usual mammalian count of seven cervical vertebrae. To gain insight into the evolutionary morphology of the neck and precisely its boundary to the trunk, we used an integrative investigation at the interface of form, function, and evolution. We leveraged non-destructive imaging techniques to conduct a clade-wide comparative and quantitative 3D shape and structure analysis within a phylogenetically informed framework. Computational modelling of the form-function relationship identified performance differences, in terms of a potential trade-off between joint mobility (assessed by range of motion analysis) and vertebral robustness (assessed by finite element analysis) across a comparative dataset of artiodactyl species (N=32). We used phylogenetic reconstruction to assess convergence and compared statistical models of trait evolution to evaluate the relative significance of mobility and robustness as drivers of the evolution of neck vertebrae morphology. This combined analysis not only revealed new insight into the unique morphology of the giraffe's neck-to-trunk boundary but, more generally, also shed light on the evolutionary dynamics of artiodactyl neck evolution.

Title: 27-1: Probing for the developmental mechanisms underlying repeated tooth loss in frogs

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Teeth are present in most living vertebrates, but complete tooth loss (i.e., edentulism) has evolved in several diverse lineages. Recently, we demonstrated that teeth have been lost completely in more than 20 frog lineages, a much higher occurrence of edentulism than in any other vertebrate clade. The mechanisms underlying tooth loss in anurans are unknown, but identifying the developmental, genetic, and environmental factors linked to edentulism in this group will provide insight to the predictability and repeatability of evolutionary processes that generate similar traits. The morphogenesis and regeneration of teeth in vertebrates is mediated by a conserved genetic regulatory network, and the loss of different molecular signals has been shown to arrest dental development and underly independent tooth loss in birds, turtles, and some mammals. Using immunohistochemistry and in situ hybridization experiments, I characterize the developmental genetics of tooth initiation and proliferation in two frog species that possess teeth and then assess if the loss of different signals arrest tooth development among four species that have independently lost teeth. With phylogenetically widespread tooth loss and separate evolutionary losses on upper and lower jaws, frogs offer an unparalleled opportunity to determine if tooth development is repeatedly disrupted by a single conserved or several novel mechanisms.

Title: 19-5: Dynamic simulation of macaque jaw mechanics during a complete power stroke of mastication.

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Finite Element Models (FEMs) are powerful tools to study form-function relationships of non-human primate jaws during feeding and glean insights on the role of food in species diversification in general, and on adaptive specializations to environmental resources. Using static FEMs we have previously shown that during unilateral post-canine chewing in rhesus macaques the largest food-related differences in maximum principal and transverse shear strain magnitudes are in the transverse tori and in the balancing-side medial prominence, extramolar sulcus, oblique line, and endocondylar ridge. However, strain patterns likely vary throughout the power stroke in vivo due to variation in the activation peaks of the jaw adductor muscles. To further study the impact of relative timing of muscle force on mandible biomechanics we built dynamic FEMs of a complete power stroke using muscle force data from in vivo experiments. Results show that peak principal and shear strains in the lingual symphysis, working (chewing) side lingual ramus and balancing (non-chewing) side corpus occur when the activation peaks of the working- and balancing-side superficial masseters, anterior temporales, and medial pterygoids have started to decline, and the balancing-side deep masseter and posterior temporalis

force peaks. These results indicate that load and strain regimes vary across a chewing cycle and are often hindered by static FEMs, which are limited to a single point of the power stroke.

Title: 4-2: Functional morphology toolkit for the evolutionary scenarist of chiropteran flight machine

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For reconstructions of complex evolutionary transitions that are not resolved by fossils, a morphofunctional analysis based on the principle of actualism can be used. Viewing an organism as a mechanical system, its crucial structures responsible for interacting with the environment and for optimal functionality and fitness can be distinguished. In the locomotor apparatus, these are primarily motors – muscles that carry out the energy input in any activity. No less important is how the mechanical transmission from these internal motors to the propulsors is organized.

Following the proposed principle for analysis of bat flight origin, the changes in the main motor of the flying apparatus, namely the pectoral muscle, are subject to priority study. The challenges for this muscle are fundamentally different from those for quadrupedal locomotion, since flight requires the significantly higher mechanical power. The direction of propulsors' action is also specific to flight - the plane of limb operation changes from sagittal to transverse.

Adaptive evolution leading both to the deparasagittalization of limbs and to an increase in the strength of the pectoral muscle as a means of suspending the body to the limbs is the general framework for proposed approach. In this framework, different possible scenarios for the transformation of this system for flapping flight should be compared and transitional types of locomotion should be tested.

Title: 34-3: Growing long in the tooth – continuously growing dentition and the power cascade model

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Undertaking dental morphology, growth and life history research on mammals with continuously growing (euhypsodont) teeth is complicated by the loss of tooth material through wear.

The power cascade model is a new representation of form based on a power law that accurately captures the shape of a broad range of pointed biological structures, including claws, horns, thorns and beaks, along with teeth from all vertebrate groups. A particularly powerful application of this model is in reconstructing tooth shape and length where material has been lost through breakage or wear.

Using the power cascade model, we examined a range of euhypsodont tooth systems to understand aspects of tooth growth, morphology and associated life history. This includes species with occluding euhypsodont teeth (e.g., laboratory mice *Mus musculus* and common wombats *Vombatus ursinus*) and free-growing teeth in megafaunal taxa (e.g., African elephants *Loxodonta* spp.). Our results allow us to calculate the volume and length of tooth that has been lost through wear or breakage and, combined with tooth deposition rates, determine the approximate age of the animal. Within our study samples we find population and sex-based differences in tooth shape and wear that are associated with ecology.

We have further integrated power cascade analyses of tooth morphology with chemical and histological techniques. This allows us to build age-calibrated life histories from individual teeth, predicting just how 'long-in-the-tooth' an animal has grown.

Title: P3-20: Effect of early-life stress on skeletal development in a tropical agamid lizard

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All animals experience stress at different stages of their life. Stressful events during early development can have long-lasting effects on the adult phenotype. During the juvenile stage, when an animal is gearing up for investment in secondary sexual traits, exposure to stressors can act as a crucial determinant in trade-offs between investment in traits associated with survival and reproduction. Additionally, rate of investment in different parts of the skeleton might vary across developmental time, depending on which body parts play a more critical role at certain developmental stage. Lastly, maintaining symmetry between body sides within individuals is necessary for efficient body movement. Any change in body symmetry would result in decreased fitness of an individual in the wild. Using a tropical agamid lizard, *Psammophilus dorsalis* as my model species, I test the effects of early-life stress on: i) growth rate of different parts of the skeleton, at multiple developmental stages. ii) fluctuating asymmetry (FA). To test these ideas, I have finished collecting 70 juvenile lizards from the wild and implanted them with corticosterone-filled implants. I then tracked their skeletal development using landmarked X-Ray images. Growth rate of the stress-induced animals differs significantly from control. This study will determine how chronic stress during a key developmental period (sexual maturity) influences trait development.

Title: 12-4: The scutulum in Rhinolophus - sesamoid and/or meniscus?

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The cone shaped pinnae in mammals are supported by auricular cartilages which narrow to form the *tubus auris*. Outside of the pinna, the thin squama of the scutiform cartilage extends from the auricle medially to where it lies within numerous auricular muscles. It is thought to act as a sesamoid for those muscles during axial rotations of the pinna. The small footplate on the lateral edge of the scutulum may stabilize the *tubus auris* during similar movements. This has not been tested, nor have there been directed efforts to describe the shape and range of motion of scutulae in general. Therein, we used a depilatory to remove fur from the head of a rhinolohpoid bat. The gross action of muscles and scutular movements during echolocation were easily observed and documented through the thin skin using GoCam HERO4 cameras. Movements of the pinnae were largely independent from the underlying scutulae. Dissection revealed an unremarkable scutular squama, rhomboidal in shape. The lateral footplate was large, consisting of a nearly complete, ring of cartilage. Its thick rim protrudes from the surface to enclose a distinct subscutular fossa, through which the *tubus auris* passes. The base of each pinna fit neatly into this socket. This suggests that the lateral portion of the scutulum serves as a cartilage meniscus against which the pinna is centered and pivots.

Title: 34-2: Thinking beyond the cusp: patterns of tooth diversity in Lake Tanganyika cichlid fishes

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The oral teeth of cichlid fishes are highly diverse and range from slender canines with a single cusp to complex multi-cusped incisors. Prior descriptions of cichlid tooth diversity are qualitative or limited in taxonomic scope. Yet teeth are used to infer ecology and characterize species, and as direct points of contact with the environment, they are constantly subjected to strong evolutionary forces. We quantified dental diversity across 81 species from Lake Tanganyika (239 specimens, 1413 teeth) using linear measurements from photographs of extracted teeth and analyzed patterns of diversity across the radiation using phylogenetic comparative methods. The major axis of tooth diversity separated species with many small teeth from those with fewer, more robust teeth while the aspect ratio and number of inner rows loaded on PC2. Within unicuspid species, tooth labial compression is phylogenetically widespread across divergent trophic groups and drives variation in stable isotope niche (PGLS, $p<0.001$). Though unicuspid species lack complex teeth with multiple cusps, they have 3.8X greater dental disparity than multicuspid species because of variation in tooth size, arrangement, and shape beyond the cusp. State-dependent speciation and extinction models indicate multicuspid teeth have no effect on species diversification, unlike in other vertebrate groups. Tooth diversity beyond the complexity of the cusp may be important to meet the functional demands of different ecological specializations in the Lake Tanganyika cichlid radiation.

Title: 35-4: A snap to the left, a swing to the right - head and body shape affect biting kinematics in reef fishes

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Fishes use various control surfaces to propel and stabilize themselves. These surfaces include paired, median, and caudal fins as well as the body itself. The contribution of these control surfaces has been established in fish swimming, and for feeding on suspended prey, but is unclear for substrate feeders. Across teleosts, biting surface-attached prey is associated with convergent morphologies that include a deep body and an elongated, tapered head. However, the functional role of these morphologies is not established. In this study, we used simplified models of various substrate-biting fish to examine the role of head and body morphology in facilitating the removal of substrate-attached prey. Models simulated the swift lateral movement of the head, previously documented in two Acanthurid species biting substrate-attached algae. We found that increased lateral surface area of the body and median fins resulted in decreased body lateral displacement, producing more stable bites. Additionally, a decrease in head surface area resulted in faster lateral head movement, known to facilitate removal of attached prey in Acanthurids. Overall, our results suggest that the laterally compressed bodies and elongated median fins function as control surfaces during feeding in substrate-biting fish. We propose that a selective pressure to extend the lateral surface area underlies the prevailing morphological convergence of biting reef fishes

Title: P4-3: Quantifying nasal Airflow in large carnivores using computational fluid dynamics (CFD)

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The computational fluid dynamics (CFD) analysis has been used to investigate the association between nasal airflow (inspired air) and ecological adaptations in big cats. Our main aim is to investigate its potential to decipher different ecological aspects in extinct big cats. To do this, we CT-scanned the skulls with soft-tissue in a sample of living big cats with different biogeographical ranges. We virtually developed models of the nasopharyngeal tracts, and applied CFD, using Flowgy software. We modeled the efficiency of the nasal airflow in three different environmental scenarios: temperate forest region, desert region, and cold or high-mountain region by varying the temperature and relative humidity parameters in the virtual environment of Flowgy. The results of the three simulated scenarios were collapsed into hyperbolas to derive the physiological function of each species. We obtained two groups according to these parameters: (i) for some species whose nasal airflow is characterized by a rapid acclimatization of the inspired air depending on the temperature and humidity; and (ii) another group with less efficiency nasal airflow for humidity and temperature in all simulated scenarios. The results indicate an association between the degree of biogeographic range and its efficiency for acclimatizing the inspired airflow. In general, this opens new avenues for the ecophysiological studies of large carnivores and the possibility to expand them to the fossil record are discussed.

Title: 5-2: Ultrastructural analysis of an extensible muscle in Boa constrictor

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Large prey ingestion in snakes produces extreme distention of the body wall as some snakes consume prey up to 100% of their own body mass. After transporting prey into the body, large snakes like *Boa constrictor* can recruit costocutaneous muscles to crawl to safety using rectilinear locomotion. The costocutaneous inferior (CCI) muscle, positioned between the skeleton and mobile ventral skin, is lengthened more than two-fold due to body wall distention caused by a large prey bolus. This lengthening may be at odds with the fundamental mechanics of vertebrate skeletal muscle by acting to lengthen the CCI muscle beyond lengths where active force production should be possible. Mechanical testing of the CCI muscle reveals an atypical length-tension relationship, suggesting ultrastructural novelties. We used transmission electron microscopy and found that CCI myofilament lengths are similar to what is observed in anurans and rodents, yet, z-disks appear staggered and sarcomere excursion is consistently less than total muscle excursion in stretched muscles. Imaging CCI muscle collagen using second harmonics indicates that collagen fibers are coiled and unwind with stretch. These results suggest that modifications beyond of the level of a sarcomere may contribute to the extensibility of the CCI muscle and that the mechanical configuration of the extracellular matrix allows it to function as a passive spring. These features may be important for large prey ingestion in *Boa constrictor*.

Title: 40-4: Red lionfish (*Pterois volitans*) use big fins and persistence to exploit the evasion strategy of prey

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It is commonly assumed that faster swimming increases the likelihood of success for both a predator and a prey. The Pacific red lionfish (*Pterois volitans*) is uniquely suited to study relationships between locomotion, morphology, and behavioral strategy. Slow moving and highly decorated with large fan-like pectoral fins, these lionfish gained notoriety as a voracious and stubbornly invasive predator in the western Atlantic Ocean. We performed kinematic measurements of individual lionfish as they pursued green chromis (*Chromis viridis*) in a cylindrical arena. Despite swimming half as fast as their prey, the lionfish were highly successful and employed a 'persistent-predation' strategy, but the influence of prey locomotion on their survival was confounded by the stochastic swimming behavior of prey. To evaluate the causal basis of predator and prey behavior on prey survival, we developed agent-based mathematical models parameterized by these kinematic measurements. We found that simulated prey survival was most influenced by the interaction between predator speed and the evasion strategy of prey. Additionally, our results suggest that slow moving red lionfish may exploit their fan-like pectoral fins to reduce the space available for prey to escape.

Title: P2-14: Soft tissues, hard limits: integrating ligament strain into joint range-of-motion estimates

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Estimating joint range of motion has played a central role in reconstructing the paleobiology of extinct species for almost a century. Current state-of-the-art digital methods have greatly advanced our ability to quantitatively sample joint mobility and function but are computationally intensive and time consuming, thus impeding broader comparative studies. Recently, we introduced ‘APSE’ (Accelerated Pose Searching with Electrostatics), an iterative algorithm for rapidly and intelligently sampling high dimensional joint pose space. APSE integrates rotations, translations, and hard-tissue (bony) constraints and recovers more viable poses in a fraction of the time taken by previous methods (hours, not days or weeks). Here, we extend the utility of APSE to include soft-tissue (ligament) constraints to ‘whittle down’ available pose space to more accurately reflect joint function. Using ex vivo cadaveric joint manipulation and the XROMM workflow, we measured maximum ligament strain values around the shoulder joint of tegu, opossum, and echidna. Including this new information in APSE resulted in a better-defined joint pose space, particularly with respect to long-axis rotation, and resulted in better agreement with the empirical ex vivo pose space compared to simulations that relied on osteology alone. We demonstrate that the addition of even simple soft-tissue constraints to models of joint mobility can greatly improve their realism, having important implications for our understanding of joint function and evolution when studying the fossil record.

Title: 4-6: Musculoskeletal modeling untangles the origins of mammal forelimb function and posture

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The 'sprawling–parasagittal' transition was a major postural shift that occurred in the ancestors of mammals, [PSE1] underpinned by musculoskeletal reorganization of the limbs. However, 'when' and 'how' this important postural shift occurred is unknown. While the anatomical changes characterizing this transition can be traced through the fossil record, how these relate to functional changes, and the acquisition of parasagittal posture, remains poorly understood. Here, we produced three-dimensional musculoskeletal models of the forelimbs of extant (n=3) and fossil (n=8) taxa that phylogenetically and functionally span the sprawling–parasagittal transition. We calculated joint range of motion (ROM) to determine a 3D pose space, using the novel APSE algorithm (Accelerated Pose Searching with Electrostatics). We then estimated muscle moment arms (MMAs) across the entire pose space for all muscles crossing the shoulder and elbow joints. Models of extant species were validated against empirical measures of ROM and MMA derived from ex vivo XROMM (X-ray reconstruction of moving morphology). Among extant species, our parasagittal taxon occupied a distinct region of pose-space, with more retracted and depressed shoulder joint angles. MMA data show increased emphasis on shoulder elevation associated with a parasagittal posture, but greater shoulder depression in sprawlers. Results from the fossil species show complex, non-linear patterns of forelimb transformation, demonstrating that the 'sprawling-parasagittal' transition is characterized by homoplasy and postural variation within the mammalian lineage.

Title: P2-17: Osteological Correlates of Carnivoran Masticatory Fascicle Lengths

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Previously, we found dietary correlates of masticatory muscle architecture in carnivorans, including across Canidae, Felidae, and Musteloidea. Namely, fascicle lengths (FLs; a correlate of gape) scale according to dietary size in certain lineages, while bite force proxies (muscle mass and physiological cross-sectional area; PCSA) scale with body size across the order. Although we
subsequently used these data to confirm osteological correlates of muscle mass and PCSA, until now, no one has confirmed osteological correlates of FLs in carnivorans – approaches that would, for instance, allow paleontologists to reconstruct gape abilities in extinct taxa. In this current study, we evaluated the correlation of origin to insertion as well as cranium only and mandible only osteological proxies with chemical dissection-based FL for this same sample

(Canidae n = 10, Felidae n = 11, Musteloidea n = 15, and 7 other carnivoran taxa). We found that 1) no osteological proxies correlated well with masticatory FLs across the order as a whole, which suggests that different carnivoran lineages have different architectural adaptations, 2) different osteological proxies correlate very closely with FLs in each lineage. Furthermore, 3) we found useful osteological correlates of FL not only from complete skulls, but also for crania and mandibles independently. This, in particular, will aid in the reconstruction of gape (a correlate of prey size) in partial fossil carnivoran specimens.

Title: 7-2: What's the point?: Morphology and function of claws in attachment in pad-bearing geckos

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Effective movement within an environment is essential for prey capture, predator avoidance, and mate acquisition. Morphology evolves to enable movement over the structural features comprising an animal's habitat. Claws are common to most vertebrates, and facilitate climbing in a range of different habitats. In addition to claws, geckos have evolved adhesive toepads that allow them to exploit various vertical and inverted habitats. The morphology and function of adhesive pads have received a lot of scientific attention in the last two decades, however, the evolution of claws in the context of toepads is less understood. We tested attachment capabilities of six Australian Diplodactylid geckos to determine the functional roles of both claws and adhesive toepads, and quantify and describe functional effects of morphology of these two components. We found that species with greater claw heights had improved performance on rougher substrates (i.e., substrates with greater surface microstructure peak-to-valley heights). Furthermore, claws were critical to attachment on vertical substrates, even in the presence of pads. Even though toe pads have evolved to aid attachment, claws still perform a critical functional role in attachment on natural substrates.

Title: 45-3: Relating olfactory behavior and nasal morphology in Southeast Asian primates

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Primates live in dynamic sensory environments that require them to use varying senses to translate external cues into behaviors. Their sense of smell enables them to navigate chemical cues produced by the environment, conspecifics, predators, and prey. Across the order Primates,

nasal geometry is known to vary in size and shape, largely attributed to regional climatic variation, but there is evidence that the nasal cavity may also be influenced by other factors. Here I explored the relationship between sensory morphology and sensory behavior. I predicted that the measures of nasal geometry (nasal index and nasal depth) would vary with sniffing behavior frequencies and that sniffing behavior would vary between social and ecological contexts. Using sensory behavioral data from semi-free ranging *Nycticebus* spp., *Nomascus* spp., and captive *Pygathrix* spp. I tested whether nasal geometry predicted sniffing frequencies in geographically overlapping primate species. Sniffing frequencies varied in social and ecological contexts across all three genera. Whereas the more gumivorous *Nycticebus* spp. had a higher frequency of sniffing in social contexts compared to the more frugivorous *Nomascus* spp. In comparing their nasal geometry, we found that their nasal depth was a better predictor of sniffing frequency compared to the nasal index. Our results highlight how morphological variations likely influences dietary and behavioral specializations.

Title: P3-7: Comparative Morphology of Olfactory Bulbs Mammals Different Ecological Groups

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The olfactory systems of representatives of different ecological groups of mammals differ in their levels of organization and play different roles in behavior. The olfactory bulbs (OB) are incredibly variable, reflecting the importance of the olfactory system in the ecology of the species. In this regard, we investigated typical and highly specialized representatives of the ranks Insectivora (*Talra europaea*, *Crocidura leucodon*, *Erinaceus europeus*), Chiroptera (*Nyctalus noctula*), Rodentia (*Myocastor coypus*, *Mus musculus*, *Spalax microphtalmus*), and Primates (*Tupaia glis*). The most primitive organization of the olfactory system is typical for common treeshrew, as evidenced by the least relative weight of the OB and its primitive histological structure. The OB of insectivores are the best developed for several reasons. However, the mole's OB are characterized by a lower-than-expected level of structure, which occurred as a result of the animal's transition to life in a more monotonous environment with a narrower spectrum of olfactory information. It is also interesting that the OB of the greater blind mole-rat, are better developed than those of the mole and other studied rodents. Nutria OB are relatively small, and the organization of their layers is the most primitive. In our opinion, such organization of the OB, is caused by the transition of animals to a semi-aquatic way of life, where the olfactory system plays a much smaller role in finding food.

Title: P2-6: Growing up sucks: modelling sucking and biting in human mandibles through development

Authors: Tahlia I. Pollock[1], Pranav Haravu[2], Alec Wilken[3], Andrea B. Taylor[4], Russell R. Reid[2], Callum F. Ross[2], Olga Panagiotopoulou[1]

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Paediatric lower jaw (mandible) congenital abnormalities have a significant and lasting impact on children's health due to airway, feeding, and potential speech and appearance-related concerns. However, we currently do not know the best methods (e.g., reducing healing time, long term patient outcomes) for repairing jaws and rehabilitating feeding. This is due, in large part, to our lack of understanding of how the healthy human jaw functions through development, where the jaw undergoes major morphological and structural changes accompanied by a transition from suckling to chewing modes of feeding. We also do not know how surgical treatment influences jaw growth and dental eruption. This project uses finite element models of normal, healthy human infants and toddlers at different ages and tooth eruption stages to test how growth constrains or directs bone mechanics. 3D jaw geometry, including crypts and teeth, was extracted from computed tomography (CT) scans to generate jaw models, to which muscle forces were applied simulating suckling and ipsilateral (left-side) biting. Our results show that loading and strain regimes are modulated by growth-related shape changes and structural differences, such as the presence or absence of crypts and mineralised teeth. These results provide novel insights into mandible biomechanics in humans in addition to providing fundamental baseline healthy control data for use in future studies on the treatment of congenital mandible abnormalities and application of surgical interventions.

Title: 18-3: Assessing the biomechanics of sabre teeth through the trade-off between puncture performance and breakage resistance

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"Sabre teeth" – elongate blade-like canines – have evolved repeatedly throughout mammalian history. However, the functional underpinnings of this reoccurring morphology remains unclear. To effectively bite into prey, all canine teeth must strike a balance between being slender enough to reduce puncture force, while being robust enough to resist breakage. We explored this trade-off in sabretooth canines by comparing these against teeth from living carnivores, integrating three-dimensional shape data with mechanical performance metrics within a functional optimality framework. Canine shape was captured via 3D geometric morphometrics in a sample representing 67 non-sabre and 20 sabretooth species. We then quantified two mechanical

performance metrics in a subset of teeth, applying finite element analysis to model tooth stress and undertaking physical puncture tests to quantify puncture force. These data were combined using a Pareto rank approach, constructing an adaptive landscape to assess optimality. Extreme sabretooth forms, like *Smilodon*, *Barbourofelis*, and *Thylacosmilus*, exhibit a combination of curvature and slenderness not found in our extant dataset, resulting in the highest stress values and lowest puncture forces of all teeth. Interestingly, these forms occupy a small peak of optimality in the adaptive landscape which is separated by a valley from another larger peak of straighter canines with varying robusticity. Our combined approach reveals new aspects of sabretooth biomechanics, providing fundamental insights into the adaptive bases for morphological diversity in pointed

Title: 32-3: Comparison of cranial development in echolocating and non-echolocating bats

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Most of bats have acquired laryngeal echolocation, a sophisticated biosonar system producing sound waves from their larynx to create acoustic images of their environment and detect their prey. The evolutionary origins of laryngeal echolocation and the implications of variation in cranial morphology on features of sound emission within the bat lineage are still debated. Cranial development, especially in prenatal stages, has been poorly studied to infer the formation and growth of key cranial features in bats although the diversification of craniofacial morphology occurs during the earlier stages. Here, craniofacial morphology and ossification timing were discussed and compared between three bat species *Cynopterus sphinx*, *Rhinolophus thomasi*, and *Pipistrellus abramus* representing the different bat lineages: pteropodids, rhinolophoids, and yangochiropterans, respectively. Pteropodids consist of bat species that are not able to generate echolocation pulse from their larynx whereas rhinolophoids and yangochiropterans are considered as laryngeally echolocating bats. 3D segmentation and modelling of cranial bones in these bat species were performed from diceCT and microCT scans of prenatal embryos. Volumetric measurements were undertaken, and landmarks were applied on 3D models to quantify the growth of cranial bones. Both *P. abramus* and *R. thomasi* possess an orofacial cleft and have a smaller orbit and shorter snout compared to *C. sphinx*. Cranial bones associated with echolocation, such as the petrosal, ossify earlier during the development in echolocating compared to non-echolocating bats.

Title: 12-1: How does the periodontal ligament support the rooting behavior of pigs, Sus scrofa?

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In pigs, *Sus scrofa,* the incisor teeth function in association with a disc-shaped snout to explore the environment for potential food. The mechanical stresses placed on the incisors have an important role in shaping the fibrous joint (tooth- periodontal ligament- bone complex, TPBC) that supports the tooth during function. The objective of this study is to assess how fiberoptic strain measurements within the PDL space of pig incisors differ *in vitro* versus *in vivo* and under different loading orientations. Fiberoptic sensors were place within the periodontal space of the central mandibular incisors of approximately 2-3 mo. old farm pigs. Fiberoptic strain measurements were made *in vitro* during incisor compression (N=19) with a materials testing machine (MTS/Sintech), whereas measurements of incisor tipping were made *in vitro* (N=6) and *in vivo* (N=6) with force calibrated springs. During compressive loading and incisor tipping fiberoptic strains recorded at comparable force levels overlapped in range (-10-19με). The results of this study suggest that fiberoptic strain recordings made *in vitro* within the periodontal space may be predictive of strain recordings made *in vivo*. The similarity of strains between orientations of applied load further suggests that the TPBC's of pig mandibular central incisors may be functionally adapted to multiple directions of load.

Title: 46-6: Early tetrapod lower jaw shape and performance across the water-land transition

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The colonization of the land by vertebrates was a key moment in the history of life marked by dramatic changes in skull morphology, including shifts in suture shape, the size and distribution of teeth, and inferred variations in jaw muscle arrangement. These changes are assumed to be associated with new feeding mechanisms and diets, and/or differing environmental constraints. We explore the anatomy and mechanics of fossil tetrapod lower jaws spanning the water-land transition – from the Late Devonian to Early Triassic – as well as those of select extant relatives and analogues. High-resolution CT scanning was used to capture lower jaw shape – including sutures – and damage and deformation were removed to produce three-dimensional models of the lower jaws of such iconic taxa as *Eusthenopteron, Acanthostega, Crassigyrinus* and others. Finite element analysis was applied to these models to test the mechanical response of the lower jaws to simplified feeding loads. Results suggest complex shifts in the relative strength of the lower jaw through the lineage. Basal taxa exhibited high stress on the biting side of the lower jaw, whereas the highest stresses occurred on the balancing side of more derived taxa, potentially linked to changes in symphyseal morphology, which permitted greater force transfer from balancing side jaw muscles to the bite point.

Title: 49-4: Regional mechanical properties of mineralized cartilage from shark vertebrae

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Elasmobranch (sharks, skates, and rays) vertebrae are composed of highly mineralized cartilage and experience bending forces resulting from swimming undulations. In swimming sharks, a double oscillating wavelength was documented, where the amplitude and frequency of the head yaw are different from the tailbeat. Those findings suggest that forces in the anterior body may differ from the posterior body. We quantified the comparative mechanical properties of vertebrae regionally (anterior, middle, and posterior) of 13 species (three orders). We hypothesized that the posterior vertebrae would be the stiffest and toughest across all species to facilitate swimming. We examined compressive mechanical properties, among body regions and species, at biologically relevant strains. We calculated stiffness (MPa, resistance to compression and deformation) and toughness (MPa, ability to absorb energy) from stress-strain curves. We found that stiffness significantly varied among regions and orders. The stiffest vertebrae are found in the anterior and middle regions of the Orectilobiformes, while the least stiff vertebrae are found in all regions of the Lamniformes. Order was the only significant effect when examining toughness; Carcharhiniformes vertebrae were the toughest and Lamniformes were the least tough. These data suggest that the stiffest vertebrae were in the middle region, and the anterior and posterior regions were similar. This work was supported by the United States National Science Foundation (IOS award 194713).

Title: 5-4: Characterization of the muscle architecture of the zebrafish palatal organ and pharyngeal jaw

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Zebrafish, used as a popular model system for studying conserved vertebrate morphogenesis, are also exceptional for examining the origin of trophic novelty. The palatal organ, a muscular pad found along the roof of the pharynx, is composed of an entangled mesh of fibers of varying diameters and lengths. While the function of this structure is unknown in zebrafish, in goldfish contractions of these muscles form protrusions that assist with food selection. Muscle fiber orientation within the palatal organ is strikingly different from parallel-fibered skeletal muscle found elsewhere in the body. Although likely derived from the same progenitor population, pharyngeal jaw and palatal musculature is very different. Preliminary data collected using a new type of transmission electron microscopy (which facilitates examining a broader region of interest) suggest that the palatal organ has an entirely unique ultrastructure, yet to be fully described. Two types of muscle fibers have been previously distinguished where the presence of triads is at either the Z-lines or A-I bands, resembling cardiac or skeletal muscle respectively. Indeed, the single nuclei that characterize these muscle fibers are most like smooth and cardiac

muscle, while the thinnest fibers most closely resemble extraocular muscles. Here, we present a multi-level characterization of muscle ultrastructure of the novel palatal organ, where characteristics of all three basic types of vertebrate muscle appear in this single muscle type.

Title: P10: Integration of the oral and pharyngeal jaws of suckers (Cypriniformes: Catostomidae)

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The functional decoupling of once integrated structures is a known mechanism of diversification. In fishes, one example of this is the two jaw system that released the oral jaws from the demands of prey capture *and* processing through the evolution of pharyngeal jaws. This morphological independence between jaws has been hypothesized to play an important role in the famed diversification of cichlids as the oral and pharyngeal jaws may evolve more independently and thus become more specialized for prey capture and processing, respectively. However, recent examinations of this hypothesis have uncovered more integration between cichlid pharyngeal and oral jaws than previously thought. Specifically, when diet is accounted for, the trajectories of morphological evolution of oral and pharyngeal jaws are similar. Here, we explore Catostomidae (Cypriniformes), a benthivorous family with diverse pharyngeal jaw anatomy, edentulous oral jaws, and similar diets across the family. Because there is not a wide breadth of dietary specialists, Catostomidae is an excellent group for studying the integration of the jaws without the influence of varying trophic demands. Further, catostomids, like most cypriniforms, have lost the upper pharyngeal jaw and stomach which makes the pharyngeal jaws extremely important as they are the only site of processing in this group. Using 3D geometric morphometrics, we quantify integration among the oral and pharyngeal jaws as well as examine correlations between the jaws and diet.

Title: 35-3: Body Shape and Bold Colour Pattern Evolution across Reef-Associated Fishes

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Reef fish communities are renowned for their vibrant colour patterns and remarkable body shape variation. We explored the evolution of these two important dimensions of reef fish diversity and the potential linkages between them, as the effectiveness of contrasting colour patterns for intraspecific communication and avoiding predation may be influenced by body shape and size. Body shape was quantified using 8 length, depth, and width measurements of 16000+ museum specimens and lateral photographs of the same specimens were scored for 14 contrasting colour pattern elements, to build a dataset on over 5000 teleost species. To investigate the tempo of pattern evolution, the co-occurrence of pattern elements, and their habitat associations we used

Hidden-Rate Markov Models. The relationships between shape and pattern were quantified using phylogenetic ANOVAs. Our analyses reveal that most pattern types, except single horizontal stripes, are more common in reef-associated lineages, which is consistent with the prediction that disruptive colouration will evolve in more complex habitats. Plus, possession of one or more vertical bars is associated with deeper bodies, a trend that is not solely driven by reef fishes, which are on average deeper bodied and more patterned than other marine teleosts. Overall, our results are consistent with expectations based on hypothesized anti-predator functions of bold colour patterns. Support for this work was provided by the National Science Foundation DEB 1556953/1830127.

Title: 17-6: Intraspecific variation in trabecular bone in metapodials – a case-study in kangaroos

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Trabecular bone is essential in dispersing forces within and through bones, and the orientation and size of the trabeculae reflect the direction and magnitude of forces regularly applied to them. As a result, trabecular bone can reflect aspects of ecology, such as locomotor strategy and habitat, as well as body mass and habitual posture. While numerous studies document differences in trabecular bone patterns between species or taxonomic groups, few studies have investigated variation within species. Previous research has established that body mass can influence trabecular bone structure, but there is limited information on the effects of other factors such as sexual dimorphism and age. This study seeks to quantify intraspecific variation in trabecular bone by utilising AI techniques on micro-CT scans of metapodials in a large sample of western grey kangaroo (*Macropus fuliginosus*). A clustering algorithm will be used to identify subgroups within a species and then correlated with known intraspecific factors such as sex and body mass. The findings of this study and the AI generated have the potential to enhance our understanding of intraspecific variation in trabecular bone structure and can serve as a foundation and tool for later studies in paleoecology.

Title: 7-3: Morphological disparity and functional adaption of Mesozoic birds manual claws

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Birds evolved from maniraptoran (meaning ‘hand snatchers’) dinosaurs, but almost all living birds have lost their foreclaws with very few exceptions, while most Mesozoic birds had distinct foreclaws, suggesting functional differences. The foreclaws degradation in birds occurred after

the appearance of asymmetric feathers and wings, irrelevant to the evolution of flight. But why did stem birds retain their manual claws, and what was their functional role, if any? Here we apply the methodology of Deakin et al. (2022) to quantitatively generate theoretical morphologies and estimate functional performance and optimal trade-offs of 274 manual claw shapes from 130 published species from Maniraptora. We use finite element analyses (FEA) to simulate von Mises stress (VMS) distribution and deformations when claws piercing, vertical-climbing, and branches-hooking, and calculate mechanical advantages (MA) and radiational efficiency (RE). We use the Pareto trade-offs between piercing VMS, MA and RE to evaluate the function of grasping, and trade-offs between VMS of vertical-climbing and branches-hooking, and MA to estimate the functional performance in tree climbing. We then exhibit these functional traits' evolution on the latest phylogenetic frameworks. Our research reveals multi-origins of tree-climbing in Maniraptora and a late appearance of arboreal crown birds. We also revealed the two major clades of Ornithothoraces (Enantiornithes and Euornithes) have markedly different climbing abilities, exhibiting clear ecological niche divergence, and explaining why only Euornithes underwent the pronounced degradation process.

Title: 45-6: Hair, there and everywhere: a comparison of bat wing sensory hair distribution

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Bats possess highly compliant wing membranes that deform during flight. Deformations arise from
passive interactions with surrounding air and from joint motions and active contractions of intramembranous muscles. Bat flight motor control would benefit from inputs to the CNS about magnitudes and rates of deformation, and their variation across the wing, but typical mammalian proprioception cannot perform this function. However, bat wings are covered in sensory hairs connected at their bases to Merkel cells, slow-adapting somatosensory receptors. The sensory hair/dome complexes appear to be sensitive to air flow, and may additionally sense localized strains. In
this study, we quantify density and anatomical distribution of sensors from whole-wing maps of hairs,
assembled from multiple fluorescence micrographs (17 species, 12 chiropteran families). We find
sensory hairs in abundance along the intramembranous muscles, the bones of the digits, and collagen-
elastin bands. We observe multiple hair-dome clusters and strip-like clusters oriented in parallel with
wing structures in some species, and overall we find sensory hair density is higher proximally than
distally. Our more detailed qualitative/quantitative description of the wing sensory hair network in

diverse bat species underscores its highly patterned but interspecifically-varying nature. These results
suggest that continued comparative and functional studies of this distinctive sensory array could change
knowledge of the nature of flight-based proprioception in the least understood lineage of extant flyers.

Title: 42-2: Development of dolphin sensory systems

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Toothed whales (odontocetes) have evolved the novel sensory adaptation of underwater echolocation, which involves locating objects and surroundings by producing and hearing reflected sound. The evolution of echolocation required intense modification of facial anatomy and formation of specialized sound production structures in the head, as well as restructuring of the brain to accommodate the processing of sound. The structure of the dolphin brain is directly linked to integral aspects of cetacean behavior and sensory adaptations, yet our understanding of prenatal brain development in the group has until now been limited to histological sections and extrapolations of the 3D shape of the brain from this material. Using reversible iodine staining methods in computed tomography (μCT) to accurately obtain volumetric, surface area, and linear measurements I quantitatively describe the development of the brains of Pantropical spotted dolphin (*Stenella attenuata*) specimens. In the first (estimated) 32–42 days of development the brain appears similar to other developing mammalian brains. Upon reaching 41–52 days, precursor olfactory bulbs appear, but by 62–78 days they are resorbed. By 62–78 days the cerebrum approaches the 'boxing glove' shape typical of adult dolphin brains. Right-oriented torsion of the temporal lobes of the cerebrum occurs as early as 32–42 days, with the right temporal lobe flattening laterally. Discovering the timing of development of important brain shape changes is integral for understanding the origins and drivers of underwater echolocation in dolphins.

Title: 53-7: Character coding for soft tissue structures, exemplified for reptile myology

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In phylogenetics, the formulation of characters can be understood as a way to abstract into tokens the complex empirical observations obtained from comparative anatomy. A character statement can be considered a set of observations (character states) that convey a function of change (evolutionary history); thus, a character statement is similar to a topological space, a mathematical concept where the elements are related to each other in a way that cannot be measured numerically. A topological approach to delineate characters goes beyond the

traditional discussion of additive or multistate coding and assesses each character statement based on its properties. In this work, we use the notions of topological space to assess how myologic structures can be described as character statements. Traditionally, myologic structures were difficult to transform into a character, given their complex interactions between the bones and the tendons and the anatomical and developmental plasticity of soft tissue, in general. For extant taxa, we used the jaw muscles of turtles because vast anatomical data are available and well-resolved phylogenetic relationships exist based on molecular data to compare the different coding techniques and their performances. For extinct taxa, we use reconstructions of limb myology for sauropodomorphs. The different coding strategies (additive coding, multistate coding, topological coding) were then assessed in their resolution.

Title: 32-2: Vocal learning, chorusing seal pups and the evolution of rhythm

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The presence of vocal learning and rhythm capacities in only a few mammals drives a cross-species hypothesis in evolutionary neuroscience: vocal learning and rhythm perception and synchronization may be causally related. Harbor seals (*Phoca vitulina*) are among these mammals, and their puppyhood is the most active vocal period in their lives. Building on multiple disciplines, this research integrates approaches from bioacoustics, speech sciences, comparative psychology, and animal behavior with attention to species' ecological sensory niches. We present data from seal pups in multiple setups: recordings of semi-natural vocal interactions in 1) individual and 2) group settings, 3) playback experiments to elicit vocal responses, 4) perceptual listening experiments to measure behavioral responses, and 5) vocal tract and brain anatomy. We complement empirical data with agent-based computational modeling aimed at reverse-engineering the putative mechanisms underlying vocal interactions. Our data suggest that seal pups have developed capacities for vocal plasticity and learning, possibly achieved via fine neural control of lungs and vocal tract. Complementarily, we show that seals can produce and perceive rhythmic patterns: their vocal exchanges show rhythmic interactivity and antisynchronous coordination. Evidence for vocal plasticity and antisynchrony, rather than synchrony, in seals suggests that the rhythm-vocal learning link across species is more complex than previously surmised.

Title: 43-7: 3D anatomy of the craniomandibular joint of derived South American cynodonts and homoplasy in the evolution of the mammalian jaw

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Previous research has described morphological changes to the jaw and postdentary bones across the cynodont/mammaliaform transition concerning the formation of the mammalian dentary-squamosal jaw joint. However, more recently discovered non-mammaliaform probainognathian cynodonts from South America have thus far not been wholly integrated into comparative anatomical studies, despite being represented by numerous specimens, including ontogenetic series. In this study, micro-CT data from twelve cynodont species, including nine specimens of *Brasilodon quadrangularis*, the sister taxon to mammaliaforms, and ten specimens of the tritheledontid *Riograndia guaibensis*, were segmented to produce 3D descriptions of the jaw articulations of these taxa, many for the first time. Hitherto unknown morphology visible in our scans overturns previous descriptions of jaw joint anatomy and demonstrates homoplasy in the approach to mammaliaforms, similar to that seen in the independent acquisition of the definitive mammalian jaw joint and middle ear in Mesozoic mammals. *Brasilodon,* contrary to previous interpretations, lacks a clear squamosal-dentary articulation and instead relies solely on a quadrate-articular joint, while *Riograndia* possesses a developed squamosal-dentary contact to reinforce the already robust primary jaw joint. We find that jaw joint evolution accelerates crownwards in cynodonts, beginning with the acquisition of a secondary jaw joint in eucynodonts and followed by a notable increase in morphological experimentation in derived probainognathians, that occurred alongside the evolution of other key mammalian features.

Title: 16-3: Is the braincase a headbutting stabilizer?

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Muskoxen (*Ovibos moschatus)* are tundra-dwelling bovids that headbutt at high velocity dozens of times per year. Their large horn bases are thought to protect their brain against trauma from such impacts to a certain extent, although instances of traumatic brain injury have been recorded in both male and female muskoxen. We seek to understand whether the braincase also evolved additional protection alongside the thick skull and horns under the pressures of natural selection.

Various animal species display grooves on the inner surface of the braincase in alignment with the gyri of the brain. These digital impressions are particularly marked in headbutting bovids. We sought to quantify whether there was a relationship between animals with more numerous and marked digital impressions and those participating in frequent headbutting behavior. To do

so, we established a simple “roughness index” using images of bisected skulls from a wide range of species. Both experienced and novice users scored headbutting animals as having a higher roughness index than non-headbutting animals, with a few exceptions. These results indicate that these animals may have evolved protections against headbutting on both the interior and exterior of their skulls in the form of a close-fitting, supportive braincase, to aid in shock absorption.

Title: P1-15: Comparative 3D myology of the koala (Phascolarctos cinereus) and common wombat (Vombatus ursinus) forelimb

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Establishing relationships between bones and soft tissues in living species can inform our understanding of functional adaptations in their extinct kin in the absence of direct data on habitual behaviours. The koala and wombats are the only surviving species of the vombatiform suborder, and represent the extant phylogenetic bracket for dozens of fossil marsupial species across 9 families. Here we present the first quantitative architectural data on the forelimb myology of the koala and common wombat, alongside interactive 3D muscle topologies and muscle maps based on physical and digital dissections. Despite obvious contrasts in how their forelimbs are used in arboreal (koala) and fossorial (wombat) functional contexts, overall they showed only minor differences in qualitative and quantitative measures of myology. When the architectural properties of antagonistic pairs of muscle groups crossing each joint were compared, the greatest contrasts were seen in muscles crossing the elbow, where wombats show greater relative emphasis on forceful elbow extension than the koala, indicative of digging adaptations. Our findings reinforce the importance of the elbow as a useful system to explore when seeking discrimination between habitual patterns of forelimb use in extinct vombatiform species.

Title: 33-10: The role of spine motion in vertical jumping performance of the common degu (Octodon degus, Rodentia).

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Jumping is one of the most common modes of locomotion in mammals. Some species developed special adaptations to maximum performance, but many others perform well without morphological specializations. Like many rodents, degus have a wide range of locomotor modes, and we aim to understand how they do achieve a good performance by adjusting body kinematics and kinetics. Animals were trained to voluntarily jump onto platforms (3x to 6x

shoulder height). Body motion was captured using X-ray fluoroscopy. Ground reaction forces of the four limbs during approach and takeoff were measured.

Here, we present our results about spine kinematics, its temporal coordination with the limbs and the role of elastic energy saving. Morphological data were captured from MRT- and μCT-scans to visualize muscle volumes, the location and dimension of fascia and tendon sheets and the skeletal morphology. Degus increase their jumping performance by increasing takeoff velocity and the peak vertical forces exerted by the hindlimbs. While the animals show moderate random variation in limb forces, contact times and the synchronization of the hindlimbs, they adjusted accurately the posture of the hindlimbs, the pelvis and the spine in preparing takeoff. The observed kinematics appear to optimize the amount of elastic energy saved in the thoracolumbar fascia and the limb tendons.

Title: P2-11: Evolution of phalangeal morphology in an ecomorphological gecko radiation with incipiently expressed adhesive toepads

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Adhesive toepads, complex morphological structures enableing animals to exhibit astonishing climbing abilities, have evolved multiple times in geckos. Although well studied in a few exemplar clades in terms of function and morphology, their evolution is poorly understood, in part due to the scarcity of studies on incipiently developed toepad morphologies. One lineage within which incipient toepads has been suggested to have arisen is the genus *Cyrtodactylus* (bent-toed geckos), an ecologically diverse radiation, whose climbing members possess enlarged subdigital scales. Previously the limited data available suggested that some members of the clade could be arranged in morphotypic series showing gradual changes in digit osteology from padless to pad bearing forms. With the phylogeny of the genus now much better resolved and knowledge about their microhabitat use greatly enhanced, we are now able to conduct a phylogenetically informed investigation of digit osteology using microCT data and applying 3d geometric morphometrics. We explored whether, and if so how, repeated gradual changes in digit osteology have occurred in scansorial species and whether such modifications differ depending on the locomotor substrate (e.g., arboreal vs. saxicolous species). We found that distinct morphological changes have arisen repeatedly in scansorial species descending from generalist ancestors. These adaptations are substrate specific for at least some of the phalanges, differing between arboreal and saxicolous species, although there were differential degrees of overlap in other phalanges.

Title: 3-2: Biomechanical insights into (para)symphyseal fracture fixation

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Treatment of lower jaw (mandible) trauma in the (para)symphyseal region is an important topic in maxillofacial surgery. To date biomechanical analyses and clinical studies have failed to clarify whether two-miniplate or lag screw fixation is the best technique for surgical repair. The two miniplate approach is surgically simpler but it involves a higher incidence of postoperative complications due to infections or plate protrusion. The lag screw approach carries less postoperative complications, yet it is technically challenging and any deviations from the surgical protocol can compromise recovery. While some ex vivo loading studies have shown that two-miniplate fixation is biomechanically more stable, others have shown the reverse. Thus, we do not know which treatment modality for the (para)symphysis better recovers natural jaw mechanics during feeding, a prerequisite for rapid fracture healing. Here we present the first study to use realistically loaded finite element models of the human jaw pre- and post-fracture and fixation to study the biomechanical implications of the two fixation modalities on feeding behaviour. Our results show that the miniplate osteosynthesis is associated with greater deviations from strain regimes and moments in the healthy control. Our results support lag screw osteosynthesis as the preferred fixation modality for (para)symphyseal fracture repair. The amalgamation of future biomechanical experiments, in vivo work and histological research will provide greater clarity on the influence of fixation technique on fealing success.

Title: 42-1: Development and morphofunction of the malleus in muroid rodents

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The three mammalian auditory ossicles (malleus, incus, stapes) serve as enhancers of sound transmission from the tympanum to the inner ear and can be functionally classified based on, e.g., the grade of rostral anchoring to the ectotympanic. The anterior process of the malleus can show a medial outgrowth, the processus internus praearticularis (PIPA), that serves as such an anterior anchor as recently described in lagomorphs and artiodactyls. Here we present a case study on the development and morphofunction of the malleus and PIPA in muroid rodents. The study is based on histological serial sections of perinatal stages of *Mesocricetus auratus* and µCT scans of adult stages of *Mesocricetus auratus*, *Cricetus cricetus*, *Peromyscus maniculatus* and *Mus musculus*. The formation of the malleus by fusion of praearticulare and mallear main body

becomes evident in early postnatal stages of *Mesocricetus*. In all species the PIPA forms a broad lamina fused anteriorly to the ectotympanic. *Peromyscus* and *Mus* show a distinct orbicular apophysis that increases inertia of the malleus and thus these species represent the microtype of auditory ossicles. In contrast, the Cricetinae have a malleus whose center of mass is close to the anatomical axis of rotation and thus show the transitional type. The microtype belongs to the grundplan of Muroidea and is plesiomorphic for Cricetidae, whereas the transitional type represents an apomorphic feature of Cricetinae.

Title: P3-1: Turbinal skeleton of Myocastor coypus (Rodentia, Mammalia)

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The mammalian nasal cavity houses a unique labyrinth of bony lamellae and scrolls, the turbinal skeleton. While the anterior turbinals (maxilloturbinal, nasoturbinal) are covered by respiratory epithelium, the turbinals of the lateral and posterior compartments of the nasal cavity (frontoturbinals, ethmoturbinals, interturbinals) are part of the olfactory system. Although the ontogeny, comparative anatomy and morphofunction of the turbinal skeleton has been studied in many rodent species clade-specific patterns are still discussed. Based on µCT scans of perinatal, juvenile and adult skulls we studied the ontogeny and comparative anatomy of the turbinal skeleton in *Myocastor coypus*; further echimyid species (*Proechimys* spp, *Callistomys pictus*) are used for comparison. *Myocastor* shows, beside a well-developed maxilloturbinal and nasoturbinal, three ethmoturbinals and one interturbinal between ethmoturbinal I and II. This pattern is also observed in the other studied species. However, *Myocastor* is unique among rodents in lacking any turbinal structures in the well-developed frontoturbinal recess. In contrast, *Proechimys* and *Callistomys* reveal one frontoturbinal and one interturbinal in this compartment. *Myocastor* also differs from the other echimyids by showing an additional respiratory turbinal, that runs lateral to the maxilloturbinal along the nasal bone. According to previous studies on the perinatal ontogeny of the turbinal skeleton in caviomorph rodents (including *Myocastor*), this additional turbinal can develop as a separate cartilaginous structure and may represent a common feature within this rodent clade.

Title: 46-8: Hear far, wherever you are: the evolution of amphibious hearing in seals

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The mammalian ear, a complex anatomical structure adapted to detect airborne sounds, is ineffective underwater due to a reliance on air-filled cavities. However, experimental evidence suggests pinnipeds (seals) can uniquely hear both underwater and airborne sounds effectively. This is due to a cavernous sinus in the middle ear which engorges with blood, enabling sound transmission by matching the density of water. Little is known about the anatomy of this sinus, so the evolution of amphibious hearing in seals has remained cryptic. Here we present the first anatomical data for the cavernous sinus in pinniped ears, and outline osteological correlates that can be used to identify its presence in extinct fossil taxa. To investigate when amphibious hearing evolved in pinnipeds, we collected wet-data from museum specimens (frozen and fluid preserved), and micro-CT scanned the basicrania of 46 pinniped species (both extant and extinct) and 20 terrestrial arctoid outgroup taxa. Using a combination of phylogenetic comparative methods and 3D geometric morphometrics, we document how the middle ear cavity and the inner ear (cochlea) evolved with the presence of this sinus, and therefore outline how amphibious hearing evolved during the land-to-water transition. Our results suggest that amphibious hearing emerged early in pinniped evolution. Also, Phocidae (true seals) possess substantial morphological variation linked to the cavernous sinus. This suggests diverse amphibious hearing capabilities are present in extant and extinct seals.

Title: 52-2: How does the pancreas of lizards develop? Lessons from the brown anole Anolis sagrei (Squamata: Iguania)

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The pancreatic gland in many vertebrates develops from three buds: two ventral and one dorsal. One lizard ventral bud extends toward the gall bladder; the second is near the gut. The dorsal bud extends toward the spleen. Differentiation of the pancreas in lizards is poorly known. Thus, this study focused on the pancreatic differentiation in the brown anole (*Anolis sagrei*) representing the clade Iguania. Embryonic tissues were analyzed using light microscopy, and 3D reconstructions were performed. The results showed that in the brown anole embryos, pancreas anlage was present from egg laying as small ducts and large cell agglomerate. The gall bladder was located close to the pancreas. During development, the splenic limb, which corresponds to the dorsal bud, developed more quickly than the others. Initially, it formed a thick process that followed the spleen anlage. In the later stages, the splenic limb was connected with the pancreas body only by the delicate process and was ended by a thick bulbous thickening. This type of splenic lobe is considered typical for lizard species. Pancreatic islets were limited mainly to this

thickening. At the end of embryonic development, the anterior limb of the pancreas reaches the gall bladder, which is different than in the pancreas of other studied lizard species. The study was supported by NCN grant (OPUS) - 2019/35/B/NZ4/00905.

Title: P3-11: Lung differentiation in the brown anole Anolis sagrei (Squamata: Iguania) embryos

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During lung morphogenesis in vertebrates, the smooth muscles play an essential role in shaping their developing epithelium. The lung wall in adult lizards is formed by specific structures called trabeculae which have a core formed by smooth muscles lined by the epithelium. Trabeculae include individual faveoli being gas exchange chambers. The muscle present in the wall of the lizard lungs maintains the lung structure. Lung differentiation in lizards is poorly known, so this work aimed to study the differentiation of the lung structure in the brown anole (*Anolis sagrei*) from egg laying to hatching. In addition, 3D reconstructions of developing lungs were made with a particular focus on the arrangement of trabeculae at the following developmental stages. Near the egg laying time, the brown anole's lungs were present as two sac-like structures lined by cylindrical epithelium. At this time, the left lung was slightly longer than the right one. During development, the lungs became large and folded; initially, the left lung was wider than the right one. At stage 12, in the walls of the lungs, trabeculae with smooth muscle cores were present for the first time. Just before the hatching of young lizards, trabeculae formed a distinct pattern, and both lungs ended at the same level.

Title: 30-6: Developmental mechanisms facilitating molar shape diversification in bats

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Teeth are serial structures that have evolved a dramatic diversity of shape during their adaptation to various diets. Despite this diversity, teeth have been shown to develop from well-conserved genomic and developmental modules. To investigate this paradox, we use the highly diverse Noctilionoid bat molars as a model system. In tandem with the colonization of various ecological niches, this group of bats have evolved all possible mammalians diets (i.e. insects, fruits, nectar, pollen, small vertebrates, and even blood) resulting in an incredible diversity of molar shape. To investigate the genomic and developmental mechanisms driving these differences, we combined

genomic, developmental, morphological and computational data in multiple species. Using a geometric morphometric approach on the first lower molar of 125 species of Noctilionoids, we identified the main axes of variation of the Noctilionoid first lower molar. We then performed a RNAseq analysis of developing molars in three species at four developmental stages followed by ISH of specific genes. We correlated changes in gene expression with morphological variation and established shape-specific and species-specific genomic and developmental signatures. Together, our results show that the rapid evolution of tooth shape can be explain both by the conserved and variable genomic and developmental modules that control tooth development, and potentially other ectodermal appendages.

Title: 33-9: Shape diversification of spine in bony fish by adaptation to mechanical forces

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The spine supports the body of vertebrates by withstanding mechanical forces such as gravity and muscle tension. In bone formation, cell activity depends on mechanical forces. Therefore, we aim to understand the relationship between the shape of fish vertebrae, which compose the spine, and the mechanical forces. Fish vertebrae exhibit different lateral structures among the species. Because our comparative observation suggested that this difference related to swimming styles, we hypothesized that mechanical forces determined fish vertebrae shape. To test this hypothesis, we built a mathematical model. In this model, high stress promotes bone synthesis, whereas low stress activates bone absorption. We adjusted the load condition and generated multiple structural features similar to fish vertebrae. By applying the lateral bending of the body, we reproduced thick ridges of migratory fish vertebrae. To confirm the computer simulation, we observed the growth of the vertebrae using micro-CT and histology. We observed that bone synthesis occurred on the edges of the lateral ridges, while bone resorption occurred in the internal hollows. The formation process was similar to the computer simulation. Furthermore, bone volume fraction decreased, and the internal hollows extended during the growth. By combining these results, we concluded that mechanical forces determined the distribution of bone-forming cells to form the lateral structures. Fish vertebrae adapt their shape to withstand external forces using a limited amount of bone.

Title: 17-3: Early evolution of trabecular-bone resistance to terrestrial constraints in a fossil lobe-finned fish

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The water-to-land transition is a major event in the evolutionary history of tetrapods. Although most studies focus on morphological limb adaptations, a few investigations were led to understand the compactness changes and orientation of the trabecular mesh in fossil limb skeletons over the water-to-land transition. The data revealed that early tetrapods from the Devonian and Carboniferous (360-300 Mya) had a very extended trabecular mesh surrounded by a thin cortical compact bone. Based on principles of comparative anatomy from extant taxa, they suggested that the limb bone microarchitecture of these tetrapods was probably too weak to allow walking on land, thereby implying that many Carboniferous tetrapods, even if morphologically adapted to a terrestrial lifestyle, were probably still greatly (if not fully) aquatic. We have conducted a Finite Element Analysis on synchrotron images of the fin humerus of the Devonian lobe-finned fish *Eusthenopteron* whose trabecular architecture is exceptionally 3D preserved and similar to that of early-tetrapods. This FEA study permitted to test the resistance of the trabecular bone to actual terrestrial constraints. Based on the model of the fin biomechanics from extant analogous ray-finned fishes, our results show that the longitudinality of the trabecular mesh largely absorbs the stress imposed by the weight of the animal to resist weight bearing. This pilot analysis will be conducted on several 3D-preserved early-tetrapod limb bones to elucidate the water-to-land transition.

Title: P4-11: Parallel evolution of trabecular bone and bone marrow haematopoiesis

Authors: Sophie Sanchez[1], Jordi Estefa[1], Luke Brosnan[2], Paul Tafforeau[3], Sifra Bijl[1], Emma Hammarlund[4], Alice Clement[5], Jozef Klembara[6], Grzegorz Niedzwiedzki[6], Camille Berruyer[6], Stephen Poropat[2], William Rickard[7], Auraya Manaprasertsak[4], Kliti Grice[2]

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The appearance of the limb is a crucial event in tetrapod evolution. Transforming a fin to a limb profoundly affects the trabecular architecture. Very few studies have been conducted to investigate these changes. Long-bone function evolved from a purely locomotory architectural role to new functionalities such as hosting the production of blood cells (called haematopoiesis) in the bone marrow. This resulted in piercing the trabecular mesh to form a marrow cavity hosting a centralized vascular system. Haematopoiesis takes place in the liver and kidney in most aquatic vertebrates but migrated into the limb bones in terrestrial tetrapods. When did this major evolutionary step happen? A recent hypothesis suggested that the migration of haematopoiesis

occurred over the water-to-land transition to prevent UV damage on haematopoietic stem cells. Using high-resolution synchrotron phase-contrast imaging, we have conducted a thorough investigation into the three-dimensional trabecular bone of (stem) tetrapods from the Devonian to the Triassic (380-215 Mya). Our results on trabecular bone contradict this hypothesis and bring indirect evidence for multiple haematopoiesis migration events in long bones later, after the water-to-land transition. This might have been result of the increasing demand for oxygenation with advanced locomotory terrestrial activity. New data from biomarkers will bring direct evidence on the earliest occurrence of red bone marrow and help us characterize the origin of bone-marrow haematopoiesis (see Brosnan et al., these proceedings).

Title: 45-8: Predicting Ecology and Hearing Sensitives in Parapontoporia

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Analyses of the cetacean (whale and dolphin) inner ear provide glimpses into the ecology and evolution of extinct and extant groups. The paleoecology of the odontocete (toothed whale) group, *Parapontoporia,* is primarily marine with depositional context also suggesting freshwater tolerance. As an extinct relative of the exclusively riverine *Lipotes vexillifer, Parapontoporia* provides insight into a transition from marine to freshwater environments. High-resolution X-ray CT scans (~3 microns or less) of three individual specimens from two species, *P. sternbergi* and *P. pacifica*, were acquired. Digital endocasts of the inner ear labyrinths were extracted non-destructively using the software VGStudioMax v. 3.5.2. Nine measurements of the cochlea including secondary bony lamina length, semicircular canal length, height, width, and fenestra cochleae surface area were added to an existing dataset covering 103 terrestrial and aquatic artiodactyls. These measurements were then subjected to a Principal Component Analysis (PCA) to interpret hearing sensitivities among other artiodactyls. From an analysis of the specimens, *Parapontoporia* was not likely to have been a narrow-band high frequency (NBHF) echolocator, and differences in cochlear length demonstrate intraspecific and interspecific variation. The semicircular canals were measured for comparison with previous work, highlighting a longer lateral canal, as expected compared with other odontocetes. Studying the inner ear of *Parapontoporia* will help inform on the 'river dolphin' transitions from marine to riverine environments.

Title: Uncovering the mechanisms of bat diversification through integrative morphology research

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A central theme in evolutionary morphology is to understand how intrinsic and extrinsic factors interact to generate diversity in form and function, a task that greatly benefits from examining

taxonomically diverse groups that have adaptively radiated. With over 1400 extant species, bats (Chiroptera) represent over 20% of all mammals and exhibit an outstanding morphological diversity that is tightly linked to their varied ecologies. In particular, bat craniodental morphologies have radiated extensively in tandem with sensory and dietary diversification, spanning morphological extremes not observed in most mammal groups. Yet, since this morphological diversity has evolved within relatively conserved mammalian developmental pathways and anatomical templates, bats constitute an ideal system to help us understand the drivers of mammalian craniodental evolution. In this talk, I will present major areas of research my lab is exploring to uncover the patterns and underlying mechanisms of bat morphological diversity. This research program integrates three major approaches: (1) documenting the macroevolutionary patterns of complex morphological traits, (2) experimentally testing how differences in morphological traits translate into differences in performance and ecology, and (3) quantitatively linking these patterns and mechanisms to the process of species diversification. I will present case studies applying this framework, which have helped us elucidate how the modification of intrinsic mechanisms and functional adaptation have together shaped the evolution of bat craniodental diversity.

Title: 14-4: X-ray motion analysis reveals 3D kinematics in the forelimb of balancing tamanduas (Tamandua tetradactyla)

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During arboreal locomotion mammals typically adjust three factors to maintain stability on challenging supports, compared to locomotion on the ground: speed, hand posture, and gait. During ground locomotion, tamanduas walk on the lateral side of their (supinated) hand. The characteristically laterally held elbow is applied in tamanduas unique ‘hook-and-pull digging’ for increased leverage. Here, we investigated how tamanduas salient forelimb posture affects forelimb kinematics during arboreal locomotion.

Each of the three parameters mentioned above is adjusted when balancing on horizontal and obliquely oriented branches (+45° and -45°). Tamanduas decrease speed, pronate the hand, and increase diagonality, providing further evidence for high diagonality in arboreal species, likely maximising stability.

Additionally, we applied a marker-less variant of XROMM to investigate adjustments in 3D kinematics of the pectoral girdle and forelimbs, comparing horizontal balancing to ground locomotion. When balancing, the elbow is more flexed and scapula, ulna, and radius are more adducted, placing the hands closer to the medial body plane. The radius shows an increased

inward rotation around its long axis, which pronates the hand during balancing. Yaw of C7 is substantial but does not differ between ground locomotion and balancing.

This study describes underlying 3D kinematics in the forelimb which facilitate posture and locomotor adjustments during balancing in tamanduas. We found a mosaic pattern of uncommon and common locomotor adjustments compared to other (semi-)arboreal mammals.

Title: 38-1:Dermal ossifications in extinct tetrapods and their bearing on phylogenetics, function, and palaeoecology

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Dermal ossifications are commonly found in the integument of vertebrates, both extant and extinct. The study of osteoderms in extant animals allows to assess their functions, often going beyond a purely defensive one, and the ecology of the osteoderm-bearing animal can often be directly observed and tested. In the fossil record, osteoderms, ranging from isolated elements to complex multi-element and layered structures, are common in many lineages, but assessing their three-dimensional form, as well as their functional and ecological implications, is usually less easily accessible. Diverse fossilisation processes (including diagenetic and taphonomic alteration and breakage of bone, and loss of bone due to weathering, etc.) often hamper our understanding of these fossils. Modern staining techniques also (usually) do not work on fossilised material, i.e., per-mineralisation and recrystallisation of bone precludes the study of soft-tissue components in those integumentary structures. While detailed classic osteological and histological studies are commonly used since the 19th century until today, it is especially the increased usage of state-of-the-art scanning and visualisation options and advanced computational tools which revolutionised fossil osteoderm research in the past decades. Here, an overview of current and past osteoderm research in extinct vertebrates is provided and novel data on selected osteoderm-bearing reptiles from the Mesozoic (including the enigmatic *Eusaurosphargis dalsassoi*, Saurosphargidae, and Placodontiformes from the Triassic) are presented and the animals' palaeoecologies are discussed.

Title: P3-8: The first 3D cranial and myological reconstruction of the highly flattened remains of Askeptosaurus italicus (Diapsida: Thalattosauriformes)

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The usage of 3D methodology is becoming more commonplace in palaeontology, allowing researchers to study taxa in unprecedented detail. However, the effectiveness and fidelity of conventional radiographic approaches is determined by the nature of preservation. Highly flattened remains, such as those of the Thalattosauriformes from Monte San Giorgio (Middle Triassic, Switzerland/Italy), render most traditional means inadequate. Thalattosauriformes are a group of secondarily aquatic reptiles from the Triassic. This enigmatic clade is characterized by high morphological disparity, particularly in their body sizes, rostral shapes and dentition types prompting questions about their functional ecology. They have remained poorly understood due to a historic dearth of material and their difficult preservation. Here we use an integrative imaging approach, combining traditional high-resolution CT scanning and angled radiography (CL), to solve the problem of low-resolution output when scanning large, flattened specimens. We created the first 3D cranial reconstruction of *Askeptosaurus italicus* using segmentation, re-positioning, and retrodeformation. Subsequently, using extant myological analogues and preserved osteological indicators the musculature was reconstructed on the cranium, providing a more realistic portrayal of muscle function and force output than traditional 2D approaches. This new approach also offers detailed morphological information for thalattosaur phylogenetics and provides 3D data to be used in quantitative shape analyses and biomechanical studies, which in turn helps to elucidate dietary specializations that produced the remarkable cranial shapes of Thalattosauriformes.

Title: 44-1: Armed to the teeth: Adaptive functionality of shark denticles from material and mechanical perspectives

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Skin denticles are a distinguishing characteristic of cartilaginous fishes and represent their oldest fossil remains (~455 mya.) By covering the body in an aligned arrangement, denticles modulate turbulence and hydrodynamic drag for locomotion, surface interactions, and even respiration. Although denticles exhibit consistent composition (mostly hydroxyapatite and collagen), a great variation has evolved at other organizational levels, particularly denticle size, shape and arrangement, along the body, between sexes, and among species. Here we demonstrate remarkable denticle modifications in the filter-feeding basking shark, both on the throat and skin. In the throat, rows of flexible gill rakers filter zooplankton when the mouth is open. We show these to be exceptionally elongate denticles that, through their comparatively thin enameloid

layer, hollow interior and arcuate form, appear to deform by inflow of water to control filtration. In contrast, basking shark skin denticles are more typical of elasmobranchs, albeit squat and robust. Their arrangement, however, is unusual, with randomly-oriented denticles clumped together to form 'paver blocks', separated by unscaled folds that allow great expansion of the head skin during feeding. The function of the disarrayed denticles is unclear, but starkly contrasts the streamlined 'scale armors' of other sharks. The heavily modified denticles of basking sharks demonstrate how mineralized biomaterials can evolve novel functions via adaptive alterations at multiple size scales and we discuss their implications from ecological perspectives.

Title: 14-2: Keeping clean: a study of self-grooming kinematics in small sized mammals.

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Ever since mammals had fur, they needed to clean themselves. Motor activities related to body care protect the animal against ectoparasites and maintain the insulating function of the fur. We aim to find out the similarities and differences in grooming movements by interspecific comparison across a variety of small-bodied mammals. Specific questions that we tackled are: What are the main targets? What are the main "tools", i.e. hind paws, forepaws or teeth? We analyzed the spatial and temporal structure of grooming sequences based on video recordings in short-tailed opossums, hedgehogs, rabbits, and rodents. Main targets across all species are the sensory organs of the head, especially the ears and vibrissae, and the anogenital region. Scratching with the hind paws, which evolved long before the origin of mammals, is ubiquitous, even in the spiny hedgehog. Differences across the species are related to social behaviour and to ecological aspects. Furthermore, specific locomotor adaptations affect the kinematics of grooming movements. In particular, shoulder mobility as well as the rotational capabilities of the forepaws or the ankle may represent constraints that must be circumvented by other kinematic solutions. Furthermore, there is evidence for the common origin of the ways mammals groom themselves which could have had a driving effect on the evolution of such mammalian-specific characters like the flexible lumbar spine or the atlanto-axial joint.

Title: 19-1: Evolutionary changes of the mammlian skull and their influence on feeding efficiency

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The origin of mammals is a vital transition in vertebrate evolution, accompanied by fundamental tranformations of features for feeding (teeth and jaw) and sensory reception of high-frequency sound. Pivotal was the decoupling of the chewing mechanism from the hearing function

ultimately increasing both chewing efficiency (fast food break down) and hearing ability (reception of higher fequencies). As a key moment counts the innovation of the mammalian middle ear, developing from major anatomical shifts in the lower jaw (and dentition), the middle ear and inner ear - a connected chain of essential structures. A solid mammalian dentary bone with precisely occluding teeth is one result of these major changes, presets needed for effective mastication (repeated chewing motions to break down food items) which is unique to mammals as a group. The ability to access and digest new food sources is a huge driver of evolution. Muscle forces, teeth and the process of chewing in combination reduce the size of food items to access vital nutriens. As a rule, the smaller particles are, the lager the surface area accessable to gut microbiota. In recent years, multifunctional detailed 3D analytical methods and kinematic simulations of feeding functions of both modern and fossil mammals and their ancestors became more and more available to shed light on the evolutionary optimization of the mammalian skull and masticatory behavior.

Title: 50-3: Morphological indicators of hunting behaviour in the carnivoran axial skeleton

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Carnivorans are one of the most diverse mammalian groups today, occupying a wide range of ecological niches. One of their key innovations is adaptation for pursuit predation, a hunting behaviour in which they chase down their prey over distance. The vertebral column pays a critical role in mammal locomotion, however it has been relatively overlooked as a tool for ecomorphological inferences. Here we investigate adaptations for running behaviour and pursuit predation in the lumbar spine of carnivorans and test the utility of the axial skeleton in improving ecological reconstruction of running behaviour in extinct species.

We use 3D geometric morphometrics to quantitatively compare lumbar morphology in carnivores with a variety of habitat and locomotor ecologies. Analyses were performed on both individual vertebrae and vertebral series to explore serial, phylogenetic and ecological influences. Our results demonstrate that carnivorans that integrate running into their hunting behaviour (e.g., pursuit/ambush hunting strategy) show a distinct lumbar morphology compared to taxa with an ambulatory mode of locomotion (e.g., most bears). Additionally, this signal varies along the column and inferences can be improved by using a serial approach. This ecomorphological signal compliments those found in other anatomical systems of carnivorans and indicates that locomotor behaviour differentially impacts evolution of the mammalian body plan.

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Title: 42-4: Open Questions in Fish Photoreception

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Why fishes show the greatest diversity in spectral sensitivity of all vertebrate groups remains an open question in the field of sensory ecology. To date, photoreceptor spectral sensitivity data have been amassed for hundreds of fish species, yet varying trends across clades make it difficult to identify the major factors influencing the observed variation. Here, photoreceptor λ_{max} (peak sensitivity) and chromacy (photoreceptor class number) values were compiled for a meta-analysis examining the ecological basis and functional significance of spectral sensitivity diversity in fishes. In addition to revealing the ecological patterns and predictors of fish spectral sensitivity, this work stresses the importance of considering phylogenetic relatedness in such studies and suggests that selection can act upon even the smallest differences in photoreceptor sensitivity. Though photoreceptor proteins (opsins) had once been thought to occur only in eyes, they are now being discovered elsewhere at a rate that is far outpacing gains in understanding their functional significance. Studies of extraocular photoreception have indicated a similarly impressive diversity in spectral sensitivity of fish skin, which has been repeatedly implicated in the ability of certain fish to change skin color (i.e., dynamic coloration). Support is lacking however, for the capacity of dermal photoreception to initiate color change apart from eyesight, leading to questions of how and why fish dermal photoreception is achieved.

Title: 30-5: Ecomorphology of snakes' teeth

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Tooth morphology has been related to diet in most vertebrate groups, except snakes. Like other vertebrates, snakes have a diverse diet, with dietary specializations such as durophagy, ophiophagy, or goo-eating. Dietary specializations are related to the morphology of the feeding apparatus in snakes, but the potential relationship between tooth morphology and diet has not been established yet. In this study, we compared the shape of the dentary teeth of 63 species of snakes with different diets using 3D geometric morphometrics and linear measurements. We tested whether prey properties and feeding ecology were related to tooth shape. We demonstrate that snakes feeding on hard or long prey have short, bulky, and almost straight teeth, with a short pulp cavity. Species feeding on bulky or soft prey, without the help of a solid substrate, and species that must hold their prey, have longer, more slender, and more curved teeth, with a pulp cavity running almost to the tip of the tooth. The functional implications of these two morphotypes remain to be tested but we propose that long, slender teeth may allow penetration of the teeth providing a good grip on the prey. Short teeth, however, may be able to resist higher or repeated load associated with eating hard or long prey.

Title: 49-3: Mechanical Behavior of Sea Turtle Shells throughout Ontogeny

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The shells of turtles, formed of bone overlaid by keratin scutes provide protections for the muscles, nerves, and viscera. The shell has long been perceived as a form of armor because of its shield like form and composite nature. Though this multi-layered structure seemingly serves a protective role, it's recent that the shell's mechanical properties have been investigated, and only in a few turtle species. The majority of this work focused on freshwater turtles and tortoises. Marine turtles receive relatively less attention though their natural history and shell form differ from the species studied. We investigated the mechanical properties of juvenile and adult green turtles (*Chelonia mydas*), loggerhead (*Caretta caretta*), Kemp's ridley (*Lepidochelys kempii*) and hawksbill (*Eretmochelys imbricata*) turtles shells. Carapace samples were mechanically tested to quantify stiffness (Young's modulus), yield strength and toughness under quasi-static compression. Our data suggests that marine turtle shells are much less stiff than their freshwater and terrestrial counterparts. Flexibility likely reflects the pressure oscillations encountered while diving. Additionally, the juvenile life stage samples are highly compliant, deforming substantially under relatively low stresses. These ontogenetic differences may result from gradual changes in the boney microstructure. Variation also exists between species with *C. mydas* and *E. imbricata* having much stronger and tougher shells, respectively, than the other species tested. Morphological and ecological differences among species likely drive this interspecific variation.

Title: 2-5: Evolution of axial regionalization in Aves during the Mesozoic and its impact on the survival of modern lineages to KPg mass extinction

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The axial column of Neornithes (modern birds) is characterized by regional fusions in caudal vertebrae (pygostyle), lumbosacrals (synsacrum), and thoracics (notarium in several taxa) that provide a rigid and stable axis during flight. Such a configuration integrates into a body plan highly suited for wing-assisted locomotion (with feathered forelimbs, modified girdles, and

crouched limbs) that evolved from running dinosaurs and stem birds over the last ~150 million years. Shifts in count numbers and fusion of vertebrae have had paramount implications on the avian diversification and flight refinement. However, how the organization of precaudal vertebrae evolved across the dinosaur–bird lineage, and how and when the highly tuned axial column of neornithines was acquired remain unexplored. Here, we quantify vertebral numbers in pennaraptoran dinosaurs –including Aves—, and show how the axial configuration of birds was driven from different shifts between two primary developmental mechanisms of body-axis organization: segmentation and homeotic regionalization. We demonstrate that the configuration highly tuned for flight of modern birds was not fully acquired until the appearance of Neornithes. The acquisition of a trunk-sacrum configuration more efficient to deal with stresses derived from the flapping flight could be a key factor in the survivorship of neornithines and the extinction of non-neornithine birds during the end-Cretaceous mass extinction event.

Title: 22-1: Investigating the Morphological Diversity of the Canine Teeth of Sabretooth Feliforms and their Extant Relatives and its Potential Use as a Diagnostic Tool

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Elongated upper canine teeth, or sabre-teeth, have evolved three times within the sub-order Feliformia. The species that wielded them flourished throughout the Cenozoic and have historically been separated into two morphological groups: dirk-tooths with longer, flatter canines, and scimitar-tooths with shorter, serrated teeth. However, quantitative morphological analysis has not been conducted on these teeth to determine the true diversity within the group, and how tooth morphology of extant feliforms compares to their extinct relatives. Using Geometric Morphometric analysis, it is shown that sabretooth canine morphology is exceptionally diverse, with no extinct clade having all its members occupy the same morphospace based on tooth length and curvature. Instead, a neutral basal morphospace is observed for all groups with diversification from this basal position seen as species become more derived. A distinct and consistent scimitar-tooth morphology is also not observed. When compared with extant taxa, several sabretooth species are seen to be morphologically similar to extant feliforms, even those that exhibit novel dietary strategies. The tooth morphology dataset created was then utilised as a diagnostic tool to determine locomotor grade and was found to be unsuitable for this task thanks to high morphological variability in tooth shape. However, further expansion of this dataset and the addition of three-dimensional shape analysis may make this morphological analysis useful for determining the function and phylogenetic position of fossil sabre-teeth.

Title: 29-4: Morphological Consequences of Domestication and Feralization in Rabbits

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European rabbits (*Oryctolagus cuniculus*) are the only species of their family to be domesticated, owing in part to their sociality and propensity to live in warrens. Originally domesticated for food and then bred as pets in Western Europe, they now have a world-wide distribution with the aid of human translocation. This complex history coupled with multiple events of translocation into different environments makes them a fascinating study system to examine morphological diversification. We examined ~1000 rabbit specimens using museum collections and pest control activities across their range including Europe, North America, South America, Southeast Asia and Australasia. We particularly focussed on Australia and surrounding islands due to the rabbits notable invasive pest status there. We compared wild animals from the native range (Iberian Peninsula) to feral and domestic animals using geometric morphometrics to characterise skull form – a proxy for body size and indicator of diet and locomotory mode. In this talk we discuss how domestication and feralization has resulted in substantial increases to morphological disparity in many aspects of size and shape. These changes shed light on the evolution of the family Leporidae (rabbits and hares) and highlight the need to examine invasive species from an evolutionary perspective. This work is funded by the Australian Research Council (FT190100803 to ES).

Title: 6-3: The Evolution of the Brain in Euarchontoglires: new perspectives and novel methodologies

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The evolution of the brain in Primates has long been a topic of intense study. Much of this work has focused on trying to understand the relatively large brain of Primates using data from living members of the Order, often set against a comparative backdrop defined by extant "insectivores". The growing availability of high-resolution imaging methods that allow for the non-destructive study of endocranial anatomy from fossils, coupled with the broadly accepted position of Primates within Euarchontoglires (and so more closely related to Scandentia, Dermoptera, Rodentia, and Lagomorpha than to "insectivores"), have started to re-write some of the narratives around primate brain evolution. Applying modern methods for quantifying shape also allows for an entirely new set of questions to be considered. The fossil record for early Tertiary euarchontoglirans reveals strong similarities between the early members of Primates, Rodentia and Lagomorpha, with the brain being nearly lissencephalic, with moderately large

olfactory bulbs, and little evidence of neocortical expansion. A new, rigorously validated set of endocranial landmarks is used in a geometric morphometric analysis to explore the trajectories of change that led from that shared ancestral form to the widely divergent brain morphologies observed in modern euarchontoglirans. This approach allows for a clearer view on when major shifts occurred in euarchontogliran brain evolution, which is a first step in being able to explain such evolutionary changes.

Title: 7-5: Putting the sharp in sharpnose: the morphology and distribution of denticles inside the olfactory rosette of Atlantic sharpnose sharks (Rhizoprionodon terraenovae)

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Elasmobranchs have diversified to fit a variety of ecological niches, leading to a wide range of body plans, head shapes, and sensory morphologies. Their olfactory morphology differs in nostril placement, olfactory morphometrics, and sensory tissue distribution. Olfactory rosettes consist of paired lamellae connected by a central raphe with various organizations of sensory and nonsensory epithelium. We describe the presence of dermal denticles in the olfactory lamellae of Atlantic sharpnose sharks (*Rhizoprionodon terraenovae*). Using micro-computed tomography (microCT), scanning electron microscopy (SEM), and histology, we visualized and described the morphology, distribution, and orientation of dermal denticles along the entire olfactory rosette and within individual lamellae. We found that denticles are present in every lamella throughout the rosette and are mainly concentrated along the excurrent channel, where water exits the olfactory rosette. Denticles are consistently present at the ends of the olfactory lamellae's secondary folds. Additionally, we find dense fields of denticles along the excurrent channel with most denticles oriented in the direction of hypothesized water flow. However, some denticles face opposing directions, possibly to redirect some flow back towards the sensory tissues. This unusual placement of dermal denticles has considerable implications for understanding water flow patterns in olfactory structures and the development of both olfactory tissues and dermal denticles in elasmobranchs.

Title: P3-16: Who nose the flow: nasal dermal denticle morphology and water flow

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Sharks are covered in dermal denticles which, depending on their morphology, affect water flow around the body. We described the morphology and orientation of dermal denticles around the nasal region of the Pacific spiny dogfish (Squalus suckleyi) using computed microtomography (microCT) and scanning electron microscopy (SEM). We coupled morphological data and dye flow visualization to connect patterns in denticle density, orientation, and morphology to water flow patterns at the incurrent naris. Specifically, the posterior region of the incurrent naris has a high density of denticles that acts as a flow barrier. Additionally, while some surrounding denticles are arranged to channel water into the incurrent naris, as expected, the shape and orientation of other denticle patches divert water out of the incurrent naris. We hypothesize that this denticle patterning can help with particle removal (to keep the nose from clogging), water flow regulation (to protect delicate olfactory lamellae), and recirculation of water within the nose (to increase the efficacy of the olfactory sensory structures). We also saw the same denticle pattern in two other shark species: the smalleye hammerhead (Sphyrna tudes) and the shortfin mako (Isurus oxyrinchus), suggesting that these patterns may be conserved among shark species. These data support the inclusion of dermal denticles as an important factor when modeling water flow in the shark olfactory system.

Title: P3-4: Understanding a missing link in the evolution of mammalian hearing and balance systems through morphometric analysis of the Ductus Reuniens

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The mammalian inner ear contains the sensory organs responsible for balance (semicircular canals + utricle and saccule) and hearing (cochlea). While these organs are functionally distinct, there remains a crucial connection between the two: the ductus reuniens (DR). Despite its functional importance, we lack comparative descriptions of DR morphology. As a result, our understanding of the evolutionary diversification of hearing and balance systems in mammals is incomplete. Using virtual 3D models derived from micro-CT, we examine the morphology of the DR and its relationship to the bony labyrinth in three humans and two guinea pigs. Anatomical reconstructions and univariate measurements were carried out in the software 3D Slicer.

3D visualizations reveal the DR as a narrow tube with an hourglass-like shape linking the saccule and cochlear duct. Data indicate considerable differences in relative DR length and width between humans and guinea pigs. Humans possess a relatively shorter and narrower DR but with wider openings to the saccule and cochlear duct. This results in a more constricted DR lumen in humans which may differentially inhibit fluid transfer between the saccule and cochlea. Our results reveal previously hidden morphological diversity in the communication between the hearing and balance systems of the mammalian inner ear. Further comparative descriptions of the DR will elucidate functional implications of such morphology, and its role in the evolution of hearing and balance.

Title: P3-2: Endosseous labyrinths, ear bones, and digital endocasts of fossil baenid turtles reveal functional aspects of hearing and balance in Paracryptodira

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Baenidae are an extinct, speciose clade of endemic North American paracryptodiran turtles that were prevalent in Late Cretaceous freshwater deposits of the Western Interior. MicroCT scans of available baenid crania revealed morphology of the modeled endocast, endosseous labyrinth, and middle ear that are poorly understood in this family. Baenids had moderately flexed brains with rounded cerebral hemispheres and minimal separation between the metencephalon and myelencephalon. Neurovascular canal dimensions indicate dominant stapedial arteries, much larger than the internal carotid arteries. Anterior and posterior semicircular canals diverge at less than 90°, are moderate in diameter and relatively similar in shape and width, while lateral semicircular canals are consistently laterally convex.

In baenids, the gracile columella auris (stapes) begins with a posterodorsally flared basis columella before arcing across the middle ear and becoming flatter on its anterior and posterior sides near its terminus. In turtles, osseous columellae convey sound vibrations from the tympanic membrane via cartilaginous extracolumellae, across the cavum tympani, and into the inner ear via the fossa ovalis, where energy from sound waves disperses within the pericapsular recess. A gracile columella, as in most baenids, vibrates more readily than a robust columella, suggesting that baenids had relatively high sonic sensitivity compared to other turtles. This study adds to the understanding of baenid hearing, balance, and neuroanatomy, and sheds light on evolution of these senses in paracryptodires.

Title: 53-5: Nothing to yawn about: comparing multiple measures of primate gape

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Previous research has demonstrated how masticatory muscles are adapted for specific diets across many primate lineages. For instance, masticatory muscle fiber lengths have been shown to correlate with experimentally derived maximum ingested food sizes (Vb) in both strepsirrhines and anthropoids. However, the masticatory apparatus is also used for behaviors not related to diet – including yawn gapes that represent dominance displays. While gape or gape proxies have been experimentally measured in primates previously via experiments in Vb, maximum bony gape (the angle at which the temporomandibular joint disarticulates), and anaesthetized gape (in

which the jaws of anesthetized specimens are open to the point of resistance), yawning gapes – likely the widest gapes that animals make during natural behavior – have never been systematically quantified. In the current study, we have compiled videos of yawning primates via publicly available resources and those shared directly by our primatology colleagues and captured still frames at their maximum. We then aligned these still frames with photographs of the skulls of conspecifics taken at equivalent orientation, and then use landmarks on these photographed skulls to approximate angular and linear gape demonstrated by the recorded specimen. These newly derived yawn gapes are then correlated to previous gape measures as well as myologically derived proxies to better understand how various gape abilities and functions scale across primate lineages.

Title: 17-5: Body size effects on trabecular bone morphology in Philippine cloud forest rodents

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The relationship between vertebrate body size and skeletal morphology can manifest differently among clades, and morphological effects of body size are often difficult to extricate from effects of ecology and phylogeny. For a controlled investigation of how body size affects the mammalian vertebral column across biological scale, we quantified cortical and trabecular bone morphology in the lumbar spine of Philippine endemic "cloud rats" (Phloeomyini). This monophyletic clade spans three orders of magnitude in body size (17g-2700g), and members are all arboreal herbivores, making them an excellent choice to isolate the morphological effects of body size in a non-model group. We collected 18 linear and six trabecular bone measurements on lumbar vertebrae of 10 species, including at least one species from every genus in the clade.

Trabecular architecture, especially trabecular thickness, is correlated with body size. Although bone volumetric density increases with body size among smaller species, that relationship may not be linear: *Phloeomys pallidus* (2500g) and two species of *Carpomys* (120-170g) all have vertebrae that are ~40% bone by volume. In gross (cortical) morphology, larger species have dorsoventrally deeper vertebral centra, which may relate to maintaining skeletal safety factor (ratio of failure strain to maximum functional strain) at larger body size. Future work will consider relative mechanical contributions of vertebral trabecular and cortical bone, and how that may vary at large and small body size.

Title: P3-3: Postnatal ontogeny of the midface and turbinals in Eptesicus fuscus

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Nasal turbinals are complex projections of the lateral nasal wall that increase surface area of the nasal cavity for conditioning inspired air or olfaction in mammals. To understand postnatal turbinal ontogeny related to these functions, we quantified turbinal size from birth to adult size in *Eptesicus fuscus*, a vespertilionid bat. We microCT scanned each specimen, first unstained, and then after iodine staining (diceCT). Using imaging software, we measured turbinal mucosal surface areas and osteological skull measurement. We complemented these data with histological sections to determine individual turbinal function in an adult *Eptesicus*. We used linear regressions to model the relationship between square root of turbinal area and age or cranial length. Surface areas of all turbinals are significantly correlated with postnatal age and cranial length. Maxilloturbinal (MT) and first ethmoturbinal (ET I) surface areas grow relatively faster relative to skull size than caudal ethmoturbinals or the frontoturbinal. Results also suggest rapid growth of palatal length and MT and ET I surface areas during the first week after birth, with lower rates of growth in other turbinals. Histology of the adult revealed the rostral end of ET I is covered with vascular respiratory mucosa. Rostrally, ET I collaboratively conditions air with the MT. These results support the hypothesis that ET I has a dual function in many mammals, and suggest this may be manifested early postnatally.

Title: P3-5: Hypotheses on the evolutionary and biogeographic history of the Ankylosauria (Thyreophora: Ankylosauria) from Gondwanan continents

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Ankylosaurs were a lineage of armored dinosaurs whose fossil record is relatively well known in the Northern Hemisphere. However, record from Gondwanan continents is scarce and remain poorly understood. The recent proposal that these Gondwanan forms belong to a monophyletic group, the Parankylosauria, is intriguing since this clade would have split off early from Laurasian ankylosaurs which in turn would conform another clade, the Euankylosauria. Branch-length calibration in phylogenetic analyses from different matrices suggest the Parankylosauria originated during the Oxfordian (160 Myr), which fits well with the establishment of the Caribbean Corridor between Laurasia and Gondwana. However, we still know little about the early history of the group: the possible oldest member, *Minmi paravertebra* (Aptian, Australia) is fragmentary and still leaves an inferred ghost lineage since the Oxfordian. Parankylosauria is based on *Kunbarrasaurus ieversi* (Albian-Cenomanian, Australia), *Antarctopelta oliveroi* (Campanian, Antarctica) and *Stegouros elengassen* (Campanian-Maastrichtian, South America). Recent proposals about that *Patagopelta cristata* (Campanian-Maastrichtian, South America) is a Nodosauridae deserve to be tested in a broad phylogenetic context. Is it possible that the Parankylosauria originated in eastern Australia and spread via Antarctica into South American Patagonia during the Late Cretaceous? Is *Patagopelta* a far-reaching euankylosaurian from Laramidia? More information on Gondwanan ankylosaurs is needed. This may provide more robust results to test these hypotheses on the evolutionary history and paleobiogeography of the armored dinosaurs of Gondwana.

Title: 53-4: Finite element model validation in biomechanics using a 3D scanning Laser Doppler Vibrometer

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Paleontologists are often interested in understanding the mechanical performance of biological structures, and finite element (FE) modeling is now widely used for this. As FE models are highly sensitive to the information used in constructing them (e.g. material properties), and given the incomplete nature of the fossil record, it is essential to thoroughly validate FE outputs to understand whether modeling reflects the biological reality. We investigate the use of a novel non-contact technique, 3D scanning Laser Doppler Vibrometry (LDV), an optical instrument that evaluates vibration velocity and displacement data from a set of points on a structure, to measure vibration and displacement patterns in bone and to compute full field dynamic strain values to validate biological finite element models. Strain data was collected from two alligator mandibles under varying loading conditions, and compared against finite element simulations. Material properties of bone and teeth were also measured using well established techniques and were included in the models. The experimental results highlight localized high strains around the tooth row and on the ventral surface. These patterns would not be resolved by traditional strain gauges and the dynamic nature of the technique overcomes the immobility required by DSPI. This work opens the door for more full field dynamic strain measurements and help to establish better confidence in our modeling of paleobiomechanics.

Title: 41-1: Scaled up defenses: Patterns and drivers of dermal armor in lizards

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Ossified dermal armor is found across the vertebrate tree of life. Despite bony plates being present in some of the earliest vertebrate ancestors (with bony dermal armor evolving before jaws and ossified skeletons), tetrapods lost this armor following the colonization of terrestrial environments. The bony armor seen in amphibians, reptiles and mammals appears to be apomorphic, with osteoderms independently evolving at least twenty times (Pareiasauria, Pantestudines, Pseudosuchia, Thyreophora, Titanosauria, Therapoda, Placodonta, Cingulata, Rodentia, three independent origins in anurans (Megophrydae, Ceratophryidae, and Brachycephalidae), and eight independent origins in Squamata—three divergent lineages of

gekkotan, lacertids, Scinciformes, Anguimorpha, Boid snakes, and one species of dwarf Chameleon). Squamates—whose very name is derived from their scaly armor— have a particularly complex pattern of armor evolution, with members of 12 extant families possessing a diversity of osteoderm morphologies and distributions. This study employs comparative phylogenetic analyses of micro-computed tomography (μCT) datasets to quantify and investigate the diversity of dermal armor across Squamata, with broadest sampling in the families that are known to possess osteoderms. Our analysis reveals a strong correlation between ecology and the distribution and degree of armor in lizards, and that three clades—Cordylidae, Anguidae and egerniine skinks—display increased rate-shifts in the distribution and extent of their armor

Title: 2-6: Geographical patterns in turtle shell morphology: functional underpinnings of ecological rules

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Here I explore the potential role of climate in shaping the evolution of turtle shell morphology. Geometric morphometrics was used to characterize shell size and shape for 1897 turtle specimens in 264 species. Both phylogenetic and non-phylogenetic regressions were used to assess the presence and nature of correlations between latitude and turtle shell morphology across species. For species with sufficiently large sample sizes and latitudinal ranges, intraspecific regressions were conducted as well. Next, GIS was used to extract climate data for localities of each of these specimens, and regressions were conducted between climatic variables and shell morphology. There was little evidence of Bergmann's rule in turtles. Turtle shells from higher latitudes were significantly taller than those from lower latitudes, but this pattern explained very little variation in turtle shell shape. Climate explained more variation in shell shape, with turtles from cooler and drier regions having taller shells and larger plastrons. Finite element (FE) modeling of heat exchange in turtle shells revealed an expected functional interpretation for these patterns - shells characteristic of colder and drier environments exchanged heat with the environment more slowly than those characteristic of warmer, wetter environments. Thus while turtle shells do not seem to consistently follow Bergmann's or Allen's rules, they nonetheless do show evidence of more complex ecomorphological patterns underlain by the same thermoregulatory processes as those more classic rules.

Title: 21-6: Comparative morphology of the passerine appendicular skeleton; implications for unravelling the early evolution of Passeriformes

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Passeriformes (passerines) exhibit extraordinary diversity among crown birds, accounting for over 60% of extant bird species. Beginning in the Eocene, the passerine crown group radiated into one of the most species-rich and widespread groups of terrestrial vertebrates in Earth history, yet much of their skeletal anatomy remains largely overlooked and uncharacterised. Here, we share recent work that has begun to unravel the morphological complexity of passerine birds. Within the wing and hindlimb, the carpometacarpus and tarsometatarsus are ecologically and functionally important skeletal elements exhibiting striking morphological variability, making them particularly character-rich components of the passerine skeleton. Here, we demonstrate the density of discrete morphological characters within the carpometacarpus and tarsometatarsus, highlighting complex patterns of convergent evolution among distantly related but ecologically similar passerine lineages such as scansorial taxa. Importantly, recognition of novel characters and character combinations have helped provide a much-needed comparative framework for interpreting the passerine fossil record. Despite widespread homoplasy, phylogenetically informative combinations of character states have helped elucidate the phylogenetic positions of both semi-articulated passerine fossils and isolated material from the Cenozoic of Europe. Our results inform on the earliest and latest occurrences of major passerine lineages within Europe, including representatives of Tyranni, which are notably absent from Europe in the present day.

Title: P4-8: A strepsirrhine primate from the late Oligocene Nsungwe Formation, southwestern Tanzania

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Lorisiform primates are today represented by dozens of species of small-bodied nocturnal, arboreal primates occupying woodlands and forests in Africa and Asia, but the evolutionary history of this remarkable group remains something of a mystery. Before the Miocene, strepsirrhine fossil evidence is sparse, primarily represented by isolated craniodental and postcranial elements from localities in northern and western Africa and Oman. Until recently, few fossils bridged the gap between fossil taxa like *Saharagalago* and *Karanisia* from the late Eocene of Egypt, and the more abundant strepsirrhine record including *Komba* and *Mioeuoticus* documented from early Miocene sites of eastern Africa. Recent discoveries from the Songwe Member of the late Oligocene Nsungwe Formation in the Rukwa Rift Basin of southwestern Tanzania include novel strepsirrhine material, helping to document this fascinating branch of primate evolution. Radiometrically dated to 25.2 Ma, a new Paleogene lorisiform is described, represented by a partial left maxilla preserving a portion of the orbital margin and a lightly worn M3. Based on the size and shape of the orbital margin, a nocturnal habitus is

inferred. Dentally distinctive from and smaller in size than described early Miocene forms, this discovery documents a rare window into primate evolutionary history from Africa south of the equator, revealing trends in palaeobiological diversity through the Paleogene-Neogene transition across habitat types and through time.

Title: 26-6: Functional morphology of human and non-human primate middle ears

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The three ossicles unique to the mammalian middle ear greatly improve acoustic impedance matching and have a strong effect on the threshold of hearing. Therefore, studying functional anatomy of the middle ear in a comparative context should inform us about its evolution and may help us to better understand hearing differences in mammals. Middle ear performance can be evaluated via the middle ear transfer function (METF). For anthropoid primates, this could be an objective and convenient way to obtain audiometric data, shedding light on the evolution of hearing and vocal communication. In addition, such data could help answer whether the human ear is special with respect to the perception of speech frequencies. Here we experimentally measure, by using Laser-Doppler vibrometry, the METF between 0.2-10 kHz for baboons (*Papio anubis*, n=4 ears), chimpanzees (*Pan paniscus*, n=5 ears; *Pan troglodytes*, n=8 ears) and humans (*Homo sapiens*, n=12 ears), and relate our findings to morphometric data of the middle ear. We found that METFs of non-human primates consistently show a greater magnitude than that of humans over the studied frequency range. This relates to the derived small pressure gain ratios and heavy ossicles of humans and suggests that spoken language likely did not shape the unique morphology of the human middle ear.

Title: 36-6: Diversifying the Power Stroke of Premaxillary Protrusion: The Evolution of Diverse Cranial Musculature in Cypriniform Fishes

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Cypriniform fishes occupy a variety of trophic niches via a suite of morphological novelties associated with feeding: including premaxillary protrusion mediated by a sesamoid bone, a

muscular palatal organ, and a pair of lower pharyngeal jaws that work against a keratinous pad on the basioccipital. Diverse morphology within the trophic apparatus provides a biological model with which we can investigate the evolution of complex systems. Prey capture is effected by protrusion of the premaxilla. Does developmental integration within the protrusile mechanism constrain diversity of trophic morphology? How can we identify the signal of constructional constraint on the pattern of morphological diversity of the A1 division of the adductor mandibula muscle in Cypriniformes? We present a biomechanical model informed by our interpretation of anatomical diversity in the element of the trophic apparatus that powers premaxillary protrusion. The model is parameterized to support simulation of mechanical linkages that we may explore experimentally. Measuring the mechanical stress regime of a simulated linkage provides selection criteria that reflect the constraint of successful sesamoid bone formation. In this way we are able to test hypotheses of developmental constraint *in silico* that are less experimentally tractable *in situ*.

Title: 46-7: Whole-body volumetric modelling of the early tetrapod Ichthyostega

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Despite being a critical event in vertebrate evolution, many aspects of the water-to-land transition in early tetrapods remain unresolved. This uncertainty is particularly evident when considering locomotion in *Ichthyostega*, one of the earliest-known tetrapods: contrary to the traditional perspective that tetrapods stereotypically exhibit a hindlimb-powered, coordinated and alternating “lateral-sequence gait,” biomechanical modelling has instead suggested *Ichthyostega* to have used a mudskipper-like, synchronously-“crutching” form of substrate-associated locomotion. However, in the decade since this latter hypothesis was proposed, further quantitative investigation of *Ichthyostega* has not been performed in detail, despite the ability of digital techniques to provide novel insight into even well-known taxa. Herein, we therefore use volumetric modelling to provide the first estimation of the inertial properties of *Ichthyostega*. We present the first body-mass model of *Ichthyostega*—created in Rhinoceros 3D, with extensive sensitivity testing of body segment masses—from which we estimate parameters such as centre-of-mass position, calculated primarily in MATLAB. To contextualize these data, we reconstruct comparable models for various taxa that either phylogenetically bracket *Ichthyostega* and/or represent potential functional analogs. Using this comparative framework, we ultimately assess the hypothesis that *Ichthyostega* would have used a forelimb-driven, “crutching” gait on land but a hindlimb-driven, “paddling” mechanism in the water. Altogether, this research both provides a renewed exploration of locomotion in *Ichthyostega* and establishes an essential foundation for future biomechanical investigations of early tetrapods.

Title: 41-2: Multi-scale interactions in the armor of fishes

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Where armor is largely defensive the diverse manifestations must reflect the quality and magnitude of the expected assault. For example, in poachers (Agonidae) the flat, unornamented, imbricate plates in the Smooth Alligatorfish (*Anoplagonus inermis*), are in stark contrast to the rough surfaced plates of the Northern Spearnose Poacher, *Agonopsis vulsa*, most of which have a single, large, curved spine. Performance measures, including crushing resistance, bending stiffness, and body bending during escape, indicate that the latter is moderately effective against gross assault with very little decrease in locomotor performance. A closer look at the role of this armor offers three areas of performance research: function of the spine, function of the rough surface, and function of patterning on the overlapping surfaces. If the assault on *Agonopsis* comes from a narrow, sharp probe, for example, from a crustacean maxilliped or periopod, a central spine will prevent the sharp tip from finding the gap between plates. Similarly, the rough surface will catch a sharp probe, preventing it from sliding into a gap between plates. The plates move easily over one another, as evidenced by swimming speed, but the interplate patterning ensures that a plate under pressure will stick to the plates it lays over. The critical mass of data on the morphology of armor in fishes points towards interesting experiments with potential technical applications.

Title: 33-3: Born to do pilates: morphological analysis of flexibility and stability in the backbone of hares and rabbits

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The European brown hare (*Lepus europaeus*) shows remarkable abilities to run at a surprising speed of up to 20 m/s and make an almost 180-degree turn in a split second. Its evolutionary sibling the European rabbit (*Oryctolagus cuniculus*) is not a specialised runner, but instead well-known for hopping and digging. Despite their distinct locomotive abilities, research on how their axial skeletons differ has been rarely done. Here we focused on the vertebral column, which has been reported to have different shape patterns between specialised modes of locomotion. This talk will discuss the skeletal traits influencing the flexibility and stability during locomotion in the hare and rabbit. The number of thoracolumbar vertebrae directly impacts the flexibility of the column. The size and shape of vertebral processes are dependent on the force muscles exert upon them, thus impacting the stability. These traits were quantified using meristic and geometric morphometric (landmark and landmark-free) approaches on 3D models from CT scans. We found that the number of pre-sacral vertebrae and the thoracolumbar-transition region were more conserved in the hare. The preliminary shape analysis on the sacrum showed the interspecific variation in the dorso-ventral curvature. Also, the landmark-free technique had more potential to

reveal subtle variation in the thoracolumbar region. These findings present new morphological evidence underlying the evolution of the different locomotive abilities in the hare and rabbit.

Title: P1-5: The bracing strut for flapping muscles: coracoid strength can be used to reveal the origin and evolution of wing-beat propulsion in birds.

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In the locomotor evolution from theropod dinosaurs to birds, it is essential to understand the origin and diversification of flapping ability. This is because flapping wings generate the propulsive force on the body, which provides the aerodynamic lifting force on the wings; and also because birds use wing-beat propulsion not only for flight, but also for swimming and incline running. A survey of 209 bird species (83 families, 30 orders) revealed that the coracoid strengths in birds that flap for propulsion significantly surpassed those of non-flapping birds, where coracoid strength is the section modulus of the coracoid relative to body mass. Therefore, the coracoids of flapping birds are strengthened to withstand the contractile force of powerful flapping muscles (e.g., *mm. pectoralis* and *supracoracoideus*). Within the flapping birds, the coracoid strengths of the soaring birds surpassed the others due to the relatively great bending force on the coracoid provided by flapping muscles that run apart from the shoulder joint than the others; while there was little difference between the wing-paddled swimming and flap-flight birds in coracoid strength, because resultant magnitude of the muscle contractile force are adjusted to be similar between them. As stated above, the coracoid strength is highly correlated with the flapping ability and can be a powerful tool for revealing the origins of powered flight in the evolution of birds.

Title: 53-8: Taking a step aside from classical geometric morphometrics: could landmark-free approaches build the future of biological shape characterization?

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During the past decades, geometric morphometrics (GM) has been extensively used to study shape variations across diverse sets of biological 3D data. State-of-the-art techniques now enable thorough and dense characterization of shapes, while multivariate statistical tools have made it possible to account for datasets increasing in dimension. Despite the existence of diverse techniques and software packages, GM in organismal biology has historically relied on the

comparison of cartesian coordinates of landmarks, that can be specified manually or computed semi-automatically. Yet, recently, a wide range of approaches based on fundamentally different mathematical principles have been proposed for automatic or semi-automatic comparison of 3D shapes, without relying on landmarks. These were originally developed within the fields of Computer Graphics or Geometry Processing. We investigated whether, and to what extent, these recent approaches can complement or provide an alternative to classical GM in quantitative biology. Here, we detail the mathematical principles, and present a case study of biological shape variation to demonstrate the strengths and shortcomings of each approach.

Title: 5-1: Hindlimb myology in the Macropodiformes

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Macropodiformes are a unique group of marsupials known for their bipedal hopping gait. Myological research to date has primarily focused on the muscles of the distal hindlimb and their contribution to the energy efficiency of bipedal hopping in large kangaroos. The morphology and functional importance of the hindlimb have been less studied, especially in species <5 kg. In this study, we provide a detailed description of the hindlimb myology in *Lagostrophus fasciatus*, the sole member of the Lagostrophinae sub-family, and identify the homologies of these muscles in the context of the Macropodiformes. We present data from dissections of 11 species, and synthesise the available literature to investigate patterns in hindlimb myology across 13 genera. We mapped myological characters to investigate potential synapomorphies within Macropodiformes. Basal species such as *Hypsiprymnodon* and *Lagostrophus*, together with species that inhabit complicated substrates (arboreal or rocky habitats), had more differentiated muscles throughout the limb, allowing for better dexterity of the hind limb through a greater range of motion. In contrast, species that use a more specialised hopping gait had less differentiation throughout the limb, and greater relative masses in their gluteal and adductor muscles. These patterns provide a platform for understanding the evolution of the hindlimb for the diverse locomotor strategies within this group.

Title: 3-4: Myosin heavy chain isoform expression in primate chewing muscles: Regional and functional heterogeneity fine-tunes muscles for specific feeding behaviors

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Over the past 30+ years, Sue Herring's work on mammalian craniofacial biology has profoundly influenced the way we study mammalian feeding system morphology, physiology, and function. Based on her work, miniature pigs became a model system for investigating craniofacial function and evolution in primates, revealing regional and functional heterogeneity in pig masseter during

ontogeny and intraspecifically. Since then, our knowledge of fiber-type phenotypes of primate chewing muscles has been based almost entirely on macaques. Here we quantify myosin heavy chain (MHC) isoform expression of the masseter and temporalis for a sample of adult male and female African apes (Hominidae), Old World monkeys (Cercopithecidae), and platyrrhines (Pitheciidae and Cebidae). Serial sections were stained against slow (MHC-1/α-cardiac) and fast (MHC-2/M) fibers. Depending on muscle size, ~300–900 fibers were counted and scored for staining intensity. Our results demonstrate clade-based regional variation in MHC profiles among the anterior superficial masseter (ASM), superficial anterior temporalis (SAT), and deep anterior temporalis. The ASM, for example, comprises an average of 51% type 1β fibers in Hominidae, 85% in Cercopithecidae, and 56% in Pitheciidae/Cebidae. By contrast, the SAT comprises an average of 68%, 41%, and 47% 1β fibers, respectively. Within these clades, regional/functional heterogeneity in fiber type phenotypes between closely-related species suggest fiber types provide a mechanism for fine-tuning specific feeding behaviors. Funded by NSF Grant BCS 1719743.

Title: P2-1: Jaws wide open: 50 years of modeling mammalian jaw gapes since Herring and Herring 1974

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Sue (and Stephen) Herring initiated the modern study of mammalian jaw gapes in 1974 by developing their geometrical model of mammalian gapes that incorporated muscle line of action in addition to skull metrics. Their integration of skeletal and superficial masseter muscle features launched concepts that extend to today's efforts to understand how muscle architecture interacts with skull form during different feeding apparatus behaviors involving large jaw gapes. In the more than 240 articles citing Herring and Herring (1974), we see a wide range of biological topics explored: a taxonomic breadth including fish, birds and mammals; efforts to understand skull and jaw-muscle design in living and extinct species; applications to comparative evolutionary biology; quantitative genetics underlying feeding apparatus form as well as studies of behavioral ecology and feeding apparatus performance. We review the historical progression of jaw gape modeling focusing on mammals over the past 50 years including integration of muscle architecture, three-dimensional estimates of muscle moment arms, tooth shape and placement and more recently muscle fiber-types. Using examples from primates, we conclude our presentation by exploring how these gape models inform broader questions related to how muscle and skull morphology integrate to impact feeding performance as well as how animals defeat potential physiological trade-offs to enhance competing performance criteria in distinct feeding behaviors (e.g., generating large gapes and large bite forces). Thank you, Dr. Herring.

Title: 12-5: A multi-proxy approach to masticatory function in howling monkeys in Costa Rica

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Muscle activity in mastication has been one of the many topics addressed in the research of Dr. Susan Herring. However, as she has so often noted, we must always be aware of the limitations of our work. For instance, laboratory-based *in-vivo* studies of masticatory function have often been conducted independently of field studies of masticatory function, largely due to the logistical challenges of the latter. This has left gaps in our knowledge in moving from detailed laboratory studies to less detailed studies in the wild. Our work with howling monkeys (*Alouatta palliata*) at Hacienda La Pacifica in Costa Rica has allowed us to gather data on three aspects of masticatory function not normally collected in the field: EMG activity of chewing muscles, material properties of foods, and rates of dental microwear on postcanine teeth. Findings to-date indicate that levels of chewing muscle recruitment are indeed positively correlated with food toughness in the wild, and these are in turn correlated with rates of microscopic tooth wear. Sample sizes are small, but the results provide interesting insights into two issues that have always been promoted by Dr. Herring: (1) the complexity of our field and (2) the benefits of using multiple approaches to investigate functional morphology.

Title: 35-6: Morphological differences in surgeonfishes shape ecological roles and response to a key stressor

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Surgeonfishes make up a core component of modern coral reef fish assemblages and contribute to a range of critical ecological functions. The morphological diversity of these fishes means they are a particularly interesting group to study from a functional perspective. Especially, given that many species closely interact with algal turfs on reefs, a group of algae expected to typify future coral reef configurations. To explore how morphology shapes these interactions in more detail, in this talk I will focus on two widely distributed and often highly abundant surgeonfish species, which are remarkably similar in terms of their superficial appearance. However, subtle differences in their functional morphology translate into marked differences in their ecological roles on reefs. Moreover, I highlight how a key stressor (sediments) can impact these fishes, with the strength of these impacts linked to differences in functional morphology. As surgeonfishes are a critical group of reef fishes, and algal turf cover, as well as sediment inputs, are poised to continue increasing on reefs, these results have implications for how future coral reefs will function. Overall, this talk will synthesise multiple lines of evidence to highlight how

understanding the morphology of reef fishes is critical if we are to understand their ecological roles and response to stressors.

Title: 8-3: Ontogeny of masticatory muscle size in tufted and untufted capuchins

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Prior research has established that tufted (*Sapajus*) and untufted (*Cebus*) capuchins differ in their feeding behaviors, with *Sapajus* consuming more resistant foods. These behavioral differences are reflected in features of the masticatory apparatus, including cranial shape, masticatory leverage, and mandibular cross-sectional geometry. Prior soft tissue research has also demonstrated that adult *Sapajus* have relatively larger physiological cross-sectional areas than *Cebus*, which is accomplished via increased muscle mass. No prior work has analyzed the ontogeny of these soft-tissue differences, and it remains unclear at what point these differences in masticatory muscle architecture manifest. Here we analyze muscle mass data for the masseter, temporalis, and medial pterygoid from ontogenetic samples of captive *Sapajus* (n=33) and *Cebus* (n=20) and a sample of free-ranging semi-provisioned *Sapajus* from Brazil (n=40). Regressions show a significant relationship between muscle mass and jaw length ($p<0.001$; $r^2= 0.63$ to 0.94) for all muscles and samples. However, while *Cebus* exhibits a pattern of isometry for all muscles, both *Sapajus* samples show positive allometry in the masseter and temporalis (but not medial pterygoid). Differences in relative muscle size among samples appear early in ontogeny but are most pronounced following M1 eruption. Adult *Sapajus* also show marked sexual dimorphism in muscle mass for all muscles, but this is not true for *Cebus*. This is the first in a series of analyses examining capuchin muscle ontogeny.

Title: 11-1: Synchrotron-based palaeohistology of a small aetosaur from the Upper Triassic Woźniki locality (southern Poland) – growth plasticity or ontogenetic variation?

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Aetosaurs were a terrestrial group of pseudosuchians distributed globally during the Late Triassic. The here studied specimen measures only approximately 25 cm in total body length, is covered in a carbonate concretion and it shows a nearly completel articulation. Propagation phase contrast synchrotron X-ray micro computed tomography, applied in this study, gives the opportunity to study indestructibly fossil material with a very high resolution. However, virtual sections do not show collagen fibres organization and therefore, do not inform about deposited tissue type, which is crucial in paleohistological studies. Humeral and femoral virtual cross-sections were analysed, showing an empty medullary cavity and a low cortex porosity of 2% in the humerus and 7% in the femur.The endosteal bone is preserved only in the humerus. Vascular density (mostly simple longitudinal vascular canals) is high in both samples. Osteocyte lacunae are abundant in both sections, but are prominent in the humeral inner cortex. Three growth cycles can be distinguished in both samples. Based on the alternating deposition of vascular and avascular layers, it can assume, that the animal was most probably growing with lamellar-zonal bone (LZB). LZB is also preserved in the Polish *Stagonolepis* and the German *Aetosaurus*.

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Title: 14-1: XROMM analysis of flipper movement during locomotion in loggerhead sea turtles

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Sea turtle forelimbs take the form of large, wing-like flippers. Prior locomotor studies showed that their predominate swimming gait uses simultaneous dorsoventral flapping of both forelimbs (powerstroking). External video also showed that the flippers undergo substantial rotation, supinating during upstroke and pronating during downstroke. We used marker-based X-ray Reconstruction of Moving Morphology (XROMM) to quantify motions of the flipper relative to the humerus and the humerus relative to the pectoral girdle. Although the distal parts of the flipper are flexible, we found that the proximal 1/3 of the flipper blade acts as a rigid body

during powerstroking, with internal deformations causing rigid body error of less than 1 mm. We found that substantial long-axis rotation (LAR) of the flipper, with individual means ranging from 85 to 148 degrees, drive the flipper's angle of attack. Due to the abducted posture of the humerus and flexed elbow, we found that LAR of the humerus (individual means ranging from 45 to 124 degrees) acts to depress the flipper during downstroke and elevate the flipper during upstroke. These XROMM results show that the posture of the forelimb, LAR of the humerus, and LAR of the flipper blade combine to produce the distinctive sea turtle powerstroke.

Title: 35-7: Three-dimensional morphometric data reveals patterns of cranial evolution associated with habitat transitions in fossil and extant tetraodontiform fishes

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Habitat transitions provide unique opportunities to study adaptation and the origin of morphological novelty. Among vertebrates, pufferfishes, boxfishes, ocean sunfishes, and allies (order Tetraodontiformes) represent some of the most extreme cases of body shape evolution ranging from square-shaped boxfish to spheroid pufferfish. They inhabit a wide range of habitats, such as freshwater rivers, estuaries, coral reefs, and sandy flats. Earlier studies on Tetraodontiformes linked habitat transitions of reef-associated clades to higher rates of lineage diversification; however, little is known about how transitioning to reefs might have influenced morphological evolution in this group. Here, we use three-dimensional geometric morphometric data for 175 out of *ca.* 450 tetraodontiform species to examine widescale patterns of skull evolution in association with habitat transitions and ancient paleoclimatic changes. Preliminary results indicate that, relative to other groups of acanthomorph (spiny finned) fishes, tetraodontiform skulls are morphologically diverse, occupying a large area of the phylomorphospace. Reef-associated species have higher morphological disparity and tend to occupy the outer boundaries of the phylomorphospace, while non-reef species tend to cluster in the middle. Furthermore, reef-associated species exhibit faster net rates of skull evolution than non-reef species, indicating that the expansion of tetraodontiform fishes into coral reef habitats was potentially a catalyst for morphological diversification.

Title: 13-1: Trabecular bone distribution and its relationship to joint loading across the ape metatarsus

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Research has long sought to determine the relationship between trabecular bone structure and joint loading, which can, in turn, enable reconstruction of joint loading in fossil taxa and improve our understanding of behaviour in the past. Reconstructing the kinematics of bipedalism in fossil hominins is an important aspect in understanding human locomotor evolution and anatomical changes to the foot are a key part of this transition.

Here, we explore the relationship between locomotor behaviour and trabecular bone structure across the metatarsus of *Pan troglodytes* (N=8), *Gorilla* spp. (N=6), *Pongo* spp. (N=5) and *Homo sapiens* (N=5), including humans from both active and sedentary populations. Using a whole-bone method of trabecular analysis, we generate morphometric maps of the distribution of bone volume fraction (BV/TV), as well as calculating mean BV/TV, trabecular thickness (Tb.Th) and degree of anisotropy (DA) in the metatarsal heads.

We found that trabecular bone distribution corresponds with predicted loading of the metatarsal head, reflecting dorsiflexion in bipedal humans and knuckle-walking apes, and plantarflexion in the arboreal taxa. Mean values of trabecular bone structure reflect, overall, species typical trabecular bone architecture, with a high BV/TV in the knuckle-walking apes and a low BV/TV in humans. The human metatarsal heads are characterised by a uniquely high DA that likely reflects the highly stereotypical loading experienced during human bipedalism.

Title: P3-10: The propatagium as an evolutionary novelty in the lineage towards birds

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The propatagium, a membranous structure spanning between the shoulder and wrist, represents an evolutionary novelty acquired in theropod dinosaurs. In extant volant birds, the propatagial muscle runs along the leading edge of the propatagium, playing an important role in manipulation of wings during flight. However, since there is no comparable structure in the other vertebrates, how the propatagial structure evolved in the lineage towards birds has remained elusive. To solve this problem, in this study, we analyzed the developmental process of the propatagium and forelimb muscles in the chicken, as well as those of forelimb muscles in the alligator and turtle, through histological observations and *in situ* hybridization. In the chicken embryos, the myoblasts of the propatagial muscle became recognizable later relative to the muscle splitting of the other forelimb muscles. Concomitant to the development of forelimb muscles, the dermis of the leading edge of the wing became hypertrophied in the chicken, unlike in the alligator and turtle. The propatagial muscle developed adjacent to the hypertrophied dermis, devoid of tendon progenitor cells, suggesting that the propatagial muscle does not interact with tendon progenitor cells unlike the other skeletal muscles of the forelimb. It is likely that the hypertrophied dermis and the late migration of myoblasts towards the hypertrophied dermis of the forelimb had been involved in the evolutionary origin of the avian propatagium.

Title: P4-18: In-vitro experiment using alligator teeth to test the relationship between diets, frequency of food contact, and dental microwear texture

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Dental microwear texture analysis (DMTA) is a method of analyzing micro-scale three-dimensional surface roughness left on tooth surfaces to estimate paleodiets. According to a recent feeding experiment on alligators (*Alligator mississippiensis*), the individuals that fed on the harder food showed a rougher tooth surface texture. While the contribution of food hardness on microwear formation was revealed, the effect of the number of contacts with food, or bite count, remains unclear. To address this problem, *in-vitro* experiments were conducted, in which alligator teeth were thrust into food items to observe changes in dental microwear texture.

Three naturally shed teeth of pellet-fed alligators were used in this experiment. Each tooth was attached to a force gauge and thrust vertically into the crawfish. Firstly, 50 punctures were made at a speed of 120 mm/min, and it was visible that new scratches were formed while existing scratches disappeared. Microscopic enamel wrinkles, which originated from natural surface structure, became flattened. However, surface roughness parameters did not change significantly. Next, additional 50 punctures were made at a speed of 600 mm/min, but patterns of change in surface roughness varied depending on the teeth. Repetition of thrusting did not linearly increase surface roughness, probably due to the effect of flattening the enamel wrinkle and also the slower speed of the force gauge compared with the actual biting speed of alligators.

Title: Impacts of Quaternary climate change on shaping past reptile and frog species and communities along eastern Australian.

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Macroecology, describing the relationship between organisms and their environments across large spatial scales, provides significant insights into the processes shaping modern biodiversity. However, macroecological insights derived under current environmental conditions have inherent limitations because they fail to account for historical events. Integration of modern and palaeo data to investigate the temporal patterns of macroecological variation offers a robust way of assessing the impacts of past events on present-day biodiversity, thereby teasing apart the relative influence of these ‘shadows of the past’. Using existing palaeontology collections, we are integrating 3D imaging and new machine-learning analytical approaches to quantify how reptile and frog species and community composition has changed over the past 500,000 years across the full latitudinal gradient of eastern Australia. The first step in this research is to assess the current understanding of the Quaternary herpetofaunal fossils in eastern Australia. We

present an overview of current understanding and identify gaps. Ultimately, this research will allow us to determine how these faunal changes correlate with climate shifts past and present, with predictions into the future.

Title: 45-2: Grasping at primate touch: integrating genetics, histology, and ecology

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The origin and evolution of primates is associated with shifts in two sensory modalities: vision and manual touch. The derived features of the primate visual system (e.g., forward facing eyes, visual acuity) have been relatively well studied. Yet, while gasping has been explored anatomically, touch has received much less attention. Manual touch, especially precision touch (the ability to detect object shape, texture, vibration, movement), plays a key role in all aspects of primate daily life. Several ecological factors have been proposed to select for enhanced precision touch, including frugivory, arboreality, nocturnality, and tool use. However, comparative studies to evaluate these factors have been limited (and sometimes contradictory), in part due to the challenges of histological analyses. We have recently begun investigating the relationships between genetic, histological, morphometric, and behavioral metrics of precision touch. Here, we review some of our work on these metrics to better facilitate comparative studies of touch in primates and non-primate mammals. Overall, our results suggest strong relationships between traditional histological measures of precision touch (e.g., mechanoreceptor densities) and alternative measures, including gene expression, dermatoglyphic features, and digit ratios. These alternative metrics may be useful for large-scale comparative projects investigating ecological factors selecting for enhanced precision touch and will facilitate a clearer understanding of the origin and evolution of derived primate traits.

Title: P1-6: On the Development of the Avian Patella

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Although the embryonic development of the canonical elements of the vertebrate skeletal system has been extensively studied, the development of smaller *accessory skeletal elements* remains largely unknown. These elements include several types of bony eminences and sesamoids. Sesamoids are small and rather variable skeletal structures associated with the connective tissue of joints. During the past decade, a modular model of *accessory skeletal element* development has emerged, describing the formation of these structures from progenitor populations independent of the main bones around them. Nevertheless, this model has only been studied in

mice. In this work, I describe the development of the avian patella through both anatomical and molecular perspectives. The patella, or knee bone, is a large sesamoid in the lower limb with a wide distribution among different groups of tetrapods arising independently in, at least, mammals, lizards, and birds. A detailed study of the morphology and tissues involved throughout the development of the knee joint in chicken embryos will allow for informative comparisons with descriptions in mice. This analysis will test the reach of the modular model for *accessory skeletal element* development for a new lineage of tetrapods, and incorporate ontogeny as a source of information for understanding the repeated evolution of the patellar sesamoid.

Title: 1-2: Mesosaurs went through an environmental and dietary shift throughout their ontogeny

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The mesosaur *Mesosaurus tenuidens* is the first secondarily aquatic amniote and one of the most enigmatic early reptiles. Mesosaurs have a very peculiar morphology characterized by long needle-like teeth and paddle-like limbs. Here, we investigate how this morphology arises during their growth and whether it is accompanied by other ontogenetic changes. For this, we examine skull, tooth, and limb proportions, as well as the depositional environments of 270 mesosaur specimens in collections worldwide. Our results present evidence of surprising ontogenetic trends in these animals as well as new insights into their ecology. We show that mesosaur growth is marked by several changes in proportion with size: (1) tooth elongation, (2) skull reduction, (3) snout elongation, (4) hindlimb reduction, and (5) manus reduction. In parallel, we highlight a disparity in the environmental distribution of ontogenetic stages, with juveniles being more common in shallow water deposits, whereas large adults are more frequent in pelagic sediments. This combination of environmental and ontogenetic changes suggest that mesosaurs underwent a diet and lifestyle transition during growth, from an active predatory lifestyle as juveniles to a filter-feeding diet as adults. We propose this change in lifestyle and environments may have been driven by the pursuit of different food sources, although the nature of this food source remains unclear.

Title: 38-2: Skeletal Diversity in the Skin: Histological Variation and the Evolution of Lizard Osteoderms

Authors: Matthew Vickaryous[1], Gabriella Willan[2], Catherine Williams[3], Alex Kirby[4], Anthony Herrel[5], Loïc Kéver[5], Arsalan Marghoub[6], Shreya Rai[7], Arkhat Abzhanov[7], Edward Stanley[8], Susan Evans[9], Mehran Moazen[6]

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Osteoderms are mineralized organs present in the dermis of many species of tetrapods. Among lizards, osteoderms demonstrate considerable diversity in size, shape, and body-wide distribution. Although variation in their histological composition has also been reported, detailed multi-taxa comparisons are lacking. Here, we quantify the tissue-composition of adult osteoderms from 21 species of lizards, including members of three major osteoderm-bearing lineages: Gekkota (geckos), Anguimorpha (anguids, helodermatids), and Scincomorpha (scincids, gerrhosaurids). With one exception (the gecko *Geckolepis*), all lizard osteoderms are composed primarily of bone, albeit with a heterogenous and often laminated organization. While most osteoderms include a combination of organized (lamellar), woven-fibred, and/or Sharpey-fibred bone, the relative contribution of each bone matrix differs, even among members of the same genus. In addition, we found that multiple genera from each lineage independently develop a highly mineralized, collagen and cell-poor capping tissue – a feature previously restricted to less than a handful of species. Expression of capping tissue varies, from thick and well-defined (e.g.,*Tiliqua rugosa*) to discontinuous (*Pseudopus*) or entirely absent (*Shinisaurus*). In *Geckolepis*, tessellations of the capping tissue directly overlying collagen plates comprised the entirety of the 'osteoderm' structure, which therefore did not meet the definition of bone. We propose that the histological diversity observed in lizard osteoderms is driven by species-specific factors including phylogeny, ecology, and function. Funding: Human Frontier Science Program (RGP0039/2019)

Title: 1-1: Craniodental traits predict feeding performance and dietary hardness in a community of Neotropical free-tailed bats (Chiroptera: Molossidae)

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Form–function studies have established a strong link between dental morphology and the mechanical properties of food items, with animals evolving tooth shapes theoretically ideal for their diets. However, information on how teeth perform is rare, which limits the understanding of how dental morphology influences dietary ecology and niche partitioning. Free-tailed bats (Molossidae) are a diverse clade of insectivorous mammals with an outstanding variation in size and craniodental traits related to ecological segregation. We investigated the mechanisms that allow dietary specialization and trophic segregation among sympatric species. To do so, we coupled dental metrics, head and skull dimensions and feeding performance, and dietary hardness measurements. We found that molar topography and skull size vary in tandem with the mechanical demands of prey. This may be explained by feeding performance capabilities resulting from molar shape and the size of the feeding apparatus, which may allow efficient processing of foods with specific properties. For instance, bats with sharper, more complex

molars and gracile heads mainly feed on softer insects, whereas bats with blunter, less complex molars, and robust heads mostly feed on tougher prey. These results illustrate how the morphology and size of feeding structures, and how they perform, may facilitate trophic segregation. Similar mechanisms may help structure other mammal communities, therefore our approaches could be helpful to understand the ecomorphological traits and processes that underlie their diversity.

Title: 7-1: Comparative variation in kinematic transmission of the beak among birds

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Most birds exhibit cranial kinesis, and can rotate the upper beak relative to the skull. Cranial kinesis has been largely overlooked in birds, but may provide new insights into the relationship between bird form and feeding.

The avian kinetic system was modelled as a four-bar linkage system using lateral images of 315 species of bird. Kinematic Transmission (KT) was compared with diet data from AVONET, as well as with our own feeding method categories. Link lengths were also compared with KT for information on mechanical sensitivity of the system. The overall shape of the linkage system was also investigated to give an insight into mechanical equivalence.

We found no clear relationship between KT and diet; however when KT is combined with gape, separation of dietary groups is more significant. Principle components analysis of the shape of the linkage system revealed that mechanical equivalence is common in bird four-bar systems. Additionally, the majority of shape change occurs within the output of the system, and analysis of link lengths revealed that as in other four-bar systems, the output link, which corresponds to beak depth, is more strongly correlated with KT than the input. This is despite the fact that in birds, the output link is not the shortest part of the system, which was the trait previously believed to drive mechanical sensitivity.

Title: 31-3: A Functional Morphospace for the Feeding System of Coral Reef Fishes

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Coral reef fishes present exceptional trophic diversity that is based on diversity in the functional morphology of the feeding apparatus. We surveyed the diversity of the reef fish oral jaw system by measuring a series of 12 morphological traits that reflect key aspects of jaw functional morphology. To capture their broad phylogenetic diversity, measurements were made on 110 species from 42 families of coral reef fishes. We emphasize a comparison between species that feed primarily using suction to capture free-moving prey with species that using some form of biting behavior to capture prey that are attached to the substrate. Not surprisingly, we find a strong impact of principal feeding mode on morphology, with suction feeders typically having greater jaw protrusion, longer jaws, and intermediate sized adductor mandibulae muscles. The average biter has short jaws, a jaw joint positioned relatively ventral and anterior, but surprising diversity in the size of the adductor mandibulae muscle. This muscular diversity among biters reflects variation in the mechanical demands of removing prey that range from brushing detritus distributed among turf algae, tearing off pieces of tough sponges, and biting off pieces of calcareous coral. Our results support other recent findings that benthic biters are a major component of coral reef fish diversity.

Title: 33-2: Vertebrate Spines and Continuum Robots

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Vertebrate structures, most notably human arms and legs, have long served as inspiration for robotic counterparts. Mechanical designs based on a small number of long, thin rigid links are the basis for most robot manipulators and legged robots today. In recent years however, emerging applications are motivating the creation of robots with smoother profiles and more adaptable behavior. To provide both the mobility and structural support for such artificial “continuum robot” structures, new types of robots based on vertebrate spines, with a much larger number of small interconnected links, are being developed.

Herein, we discuss the interrelationship between the creation of such continuum robots and the natural structures which inspire them. We explore the potential for the crossover of knowledge between disciplines, resulting in the creation of new understanding of biological vertebrates. In particular, the ability in robots to create variations of the existence proofs observed in natural vertebrates offers the possibility of exploring, in robots, gaps in the fossil record, and asking “what if” questions. The discussion is supported by several case studies, including prehensile robot end effectors inspired by the tails of pangolins and syngnathids, as well as novel robot manipulators and continuum robot surfaces with internal structures directly inspired by the human spine.

Title: 12-7: Myological diversity of the masticatory apparatus of herbivorous mammals

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Masticatory muscle configurations, functions and dietary habits evolved in a diverse array of ecomorphotypes across mammalian lineages. Herbivorous mammals are traditionally classified as "ungulate-grinding" or "rodent-gnawing" morphotypes, although these categories do not adequately encompass the diversity of herbivores. We compiled topographical and weight data for masticatory muscles for 104 herbivorous and 10 non-herbivorous extant species of 14 orders, including novel data for 31 taxa. Additionally, we included inferred data for four extinct taxa. We constructed a myological phylomorphospace and proposed a comprehensive scheme of 15 masticatory mammalian morphotypes. Almost identical muscle proportions between early mammaliaforms and mammals and extant carnivores were recognized. Extant herbivores diversified along 13 morphotypes distributed along two main pathways, that did not reflect the traditional types. A complex scenario and different morphotypes are proposed for plesiomorphic herbivorous mammals, and one herbivorous morphotype cannot be differentiated from carnivores and generalized ones only considering muscle proportions. Differing from Turnbull's proposal, the large disparity of rodents cannot be encompassed by a single category or pathway. Features of some derived extant euungulates and diprotodonts resemble rodents, but only extant wombats and some extinct South American native ungulates closely converged with them, the latter including a morphotype falling outside the extant pathways. The here proposed scheme could be useful to understand the herbivore diversity and for selection of extant models when palaeobiological reconstructions are attempted.

Title: Musculoskeletal adaptations in macropodoids – convergence and functional analogues

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Morphological convergence, shared phenotypic traits representing adaptations to particular behaviours or environmental constraints, provide a useful way of understanding animal ecology and evolution. Certainly, the search for functional analogues between marsupial and placental mammals has been a mainstay in understanding and communicating marsupial diversity. From marsupial moles to 'Tasmanian tigers', the attribution of familiar names to unfamiliar animals provides an accessible way of broadly categorising animals, but is it possible to find true

analogues between these two groups, and if so, what are they? Marsupial moles are certainly 'moleform', but Thylacines are neither 'tigers' nor 'wolves'. More difficult again are the Macropodoids, kangaroos and their relatives, who are far more diverse than typically considered. As the dominant mammalian herbivores of the Australian continent, they range from diminutive rainforest inhabitants to large and specialized saltators of open arid areas, giant bipedal walkers and rock dwellers, and while most are terrestrial arboreal forms have evolved more than once. In reviewing recent research in this field, I present case studies that highlight some of the great diversity in morphology that belies the taxonomic classification of 'macropods', and propose some alternative hypotheses of marsupial-placental convergence.

Title: 8-1: Revisiting old questions with new methods: interplay between embryonic motility and craniofacial development

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Evolution of diverse viable jaw morphologies is thought to be linked to coordination of muscle and bone development by neural crest cells through mechanisms such as modification of the biomechanical environment by embryonic motility. To investigate how embryonic motility influences skull morphology, we replicated an historic experiment in muscle paralysis, taking advantage of new methodologies that allow us to quantify musculoskeletal anatomy more precisely. We induced muscle paralysis in developing chicks with injection of decamethonium iodide at 10 days of incubation and harvested at 17 days. We then compared the morphology of the jaw and cranium to untreated embryos using diffusible-iodine contrast-enhanced computed tomography (diceCT). Like the earlier study by Hall and Herring, we found consistent differences in the size and shape of the mandible in paralyzed chicks. In addition, we found that other muscle attachments were smaller or less ossified, including the attachments of the adductor mandibulae to the cranium and of the pterygoids to the mandible. These results highlight specific areas of the skull that appear to be mechanosensitive and suggest muscles that could produce the biomechanical stimuli necessary for normal hatchling morphology. Building upon this important work by Herring and others, we will use geometric morphometrics and 3D muscle fascicle tracing to test hypotheses linking muscle architecture to evolutionary and developmental morphological changes in feeding system of birds and other diapsid clades.

Title: 29-1: Polish Crested Chickens: A Promising New Model System with Aberrant Head Anatomy

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Vertebrate models, from zebrafish to zebra finch, have been indispensable for understanding the processes underlying head development and evolution. However, the capacity of existing model organisms to infer actual evolutionary changes is limited because they are often separated by extensive phylogenetic gaps. A comparative model system with a pair of closely related, yet phenotypically divergent, species would strengthen the inferential power of evo-devo studies. Here, we introduce a promising model organism—the Polish crested chicken (PCC)—with aberrant brain and skull morphologies. PCCs undergo cerebral herniation where the forebrain expands dorsally, leading to a prominent cranial protuberance with supernumerary foramina. Coupled with standard domesticated chickens, PCCs form a compelling comparative model system for investigating rapid evolution of cephalic structures. In this study, we use micro-computed tomographic (μCT) imaging and high-density 3-D geometric morphometric methods to visualize, model, and evaluate differences and changes in the head anatomy of PCCs to standard breeds. Results demonstrate that PCCs possess (*i*) a truly unique brain shape among modern birds; (*ii*) 'emissary' arteries from internal carotid branches that supply extracranial structures; and (*iii*) divergent brain-ventricle proportions. With this study, we demonstrate the utility and potential of PCCs as a model system to interrogate the emergence of novel morphologies and interactions between multiple head structures.

Title: P3-14: Development and evolution of the jaw joint and middle ear structures in the dinosaur-bird lineage

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The middle ear structure had independently evolved multiple times in the tetrapod lineage. In the mammalian lineage, in particular, the evolutionary transition from the jaw skeletal elements to the middle ear bones has been well documented, while in the other lineages, the evolutionary processes of the middle ear structures have remained insufficiently studied. To compensate for this problem, in this study, we focused on the evolution of the jaw joint and middle ear in the dinosaur-bird lineage. First, we performed observations of the developmental processes of the jaw joint and middle ear in the chicken, alligator, and turtle. Unlike the other diapsids, extant birds possess two processes extending caudally and medially from the mandible at the jaw joint, and the homology with the retroarticular process (RAP) of the other diapsids was unclear. Upon this problem, our observations are suggestive of that the medial process of the avian mandible is homologous to RAP, as it was observed that in chicken embryos, the caudal end, to which the mandibular depressor muscle attaches, secondarily changed its orientation medially. Concomitant to this embryonic transformation of RAP, the arrangement of the middle ear including the columella auris changed, and the external auditory meatus invaginated deeply. According to the fossil record, medially-oriented RAPs would have evolved in the Coelurosauria, thus it is possible that coelurosaurs were furnished with deep ear canals.

Title: 43-6: Evolutionary patterns in the composition of the tetrapod lower jaw

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Tetrapods (limbed vertebrates) are a diverse clade that originated around 390Ma and are seen today in over 30,000 species of amphibians, reptiles and birds, and mammals. Tetrapods have exploited a broad range of ecological niches through this time, and the lower jaw, as the primary feeding mechanism, has undergone substantial morphological and functional evolution. For instance, the earliest tetrapods had up to twelve elements comprising their jaw, whereas mammals have only retained one element. We wanted to understand how the composition of lower jaw elements changed through Tetrapoda. We coded the presence or absence of lower jaw elements for over 1000 tetrapod species. We also coded the presence and absence of teeth on variably tooth-bearing elements, and other characters that could be tracked across the tetrapod tree such as the presence or absence of a beak or a mandibular fenestra. We combined the species level data into clade scores and reconstructed the evolution of the individual elements through ancestral state reconstruction. We found that there have been losses in elements in nearly every tetrapod clade, but also multiple gains across the tree. Tooth-bearing elements have unilaterally decreased, resulting in simpler dental compositions towards the extant tetrapods. Our results demonstrate that the lower jaw has undergone significant compositional evolution over the last 390 million years, towards an overall simplified mandibular composition seen across living tetrapods.

Title: 25-5: First turbinals from an allotherian mammal from Meniscoessus robustus (Cimolodonta, Multituberculata) of the Late Cretaceous of North America

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Nasal turbinals are not well known among the extinct mammalian lineage Allotheria. The turbinals of spectacular gondwanathere crania were not preserved, and bone specks in cross-sections of the nasal cavity of the multituberculate *Kryptobaatar* have been the only remnants described. Study of CT scans of NSM 20436 (National Museum of Nature and Science, Japan), a cranium of the cimolodontan multituberculate *Meniscoessus robustus*, reveals partially preserved nasal turbinals in place in the posterior superior nasal cavity. We preliminarily identify these as the proximal parts of a complex ectoturbinal 1, proximal portion of ectoturbinal 2, and fragments of a third turbinal. The preserved turbinals are associated with at least three ethmoturbinal ridges; there are seven additional ridges occurring in a fan arrangement that extends to the posterior and inferior parts of the olfactory recess, visible on the ethmoid and orbitosphenoid. In

addition, a ridge corresponding to the tectal lamella of the nasoturbinal described in the gondwanathere *Vintana* is present. No maxilloturbinal is preserved, although there is ample space in the nasal cavity and it was likely present.

Allotherian mammals had proportionally large olfactory bulbs, so the discovery of extensive olfactory turbinals is unsurprising. The inferior and posterior extent of the turbinals indicated by ridges is similar to that seen in extant small terrestrial mammals, significant because this taxon is best known from stream channel deposits.

Title: 55-2: Shapes and traits that don't match: the thylacine as a mammalian evolutionary curiosity

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The thylacine's famously wolf-like skull shape represents an extraordinary departure from the marsupial shape, showing uncanny cranial phenotypic convergence with placental canid carnivorans. In this study, we analyse new and existing data to show that the combination of morphological traits exhibited by thylacines is complex and inconsistent with any living mammal. Using geometric morphometric analysis of cranial shape in marsupial and placental carnivores, we show that the thylacine skull has near-identical Procrustes distances from marsupials and canids due to being marsupial-like neurocranially and canid-like viscerocranially. In addition, its skull size is substantially larger relative to the species it is most convergent in shape with (small jackals and foxes), and overall larger than expected across our sample of carnivores. A morphological mismatch with other mammals is also evident from analyses of the limb and its proportions. Other unusual anatomical details of the snout in particular, which are not picked up by geometric morphometrics because they are only displayed by the thylacine, further contribute to the overall evidence that thylacines are a unique mammal. The extinction of the thylacine therefore represents an even more serious loss to mammalian biodiversity than previously appreciated. The study of the thylacine continues to promise important future insights into the adaptive basis of the evolution of mammalian form.

Title: P1-18: Ozboneviz: A virtual 3D database of Australian vertebrate fauna skeletons

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Vertebrate skeletal morphology sits at the core of comparative zoology, palaeontology, and zooarchaeology. Access to well-curated comparative reference collections is therefore crucial for researchers working in these fields. However, Australian local reference collections vary in quality and coverage; moreover, the rapid extinction of many Australian vertebrates over the last 230 years means that some specimens are extremely rare. Access to comprehensive samples of skeletal anatomy is therefore time consuming, expensive, and inequitable. Here, we report how the Ozboneviz database addresses these issues in a specifically Australian context. Ozboneviz is supported by the Australian Research Council Centre of Excellence for Biodiversity and Heritage (CABAH). It uses MorphoSource to provide high-quality digital representations of ten target bones for >100 Australian/New Guinean vertebrates, using a mixture of CT scanning, surface scanning, and photogrammetry. Ozboneviz works in collaboration with diverse collections in Australia, and is a use case for the value of larger-scale collections such as the oVert network. In this poster, we will reflect on the consultation process for designing the database, and expand on copyright and intellectual property concerns arising within Australia. We discuss issues of sustainability and maintenance, highlight already existing research outcomes arising from Ozboneviz, and share our experiences with the dissemination of the database to the public through diverse outreach avenues.

Title: 35-5: How to measure color pattern variation in coral reef fishes

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Color is a rich source of biological information, especially among reef fishes, whose color patterns are widely studied in evolutionary, ecological, behavioral, and developmental contexts. Given that fishes lose their color in preservation, a practical way to collect large datasets on reef fish color is typically to use images aggregated collected in the field, often across many locations and field seasons. However, most metrics for color are restricted to point measurements or require expensive equipment and restrictive conditions that cannot be applied to aggregate datasets. We present a new method and software for comparing color pattern variation that works even with images from multiple sources. First, we align images and remove backgrounds with landmark registration, producing a stack of ‘homologous’ raster images of identical dimensions. We then classify each pixel in each raster image into one of a set of color classes, which can be done automatically (if images are relatively consistent) or with manual editing (if images vary widely). On the resulting raster stacks, we can apply any dimension reduction technique (e.g. principal components analysis or linear discriminant analysis) to analyze variation of one color class or the color pattern as an aggregate. We demonstrate the use of this method for characterizing both within-species variation and between-species variation, and discuss the challenges, promises, and future directions of color pattern analysis in reef fishes.

Title: 18-1: Sabertooths and beyond: a review of hypertrophied canines and their uses

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Sabertoothed predators are among the most instantly recognizable of all fossil organisms. Their elongated, blade-like canines, which have evolved repeatedly in many lineages, have fascinated scientists and non-scientists alike. However eye-catching, these teeth are just one example of a broader category: hypertrophied canines. Although no firm definition exists for what constitutes a “sabertooth”, comparison with related taxa in any specific case makes it easy to agree what ‘hypertrophied’ means. Thus, walrus canines are hypertrophied by comparison with other pinnipeds, musk deer canines by comparison with other ruminants, and machairodont canines by comparison with other cats. This overview presentation will discuss the diversity of structure and function of hypertrophied canines among living and extinct Therapsida, from gorgonopsians of the Permian to walruses of today, setting the stage for more detailed presentations to follow. The presentation will introduce a number of topics related to hypertrophied canines. For instance, in non-predators, are (or were) the canines only for display or also for defense or intra-specific combat? In extinct non-predators, were the canines only present in males or also in females? Did all sabertoothed predators kill their prey in the same way? If not, how did they differ? Were all supposed sabertoothed predators really active hunters? And finally, the most discussed and controversial question of all: how, precisely, did “sabertooths” ′kill their prey?

Title: 43-5: Biomechanical basics for the evolution of cranial openings in amniotes

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Most important progress in our understanding of the functional morphology of the vertebrate skull was made by the application of the Finite-Element-Systems-Method. A first approach focusses on the investigation of stress distributions in existing, often extremely well-documented structures, called the FES-Analysis (FESA). A second approach is used in order to find out why at all the observable structures exist. In the latter case, an ample Bauraum is provided to which mechanically relevant forces (bite forces, muscle forces, weight) are applied and pre-existing shape characteristics are considered (sensory organs, brain). This application is called the FES-Synthesis (FESS). In the present study, we provide a basal view on skull biomechanics and offer a framework for more general observations using such modeling approaches in the future. We concentrate our discussion on the cranial openings in the temporal skull region and work out two major, feeding-related factors that influence the shape of the skull. We argue that (1) the place where the strongest biting is conducted as well as (2) the handling of resisting food (sideward

movements) constitute the formation and shaping of either one or two temporal arcades surrounding these openings. Diversity in temporal skull anatomy among amniotes can be explained by specific modulations of these factors with different amounts of acting forces which inevitably lead to deposition or reduction of bone material.

Title: P2-9: Correlation of precipitation and hatchling morphology in sea turtles Caretta caretta and Chelonia mydas

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The loggerhead sea turtle (*Caretta caretta*) has a worldwide distribution and spends most of its life in marine and estuarine environments. The green sea turtle (*Chelonia mydas*) also has a worldwide distribution. Nevertheless, the Atlantic and Pacific Ocean populations are more genetically isolated from each other. We used morphometric and geo-climatic data from the literature and field measurements from all over the world to assess the response of sea turtles to changes in temperature and precipitation on land. The hatchlings of *Ca. caretta* and *Ch. mydas* are growing larger (straight carapace length) as the precipitation increases in the nesting sites. According to the most recent IPCC report, the projected changes in precipitation may not differ greatly from their current values, except for an increase in seasonality, with spring becoming drier and autumn becoming wetter. Here we found that *Ca. caretta* shows an increase in straight carapace length as annual precipitation increases. Still, a decrease is seen in *Ch. mydas*. These observed trends may provide a glimpse of the ways in which the ecosystems may respond to changes. Although as the temperature rises, jellyfish become more abundant in the zooplankton and can support larger individuals, the concomitant decline of shrimp-like elements in the plankton that supports sea birds may increase the predation rates on turtle hatchlings that are larger.

Title: P2-10: Functional morphology of the skull of Henodus chelyops (Placodontia)

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The Upper Triassic "one-toothed turtle-like" sauropterygian *Henodus chelyops* is only known from Tübingen-Lustnau, Germany. The body is covered by a shell; the limbs and neck are short. The skull is rectangular, and in many regards, it mimics that of modern turtles, but with one tooth "left" on each jaw. In total, eight skeletons are preserved, incl. seven skulls. We re-described the skull anatomy of the species taking intraspecific variation into account. Using the Anatomical Network Analysis (AnNA), we studied the functional morphology of the skull, also based on different historical reconstructions of its anatomy. We found a left-right modular separation of the skull, which indicates unilateral bite with the remaining placodont tooth. This differs from a turtle, in which a separate snout module was described and which is associated with the turtle beak. Other functional modules vary among different *Henodus* skull reconstructions, highlighting the sensitivity of the AnNA-approach. Using FEA, we also studied detailed stress and strain distributions in the skull. In union, we receive a good picture of functional anatomy and provide hypotheses on major forces acting on the skull. Much of the skull shape can be explained by the specific biting in *Henodus*. In addition, neck retraction forces might enforce the stepwise closure of the upper temporal openings in *Henodus*, mirroring what likely happened in early turtle evolution.

Title: 43-1: The Perks of Being a Eupercarian: Rapid Skull Shape Evolution in a Massive Radiation of Bony Fishes

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Eupercaria, an enormous clade of teleost fishes, reigns supreme as one of the most diverse clades of vertebrates, extant or otherwise. They have colonized all seven continents, their range extends to almost every aquatic habitat from freshwater to the deep sea, and they exhibit numerous distinct ecologies and morphologies. Accordingly, many questions remain about the drivers of this radiation and how rapidly the diversification took place. Here, we use 3D geometric morphometrics, phylogenetic comparative methods and a novel phylogenetic hypothesis based on exon capture genomic data to quantify the tempo and mode of skull shape evolution across 600 species of Eupercarian fishes. We find a rapid burst in the rate of skull shape evolution and an increase in morphological disparity that roughly coincides with the KPG extinction event 66 mya, suggesting that this mass extinction event opened niches that ancestral eupercarians then rapidly filled. Finally, within eupercarians we find high rates of morphological evolution and disparity in Acanthuriformes and Tetraodontiformes while other clades like Perciformes and Labriformes exhibit intermediate levels of morphological disparity and rates of skull shape evolution. We hypothesize that habitat and diet played important roles in promoting the rapid diversification of the eupercarian skull during the Cenozoic.

Title: 18-4: Comparative serration histology in hyper carnivorous fossils

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Serrated, blade-shaped teeth have convergently evolved in a range of carnivorous taxa. The gross morphology of serrations suggests a stereotyped morphology and function; however, increasing histological sampling has revealed that there is underlying morphological and functional diversity in serrations. Here, we present comparative histological data from a theropod dinosaur, an early apex synapsid predator *Dimetrodon*, a saber-toothed gorgonopsian therapsid, and the extinct saber-toothed cat *Smilodon*. These data reveal two important findings regarding the evolution of serrations in extinct vertebrates. First, we find a wide range of tissue compositions and arrangements in the taxa sampled with dentine and enamel contributing–in varying proportions–to theropod, *Dimetrodon*, and gorgonopsian serrations.
Interestingly, *Smilodon* serrations are entirely composed of enamel which may be related to phylogenetic constraints associated with mammalian tooth development. Second, we find convergence in the composition and arrangement of dentine and enamel in theropod dinosaurs and gorgonopsian therapsids. Their serrations formed through developmental folding that allow for greater abundance of serrations along the edges of their teeth as well as greater force dissipation. The variation and convergence of serration histology presented in these data reiterate the importance of examining tissue-level structure to assess cryptic diversity in morphology and functionality of dental structures, especially those that are abundantly present in both extant and extinct taxa.

Title: 2-4: Mass extinctions make way for mitochondrial metabolic endothermy in amniotes

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Amniotes include the only living animals capable of metabolic thermoregulation (endothermy). They generate heat as a by-product of mitochondrial respiration. While potential co-evolution between metabolism and environmental or ecological perturbations has previously been suggested, the nature of such feedback mechanisms is yet unknown, largely due to the lack of a metabolic proxy integrable across of living and extinct taxa.

Here, I present a novel molecular metabolic marker detectable in modern and fossil skeletal tissues via non-destructive vibrational spectroscopy: systematic analysis (500-3000 cm^{-1}, 10 replicates) of >80 modern and fossil amniote long bones, sampled with special emphasis on time

intervals before and after Mesozoic mass extinctions, demonstrated that the quantity of metabolic lipoxidation markers, byproducts of aerobic respiration, correlates (r=0.87) directly to the basal metabolic rate. The effect of fossilization is empirically captured, modelled *in vitro* and *in silico*, and corrected, allowing for the integration of metabolic signals in living and extinct taxa: tracing the evolution of metabolic rates across a time-scaled consensus phylogeny allowed for the comparison of trends in the emergence of endothermy and its downstream manifestation in bone-microstructure and morphology. We find a significant, positive correlation between the observed five independent evolutionary origins of metabolic endothermy and niche space availability after the P/T and K/Pg mass extinctions, and discuss the impact of ecological versus environmental variables on the selection for increased metabolic fitness.

Title: 8-6: Bendy Hyoids: In-Vivo and Ex-Vivo Loading and Stiffness of the Hyoid Arch in Elasmobranchs.

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Despite having cartilaginous skeletons, many elasmobranchs bite or crush vertebrate bone and hard-shelled invertebrates. The ability to produce and withstand these crushing forces is thought to be linked to tesserae. *In vivo* deformation and *ex vivo* stiffness of the hyoid cartilages was investigated in ecologically and phylogenetically diverse elasmobranch species to better understand their function during food capture. We evaluated two hypotheses: 1) the hyomandibula routinely bends during food capture, and; 2) the ceratohyal element is stiffer in suction feeders relative to other prey capture modes. We measured strain in the hyomandibula of live fish during voluntary feeding or muscle/nerve stimulation to determine whether bending occurred during mouth opening and closing. Whole cartilages were loaded to yield under compression to measure Young's modulus (E) and calculated the second moment of area (I), a proxy for stiffness, from cross-sections. In-vivo results show strong evidence that the hyomandibula bends during mouth opening and closing. In contrast, neither measure of stiffness (E or I) differs significantly among suction feeding, suction biting and ram biting species for either element. DFA reveals that the morphological variables used in this study can separate ram feeding from modes that use some suction. Young's modulus does not discriminate as well among feeding modes. Perhaps morphological variables related to strength, rather than stiffness, are another place to look for patterned variation among these groups.

Title: 25-1: Rethinking animal domestication as a process, with degrees and diversity

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Words and phrases are essential to encapsulate and convey meanings. Usually those meanings are assumed to be universally understood but, unfortunately, many essential terms in biology carry implications that either restrict or slightly shade their meaning. Those ancillary influences, in turn, can subtly affect the questions that are asked and the directions of research carried out. The term “animal domestication”, the focus of this talk, carries such ambiguities. The phrase has a dual meaning, denoting both an end-state and a process, and this distinction is not always made clear. It is also usually taken as a binary condition, with an animal breed being regarded as either “domesticated” or not. In this talk, I will put the argument that domestication is most usefully thought of as a process , one that exists as a matter of stages and degree, and which can yield significant differences in its outcomes in different species. I will show how vertebrate domestication can and perhaps should be reconceptualized in these terms, as a generic process yet one that yields somewhat different end-states in the different species, where those differences can matter. This view has distinct implications for how domestication can best be investigated and such approaches will be discussed.

Title: 44-2: Nanoscale Investigation of an Enigmatic Skeletal Tissue type: Lizard Osteoderm Capping Tissue

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Many lizard taxa develop skeletal plates or osteoderms within the dermis. Osteoderms from some species include a highly-mineralised and cell-poor capping-tissue of unknown composition. Although this capping-tissue, termed ‘osteodermine’, was initially identified in fossil taxa, we have confirmed the presence of a similar cell-poor layer in representative extant members of Anguimorpha, Scincomorpha, and Gekkota. To interrogate this enigmatic tissue, we employed phase-contrast synchrotron nano-holotomography in samples of the capping-tissue and underlying osteoderm from six modern taxa: *Heloderma, Pseudopus, Broadleysaurus, Tiliqua, Tarentola*, and *Geckolepis*. Our high-resolution data reveals that capping-tissue is distinct from bone, dentine, and enamel. Unexpectedly, our findings reveal considerable inter-specific variability. While osteocytic lacunae and interconnecting canaliculi are absent from *Geckolepis* capping-tissue, in other species they form extensive but taxonomically variable networks. For example, in *Broadleysaurus*, the capping tissue is heavily invested with canaliculi emerging near-vertically from osteocytic lacunae, which form a horizon adjacent to contact with the

underlying bone. In contrast, lacunae in *Heloderma* occur sparsely throughout the capping layer, with canaliculi being more radially arranged, while in *Tiliqua* lacunae are organized into horizons. We documented differences electron density within capping-tissue of some species, periodicity of deposition or variability in chemical composition. When combined with serial histology, our data suggests that, similar to bone, the capping layer of lizard osteoderms is a dynamic tissue capable of remodelling.

Supported by HFSP and ESRF.

Title: 9-5: The influence of diet on dental complexity in damselfishes

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Fishes represent almost half of all vertebrate diversity and demonstrate an incredible range of dental diversity, but their dentitions are vastly under-studied. We expect tooth complexity to correlate with diet based on findings within other vertebrate lineages but quantitate methods have yet to be applied to fishes to confirm whether this pattern extends beyond tetrapods. Methods based on advances in 3D-imaging and analysis techniques, known as Orientation patch count rotated (OPCR), have been used to reliably measure surface complexity of mammal and saurian reptile teeth. These analyses reveal herbivorous taxa possess higher overall tooth complexity than other dietary groups. We use microCT scanning and OPCR to determine whether overall dental complexity across the oral jaws correlates with diet in the speciose and ecologically diverse damselfishes (Pomacentridae). Using a phylogenetic comparative framework, we test the hypothesis that herbivorous species have significantly more complex dentitions than omnivorous and planktivorous species. Our results confirm that tooth complexity correlates with diet in damselfishes, with herbivorous damselfishes exhibiting significantly higher tooth complexity than non-herbivores. However, in contrast to mammals, we demonstrate that dental complexity increases anteriorly in herbivorous lineages. This work suggests that herbivory imposes consistent selective pressures, driving adaptive shifts toward more complex tooth topologies across vertebrates. This research is supported through grants from Clemson University, the Society of Integrative and Comparative Biology, and the Society of Systematic Biologists.

Title: 3-5: Morphology, Movement, and Mastication: Dr. Sue Herring's Impact on the Study of Mammalian Chewing

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Dr. Sue Herring's research contributions relating to the mammalian feeding apparatus span an incredibly prolific 6 decades. The legacy of her work is enormous. From describing cellular and tissue structure as it relates to function to understanding morphology in the context of whole organism behaviors, her research touches on virtually all aspects of mammalian feeding apparatus form, physiology, and biomechanics. Her work bridges anatomy, comparative morphology, and carefully designed experimental studies, often utilizing novel experimental methods and morphological approaches to describe structure-function relationships of muscles, bones, cartilage, and other tissues. In this talk, we leverage Dr. Herring's fundamental contributions to research on mammalian feeding as inspiration for discussing ongoing research and questions in mammalian mastication. Emphasizing technological innovations for characterizing movement, which were not previously available to Dr. Herring, we address how her many insights on mammalian feeding lay the groundwork for ongoing explorations of masticatory dynamics to address comparative evolutionary and clinical questions. We focus on her discoveries and their subsequent impact in several areas including postnatal growth and the ontogeny of mastication and jaw muscle function. Finally, we will discuss avenues and challenges for future work on mammalian mastication, and how Dr. Herring's contributions and the advice she gave in 1988 aimed at functional morphologists, particularly experimentalists, still set the standards and expectations for the future of our field.

Title: 29-5: Modularity patterns in mammalian domestication: assessing developmental hypotheses for diversification

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The neural crest hypothesis posits that selection for tameness resulted in mild alterations to neural crest cells during embryonic development, which directly or indirectly caused the appearance of traits known as the "domestication syndrome" (DS). Morphological data supporting this hypothesis are limited and the validity of the DS has been questioned. Using the frameworks of morphological integration and modularity, we assessed patterns that concern the embryonic origin of the skull and issues around the neural crest hypothesis. Geometric morphometric landmarks were used to quantify cranial trait interactions between six pairs of wild and domestic mammals, comprising representatives that express between five and 17 of the traits included in the DS. We predicted the presence of neural crest vs mesoderm modular structure to the cranium, and that elements in the neural crest module would show lower magnitudes of integration and higher disparity in domestic forms compared to wild forms. Our findings support modular structuring based on tissue origin (neural crest, mesoderm), and low module integration magnitudes for neural crest cell derived cranial elements, suggesting

differential capacity for evolutionary response among those elements. Covariation between the neural crest and mesoderm modules accounted for major components of shape variation for most domestic/wild pairs. Contrary to our predictions, however, we find domestic/wild pairs share similar integration magnitudes. Higher disparity in domesticates is not associated with magnitude changes to integration.

Title: 19-2: The universal wear process: mandible microwear texture analysis of crickets raised on different diets

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Animals have evolved tools for comminuting diverse foodstuffs. While vertebrates possess mineralized teeth, insect mandibles often bear serrated cusps hardened by metal inclusions. Feeding experiments have shown that microscopic dental enamel wear marks (microwear) are caused by contact with ingesta.

To test if insect mandible microwear is also diet dependent, we kept freshly molted adult two-spotted crickets (*Gryllus bimaculatus*) for 4 weeks on alfalfa-based rodent pellets with and without added mineral abrasives (loess, quartz, volcanic ash). Six individuals each were terminated after 1, 3, 7, 14, 21 and 28 days.

Crickets on all diets showed progressive mandible wear. Measurement locations along the distal cusp were differently affected. Furrow depth increased strongly from day 1 to 3 on diets with large quartz and volcanic ash particles and was significantly larger than on the control diet after 28 days. Complexity of wear marks increased from day 1 to 28, while surface roughness increased on diets with large abrasives.

The results are comparable to observations made in guinea pigs fed the same diets in previous experiments. Cricket mandible wear progressed faster, and was affected by all abrasives, but similarly to guinea pigs, large quartz and volcanic ash caused the deepest, most complex lesions. This indicates a universal wear process, supporting that microwear analyses might be useful for diet inference in invertebrates.

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Title: 5-6: Adaptation and integration in the muscle moment arms of two hip extensors in caviomorph rodents

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Lever-arm mechanics are often used to understand how the vertebrate locomotor apparatus is adapted to specific lifestyle-dependent functional demands. In interspecific ecomorphological studies, the length of a muscle's osteological in-lever is commonly used as a simple indicator of the muscle's force-generating potential. However, this static perspective does not account for the dynamic changes that a musculoskeletal lever-arm system undergoes during locomotor performance. Here, we use the software Maya to virtually model the dynamic changes of muscle moment arms (MMAs) throughout a joint's range of motion. As a study system, we investigate the MMAs of the two hip extensors gluteus medius and biceps femoris using virtual models of femora and pelves from approx. 50 species of the diverse clade of caviomorph rodents. We aim to understand how the MMA reflects the needs of different lifestyles, how MMAs of different muscles acting on the same joint are integrated throughout locomotion, and which underlying morphological differences are responsible for changes in the MMAs. First results indicate that the length of the MMA of the glutes medius is a sigmoidal function of the hip extension angle. Differences among lifestyles are most pronounced at smaller extension angles, with arboreal species displaying larger MMAs compared to their fossorial and cursorial relatives. This could reflect the need for powerful hip extension when climbing in a crouched posture as compared to terrestrial locomotion.

Title: 51-2: Testable Narratives of Evolution: Walter J. Bock's Account of Historical Explanation in Biology

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In addition to his contributions in functional morphology, Walter J. Bock wrote extensively about the nature of explanation in biology. Through a series of papers, he developed an explanatory dichotomy intended to capture questions derived from the causal duality proposed by Ernst Mayr. Bock's dualistic model distinguishes functional explanations, which give an account of proximal causes in the form of nomological-deductive explanations, from evolutionary explanations, which give an account of ultimate causes in the form of historical-narrative explanations. His insight that explanations about biological classification and evolutionary history are distinct from those about functional morphology, and that the latter are necessary components of the former, was fundamental to showing how adaptive scenarios, which aim to reconstruct evolutionary histories, could be objectively evaluated. For Bock, adaptive scenarios were not merely just-so stories, but scientifically rigorous explanations constructed from an argumentative chain of functional explanations. They are, therefore, tested by evaluating the causal linkages among the relevant functional explanations and by judging the plausibility of the entire narrative when compared against rivals. Although his philosophical contributions to the nature of explanation have largely been ignored by biologists and philosophers alike, Bock should be recognized for emphasizing the uniqueness of historical explanations in biology and

for his pioneering efforts to justify the objectivity and testability of biological narratives in evolution.

Title: 2-2: Disentangling drivers on morphological change through time: Late Quaternary evolution of the endemic Eivissa (Ibiza) Wall Lizard

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Understanding how phenotypes respond to environmental, inter- and intra-specific shifts is crucial to combatting the current biodiversity crisis. We present the iconic Eivissa Wall Lizard *Podarcis pityusensis* as a unique model to link micro- and macro-evolution over a geological timescale, Eivissan islands acting as a 'natural laboratory' to investigate drivers on morphological change. Fossil jaw shape spanning the last 30,000 years is analysed using 3D geometric morphometrics; this period encompasses major ecological shifts (including the last glacial maximum ~18,000 ya), isolation of islet populations (varied dates) and human arrival (~4000 ya), before rapid urbanisation during the last century. Jaw shape is analysed alongside bite force and population dynamics in modern *P. pityusensis* populations which inhabit diverse habitats and exhibit diverse life history strategies. Modern Eivissa wall lizards show low morphological disparity and contrary to trends observed in other island lizards, *P. pityusensis* displays an increase in size since human arrival. Larger body size is associated with stronger bites in modern *P. pityusensis* communities, with bite force also influenced by population dynamics. Thus, this system elucidates effects of human-induced pressures such as habitat fragmentation, predation and urbanisation on morphology and life history strategy. Studying shape in one species over a macroevolutionary timescale allows us to disentangle drivers on morphological evolution, generating findings that can be applied while drawing conservation priorities for island reptiles across the globe.

Title: 11-2: Evaluating femur volume as a predictor of body size in Pseudosuchia

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Throughout their 250-million-year evolutionary history, members of Pseudosuchia diversified into terrestrial, semi-aquatic, and fully aquatic niches. The biology of *Alligator mississippiensis* (alligator) is the most extensively studied of all extant pseudosuchians, making it an exemplar for interpreting biological variables of its extinct relatives. Of particular paleobiological interest are linear measurements of limb bones, skull metrics, and total body length as predictors of body mass, but results cannot account for the extreme allometric differences in body mass between captive and wild crocodylians or sexual size dimorphism. This study investigates the novel use of alligator femur volume as a proxy for body mass. Captivity status, sex, mass, total length, and skull length were recorded for 61 deceased alligators. Ordinary least squares regressions modeled the relationship between the femur variables of length, midshaft circumference, and volume and those of body mass, total length, and skull length. ANCOVAs were performed on each model to investigate sex and captivity status as covariates. Results confirm that femur volume is a strong predictor of body size variables and mitigates allometric differences introduced by captivity status and by sex. This study then uses femoral volume and its relationship with the examined variables to predict the body mass of extinct pseudosuchians independent of individual variation in growth rates, environmentally induced effects on growth, and size dimorphism.

Title: 4-5: Evolutionary dynamics of the synapsid pelvis and femur provides insight into the origin of mammalian limb posture

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Most mammals exhibit parasagittal limb postures and excursions during terrestrial locomotion. In contrast, the ancestors of mammals, the non-mammalian synapsids (NMS), used sprawling limb postures and horizontal excursions. Exactly how and when mammalian-style limb posture and movement evolved remains unresolved. Here, we aggregated a large dataset of 13 linear and angular measurements from the pelves and femora of extant mammals and reptiles (n=47) and extinct NMS (n=91) and compared them using contemporary morphometric and phylogenetic comparative methods. Our analyses suggest several key findings. First, the morphology of these bones among NMS is largely distinct from modern forms, emphasizing that the extant "sprawling-to-parasagittal" postural continuum is insufficient to characterize synapsid diversity. Further, evolutionary modeling points to multiple shifts in trait optima among synapsid grades for the femur but only one shift for the pelvis, pointing to a mosaic pattern of hindlimb evolution. Despite each bone following its own evolutionary trajectory, both the pelvis and femur become more gracile and elongate with less area for muscle attachment, reflecting a broad trend to more mechanically efficient musculoskeletal geometry. Overall, the evolutionary dynamics of the pelvis and femur suggest synapsid hindlimb evolution was complex and that the origin of mammalian-style posture was protracted. A deeper investigation into how morphology translates to function may help shed further light on the evolution of parasagittal limb posture and movement.

Title: 1-6: Head Shape, Foraging Strategies, and Prey Selection in Two Sympatric Sea Turtle Species

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Sea turtle head shape varies with diet, ontogeny, and phylogeny. Robust heads with wide, v-shaped jaws are common among the Cheloniidae. However, two species stand out in having distinctly different head shapes. At one extreme is the blunt-faced green turtle (*Chelonia mydas*) with u-shaped mandibles; the other is the hawksbill (*Eretmochelys imbricata*) with an elongated face and narrow, v-shaped jaws. We hypothesized that these two extremes reflected where and how each species forages, promoting different patterns of facial development during ontogeny. To test these ideas, we recorded observations on both species while feeding on Hawaiian reefs. We also measured head shape in live turtles and skull shapes of immature and adult turtles, focusing on facial vs. neurocranial proportions and jaw shape. Facial elongation compared to neurocranial proportions was most pronounced in juvenile hawksbills but in adults, proportional differences were reduced. In green turtles, facial vs. neurocranial elongation differences in juveniles to adults were less extreme. The two species occur sympatrically on shallow reefs where both forage on algae. While hawksbills fed on algal colonies located in crevasses (often removing obstructions to gain access to particular kinds of algae), *green turtles* scraped algae from larger colonies growing on open flat hard surfaces. Thus, facial proportions appear suited to efficient, but contrasting, dietary preferences and foraging techniques in each species.

Title: 26-1: Paleoneurobiology of the Tetrapod Olfactory Bulb Inferred from Extant Chemoreceptor Repertoires

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To date, the only window into inferring olfactory capabilities in fossils is using the olfactory bulb ratio, which is defined as the ratio between the largest diameter of the olfactory bulb and the cerebrum. There are direct interpretations of the functional implications of olfactory bulb ratio, such that the number of glomeruli cells within the olfactory bulb may directly reflect the number of distinct converging olfactory sensory neurons that express singular alleles of olfactory receptor genes. Thus, the larger the olfactory bulb relative to brain may reflect a greater number of environmental odorants the brain can interpret, but the relationship has not been explicitly tested as a rule for tetrapods. Using number of intact chemoreceptors (both olfactory and

vomerolfactory genes) as a response, we used a Bayesian hierarchical model to predict olfactory bulb ratios in extant tetrapods. Of the > 300 tetrapod genomes available, compiled complementary morphological and genetic data for ~200 specimens. Through incorporation of all possible chemoreceptor genes, we discovered a very tight relationship of osteological proxies and number of chemoreceptor genes. Thus, the predictive abilities of fossil morphology to understand the genomic basis of chemosensory diversity in extinct dinosaurs is possible. Using the olfactory bulb ratio of > 200 tetrapod fossils, we inferred the chemoreceptor repertoire size to help unveil shifts in expansions and contractions at the genomic level during tetrapod diversification.

Title: 6-1: Sharks, smarts, and headstarts: Brain evolution in cartilaginous fishes

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Although historically believed to be pre-programmed eating machines, with small brains responsible for processing primarily olfactory input, we now know that sharks and their relatives (Class: Chondrichthyes) possess a battery of highly developed sensory systems, are capable of a wide range of complex behaviors, and have relative brain sizes that are comparable to birds and mammals. Broad variability has also been documented within cartilaginous fishes regarding the size and complexity of the brain and its major regions (olfactory bulbs, telencephalon, diencephalon, mesencephalon, cerebellum and medulla). This variability is often associated with primary habitat, life history traits, or specific behavior patterns, even in phylogenetically unrelated species that share certain lifestyle characteristics, potentially providing a link between brain form and function. This talk will review much of what we know about the brain to date across three major axes: (a) how brain organization varies interspecifically across cartilaginous fishes, including ways we're incorporating high resolution bioimaging to explore the brain *in situ*; (b) how brain organization varies intraspecifically, both in terms how the brain changes normally throughout the life of a single species, as well as (c) in experimental models, where we can assess brain plasticity in different environmental conditions. Taken together, these data suggest that patterns of brain organization may allow us to make predictions about the behavioral ecology and sensory specializations in these unique fishes.

Title: 33-7: Hole in Two: describing the basivertebral foramina in Tardigrada

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Sloth vertebrae possess two foramina on the ventral surface of the centrum. This character, the intrarachidian or basivertebral foramen, has not been examined in developmental,

biomechanical, or functional contexts. We describe this morphology and note patterns through the vertebral column, development, and between taxa. The foramina are present in all trunk vertebrae and occasionally the cranial sacrals in all sloths, including fossil taxa. They lead into canals that traverse the centrum and exit at the dorsal foramina for the basivertebral veins, intrarachinian circulation, or intraspinal venous circulation, as described by de Burlet in 1920. In some specimens, only one foramen is present, typically the left. This occurs more often in cervical vertebrae but occasionally in thoracics and lumbars. The cranio-caudal length of the foramina correlates significantly with other vertebral dimensions, with fossils often exhibiting more positive allometry than extant taxa. In adults and juveniles, these foramina are largest in caudal thoracic and lumbar vertebra and smallest in cervicals, although they are relatively smaller in juveniles. Among neonates, the foramina are comparatively large, spanning almost the entire craino-caudal length of each centrum throughout the vertebral column.
In *Bradypus* and *Pseudomegatherium*, the wall between the two foramina has been resorbed in some lumbar and thoracic vertebrae, creating a single, wider foramen. This morphology presents an opportunity to further examine anatomy and functional morphology of sloth vertebrae.

Title: P1-12: The chondrocranium of the common musk turtle (Sternotherus odoratus, Kinosternidae, Cryptodira, Testudines), with a comparison to other turtles

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Based on histological sections, the chondrocranium of the common musk turtle was reconstructed, and compared to other turtles. It differs from that other turtle chondrocrania by possessing elongated, slightly dorsally orientated nasal capsules with three dorsolateral foramina, which might be homologous to the foramen epiphaniale, and by having an enlarged crista parotica. Additionally, the posterior part of the palatoquadrate is more elongated and slenderer than in other turtles, while its ascending process is connected to the otic capsule by appositional bone. The proportions of the chondrocranium were also compared to those of "mature" chondrocrania of other turtle species in a Principal Component Analysis. Unexpectedly, the *Sternotherus odoratus* chondrocranium is not similar in proportions to those of chelydrids, the closest related species in the sample. The results indicate differences in the proportions among larger turtle clades. *S. odoratus* is an exception to this pattern since it shows elongated nasal capsules similar to the trionychid *Pelodiscus sinensis*. A second PCA comparing the chondrocranial proportions of multiple developmental "stages" mostly shows differences between trionychids and all other turtles. *S. odoratus* is again similar to trionychids along PC1, but its proportions are the most similar along PC2 and PC3 to older "stages" of americhelydians, which is related to chondrocranium height and quadrate width. We discuss potential ecological correlations of our findings mirrored in late embryonic stages.