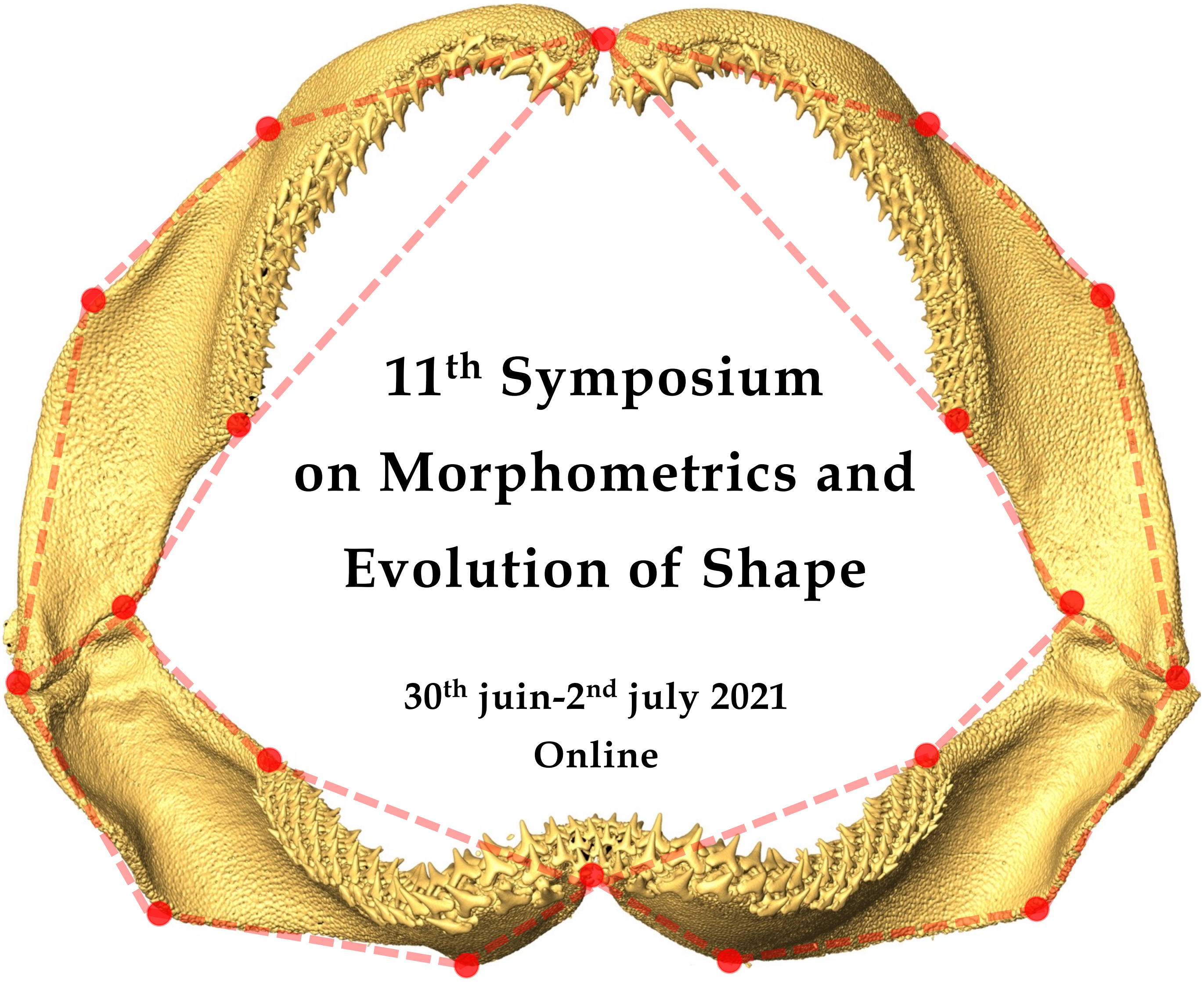

11th Symposium on Morphometrics and Evolution of Shape

30th juin-2nd july 2021
Online

Programme, abstracts and instructions for participants and panelists

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Foreword

Dear colleague,

Welcome to the the Symposium on Morphometrics and Evolution of Shape (SMEF) 2021. Since about 20 years, this symposium has been organized every two years in France and is open to anyone interested in the evolution of biological forms (paleontology, anthropology, developmental biology, archaeology, medicine, evolutionary sciences, bioinformatics, etc.). It is an opportunity to federate the community around new developments and ongoing applied researches. Because of the current sanitary crisis, the workshop organization has been postponed from 2020 to 2021 and it will be held completely online.

This year, the 11th Symposium on Morphometrics and Evolution of Shape (SMEF) is organised by the Institute of Evolutionary Science of Montpellier but is online. The conference will be held from the 30th of june to the 2nd of july 2021.

In order to facilitate communications and interactions during the meeting, we will use zoom (https://zoom.us/) for oral presentations and discord (https://discord.com) for poster sessions via chat rooms. These applications are freely available and multiOS. It is recommended to install these two applications on your computer well before the congress time. If you do not wish to install them on your computer, they can be used directly on your internet browser. We highly recommend you to test beforehand that they work properly. Sessions will start at 9.00 Paris time zone in order to allow a maximum of worldwide participants to take part in the event. Poster presenters will be allowed a space in discord (https://discord.com/) to interact with participants and a few minutes slot for a brief presentation to the whole audience on zoom. All oral presentations will be given on zoom.

The language for the symposium will be English. After June 15, the online registration module stopped, but late registration can still be done on demand at julien.claude@umontpellier.fr and allowen.evin@umontpellier.fr. Registration will definitely be closing on June 25.

This year, we are honored to welcome Prof. Joan T. Richtsmeier for the inaugural keynote paper. In addition, every days will end by workshops dedicated to softwares, computing development and demonstration. The programme given here is definitive.

We would have highly prefered to organise this event in person in Montpellier (France) as originally planned, but we will hope that we will benefit from this new format to make the event even more outstanting and memorable. We hope this peculiar workshop, held online for the first time, and with a number of participants and number of countries represented never reached before, will be as stimulating as the previous versions and stimulate new exchanges and debates. We know that exchanges are not necessarily easy online but we will do our best to ensure that everyone can participate.

We are looking forward to seeing you soon.

June 29, 2021
Julien CLAUDE & Allowen EVIN

Programme (given in Paris time zone)

The zoom webinar URL will be: :
https://umontpellier-fr.zoom.us/j/88949604845?pwd=aXlGQVErRG0wZXpSNzQwL1JxWDZkQT09.
If a password is required it will be 638581.

The online seminar room will be open 30 minutes before starting everyday; training sessions for panelists will be organised and open on June 28 and 29 in the mornings from 9.00 to 10.30; and afternoon from 14.00 to 15.30 (Paris time). Panelists are highly advised to join to these training sessions as the programme is dense and as we wish to limit technical problems.

After each talk or poster will be indicated the ID of the "discord" chat room if you want to discuss more, after the zoom sessions, with panelists and their co-authors. The discord server invitation is : https://discord.gg/8nXAYnQSac.

The definitive programme is provided here, please consider that small changes occurred since the preliminary program and check well your time if you are panelist.

30 June 2021

- 9.00-9.10 Introduction Julien Claude and Allowen Evin.[smef-general]
- 9.10-9.30 Gliding in the Amazonian canopy : adaptive evolution of flight in *Morpho* butterflies. Camille Le Roy et al.[smef-leroy]
- 9.30-9.50 Decomposing morphological variation at different spatial scales : Application of the package prWarp to the primate skull. Anne Le Maître et al.[smef-lemaitre]
- 9.50-10.10 Morphological variation of the hominid navicular bone : Implications for behavioral driven divergence. Rita Sorrentino et al.[smef-sorrentino]
- 10.10-10.30 GMM of featureless surfaces : a case study of the anuran pelvis. Javier H. Santos-Santos et al. [smef-santos-santos]
- 10.30-10.40 Break
- 10.40-11.00 Investigation of the covariation patterns between the respiratory turbinates the incisor and the skull. Arthur Naas et al.[smef-naas]
- 11.00-11.20 Modularity patterns in mammalian domestication : assessing developmental hypotheses for diversification. Laura Wilson et al.[smef-wilson]
- 11.20-11.40 Biomechanical constraints associated with captivity alter craniomandibular shape and integration. Dimitri Neaux et al.[smef-neaux]

- 11.40-12.00 Warthogs (*Phacochoerus*) are peramorphic relative to their presumed ancestor Metridiochoerus modestus based on shape analyses of crania and mandibles. Antoine Souron.[smef-souron]

- 12.00-13.10 Break

- 13.10-13.30 Comparison of ontogenetic and static allometry among three phylogenetically distant species of armadillos. Kévin le Verger et al.[smef-le-verger]

- 13.30-13.50 Regional differentiation of the axial skeleton during the development of the nine-banded armadillo (*Dasypus novemcinctus*). Lionel Hautier et al.[smef-hautier]

- 13.50-14.10 Testing the accuracy of 3D automatic landmarking via genome-wide association studies. Yoland Savriama and Diethard Tautz.[smef-Savriama]

- 14.10-14.30 Analysis of intraspecific variation in the bone microstructure of *Sciurus vulgaris fuscoater* humeri. Stefanie Luft et al.[smef-luft]

- 14.30-14.40 Break

- 14.40-15.00 Understanding the genetic architecture of *Drosophila melanogaster* wing shape is complicated by genetic and environmental effects in artificially selected and wild caught populations. Katharine Pelletier et al.[smef-pelletier]

- 15.00-15.20 Biomechanics and morphological patterns in head-first burrowing frogs. Marta Vidal-Garcia et al.[smef-vidal-garcia]

- 15.20-15.40 Sex differences in the pelvis did not evolve de novo in modern humans. Barbara Fischer et al.[smef-fischer]

- 15h50-16.40 **Inaugural presentation :** Using morphometrics to understand developmental shifts underlying diversity, Joan T. Richtsmeier[smef-richtsmeier]

- 16.40-16.50 Conclusion/Break [smef-general]

- 16.50-19.00 SlicerMorph, Murat Maga [smef-slicermorph]

1 July 2021

- 9.00-9.20 Studying the current diversity of barley using geometric morphometrics on modern seeds: protocol and first results. Angele Jeanty et al. [smef-jeanty]

- 9.20-9.40 The longevity of the crop reflects on their seed characters (size and shapes) in selected rice varieties of Tamil Nadu . Parthiban Mylswamy and Mahendiran Mylswamy [smef-mylswamy1]

- 9.40-10.00 *Mazama insulae* : an extinct dwarf deer from Playa don Bernardo, Panama (6000 cal. BP). María Fernanda Martínez-Polanco [smef-Martinez-Polanco]

- 10.00-10.20 Morphometric analysis of a well preserved *Machairodus* skull (Carnivora, Felidae) from the late Miocene of Rhodos (Greece) with some taxonomic notes on the *Machairodus aphanistus – giganteus* transition. Anneke H. van Heteren [smef-van-heteren]

- 10.20-10.30 Break

- 10.30-10.50 Cranial shape variation in mink : Separating two highly similar species. Eloy Gálvez-López and Philip Cox [smef-galvez-lopez]

- 10.50-11.10 Confounded variation ? Assessing the impact of intra-specific morphological variability on inter-species comparisons : a case study using petrous bones of extant and extinct suids (Mammalia, Artiodactyla). Karl Baltazart et al. [smef-baltazart]
- 11.10-11.30 Are petrous bones just a repository of ancient molecules? Investigating biosystematic signals in caprine petrous bone using 3D virtual morphology. Camille Bader et al.[smef-bader]
- 11.30-11.50 Sheep or Goat ? Identifying isolated teeth and mandibles using geometric morphometrics. Marine Jeanjean and Allowen Evin [smef-jeanjean]
- 11.50-12.10 Short presentations of poster - First session -
- 11.50-11.54 Advancing Ancient Mollusk Shells as Multi-Proxy Archives of the Past. Clio Der Sarkissian et al. [smef-der-sarkissian]
- 11.54-11.58 MiniBreak
- 11.58-12.02 Patterns of sexual dimorphism in the modern human fibular extremities : a geometric morphometric approach. Annalisa Pietrobelli et al. [smef-pietrobelli]
- 12.02-12.06 Shape changes of the diaphragmatic domes during breathing in COPD patients : a 3D geometric morphometrics analysis José María López-Rey Pérez et al. [smef-lopez-rey-perez]
- 12.06-12.10 Effect of Low Frequency Electromagnetic Field (50 Hz, 1.5 mT) on Wing Shape and Fluctuating Asymmetry of *Drosophila melanogaster* in Five Generations. Farzaneh Morovat and Saber Sadeghi [smef-morawat]
- 12.10-13.30 Break
- 13.30-13.50 Computer vision and morphometrics to study quarantine nematodes. Romain Thevenoux et al. [smef-thevenoux]
- 13.50-14.10 Computer vision meets morphometrics : the virtue of challenge. Nicolas Parisey and Vincent Bonhomme. [smef-bonhomme]
- 14.10-14.50 Short presentations of poster - Second session -
- 14.10-14.14 Changes in form and function of the caudal tubes in *Panochthus* Burmeister, 1866 (Xenarthra; Glyptodontidae) along the Pleistocene Martín Zamorano and Richard Fariná [smef-zamorano1]
- 14.14-14.18 Assessing the usefulness of wing morphometrics to identify three forensically important fly species (Diptera: Muscidae) from Colombia. Giovan F. Gómez et al. [smef-gomez]
- 14.18-14.22 Geometric Morphometrics provinding new insights into the study of lithic form in Brazilian archaeology. Renata Pedroso De Araujo [smef-de-araujo]
- 14.22-14.26 Claws Of The Caribbean. Michaela Kerschbaumer and Tobias Pfingstl [smef-kerschbaumer]
- 14.26-14.30 Ecomorphological changes of the mandibles of two living caiman species in the post-hatching Ontogeny. María Victoria Fernandez Blanco et al. [smef-fernandez-blanco]
- 14.30-14.34 Giants of the Pampean plains (Argentina) during Early Pleistocene (Ensenadan). The case of *Panochthus* (Xenarthra, Glyptodontidae) : comparative descriptions. Martín Zamorano et al. [smef-zamorano2]

- 14.34-14.38 Longer horns and small eyes : how *Onthophagus bidens* copes with exaggerate male weaponry development (Coleoptera, Scarabaeidae). Angela Roggero et al. [smef-roggero]
- 14.38-14.42 Pattern and magnitude of outer enamel surface (OES) and enamel-dentin junction (EDJ) shape covariation in upper molars among living hominoids. Miguel Delgado [smef-delgado]
- 14.42-14.46 Preliminary morphometric analyses in the skull and mandible of short-tailed opossums, genus *Monodelphis* (Didelphimorphia, Didelphidae). Júlio Silva et al. [smef-silva]
- 14.46-14.50 Skull and mandible shape variation in mouse opossums, genus *Marmosa* (Didelphimorphia, Didelphidae): a preliminary assessment. Paula Maia and Diego Astúa [smef-maia]
- 14.50-14.54 The South American camelids domestication at the south-central andes through the morphogeometric evaluation of the phallanges. Anahí Hernández and G. Lorena L'Heureux [smef-hernandez]
- 14.54-14.58 Outlining the dental evolution among Miocene Cricetids. Patricia Carro-Rodríguez et al. [smef-carro-rodriguez]
- 14.58-15.10 Break
- 15.10-15.30 Morphological diversification and decline of Devonian trilobites from North Africa. Valentin Bault et al. [smef-bault]
- 15.30-15.50 Phenotypic diversification of extinct and endemic Lesser Antillean rice rats (Oryzomyini tribe): combined geometric morphometrics analysis of archaeological teeth and mandibles. Durocher et al. [smef-durocher]
- 15.50-16.10 Morphological evolution of the *Crocidura poensis* species complex. Inessa Voet et al. [smef-voet].
- 16.10-16.30 Morphological evolution in the pelvis of Didelphidae marsupials : phylogeny, size and function effects. Diego Astua [smef-astua].
- 16.30-16.50 Mandible shape diversification in didelphid marsupials (Didelphimorphia: Didelphidae). Francisco Silva-Neto and Diego Astua. [smef-neto]
- 16.50-17.00 Conclusions/Break [smef-general]
- 17.00-18.00 Workshop and Demo : MorphoDig Renaud Lebrun [smef-workshop-morphodig]

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- 9.00-9.20 A first 3D morphometric analysis to investigate adaptations of cephalopod beaks. Marjorie Roscian et al. [smef-roscian]
- 9.20-9.40 Geometric morphometrics of leaf phenotypic plasticity : linking bioclimatic variables and leaf phenotypes in European goldilocks buttercups. Ladislav Hodac et al. [smef-hodac]
- 9.40-10.00 A landmark-free approach to quantify climate-related variation of the human nasal airway. Laura Maréchal et al. [smef-marechal]

- 10.00-10.20 Deciphering the mandibular shape variation in a group of a Malagasy primates using Fourier outline analysis. Jeanne Emma Miarisoa and Sébastien Couette [smef-marisoa]
- 10.20-10.30 Break
- 10.30-10.50 Discrimination of the red dwarf honey bee populations using wing geometry in southeastern Iran: Kerman province Taghi Ghassemi-Khademi et al. [smef-ghassemi-khademi]
- 10.50-11.10 Differences in inner ear asymmetry levels between slow-moving and fast-moving primates. Renaud Lebrun et al. [smef-lebrun]
- 11.10-11.30 Investigating the relationship between diet and mandibular morphology : new insights from a controlled-feeding experiment on domestic pigs. Margot Louail et al. [smef-louail]
- 11.30-11.50 3D analysis of vertebral morphology in Dall's porpoise (*Phocoenoides dalli*) : an example of habitat driven morphology-functional adaptation. Maria Marchesi et al. [smef-marchesi]
- Break
- 13.00-13.20 Filter criteria for the profitable use of digital images, taken under field conditions, and augmentation in Machine Learning. Mahendiran Mylswamy and Parthiban Mylswamy [smef-mylswamy2]
- 13.20-13.40 Filtering out spurious effects of pitch, yaw and roll when digitizing on pictures of 3D objects. Julien Claude et al. [smef-claude]
- 13.40-14.00 The Borrowing of Concepts from Geometric Morphometrics to Archaeology : Homology, Landmark Types, Modularity, and Allometry. Mercedes Okumura and Astolfo Araujo. [smef-okumura]
- 14.00-14.20 Shall we measure more in morphometrics? ... By the way, more of what? Andrea Cardini [smef-cardini]
- 14.20-14.40 Break
- 14.40-17.00 Workshop and Demo R session
- 14.40-15.00 Resources for Morphometrics in R : past, present, future. Julien Claude [smef-workshop-R]
- 15.00-15.20 Morpho and Rvcg. Stefan Schlager. [smef-workshop-MorphoRvcg]
- 15.20-15.40 Momocs and MomX - Vincent Bonhomme [smef-workshop-MomocsMomX]
- 15.40-16.00 digit3DLand - Nicolas Navarro and Remi Laffont [smef-workshop-digit3DLand]
- 16.00-16.20 ShapeRotator - Marta Vidal-Garcia [smef-workshop-ShapeRotator]
- 16.20-16.40 prWarp - Anne Le Maître [smef-workshop-prWarp]
- 16.40-17.00 Phylogenetic Multivariate Linear Models : fitting, testing, and assessing multivariate models in R. - Julien Clavel [smef-multivariatemodel]
- 17.00 - 17.20 Discussion and conclusions [smef-general]

Instructions and Recommendations

Zoom and Discord

Using Zoom during the conference

In order to follow the workshop, participate, and ask questions, you need to install the zoom client on your computer. The installation is simple and works for all operating systems. For zoom, you just have to follow the instruction at https://zoom.us/download. If you do not want to do the full installation, you can also use it directly as a plug in in firefox or chrome.

- **Everyone** : Make sure that you have your surname and name indicated correctly. If you are using a pseudo, please rename yourself so you can be identified by the moderator of the session.

- **Panelist** : Please be ready at least 15 minutes before your talk. If you need training/checking your presentation before the symposium, just email us and we will give you a slot a few days ahead of the conference. Pdf presentations are preferred. Make sure that they are not too heavy. Think about ending your talk at least 5 minutes before the end so that people can ask questions. You will have to share your screen, and to unmute your microphone when starting your talk. You can also activate your webcam (but this is not mandatory). If you feel that your presentation or sharing screen might generate problems, you can email the .pdf of your presentation and we will display it for you(julien.claude@umontpellier.fr, allowen.evin@umontpellier.fr) ; for email larger than 10 Mo, please use a large file transfer system. When you have finished your talk.

- **Attendee** : After the talk is finished, you can raise your hand, and the moderator will allow you to speak. Do not forget to unmute your microphone before you speak. If you need (for instance during general discussions), you can ask the moderator to allow you to use the camera or share your screen and temporarly change your status as panelist.

To attend the workshop go to :
https://umontpellier-fr.zoom.us/j/88949604845?pwd=aXlGQVErRG0wZXpSNzQwL1JxWDZkQT09. If a password is required, it will be 638581. These link and password are only for registered persons, we expressly ask you not to share it.

Using Discord before, during, and after the conference

Because people often want to discuss more after each presentation, we have set up chat-rooms for the different talks during the seminar using discord. Before the conference (and as soon as

possible), you can register to the server following that invitation :
https://discord.gg/8nXAYnQSac

With that invitation, you can access to the server and the different chatrooms or channels related to each presentation. You can use discord on your browser or you can install it on your computer. You will have to indicate your date of birth before you login, that information will not be displayed at any time but it is required to validate your account. Keep in mind that these chatrooms are public, so we advise you to use english langage to engage discussions and chat there.

Think of this space like the hallways and social spaces in an in-person conference. Here is where you can go to discuss panels and talks, find people interested in the topics important to you, get technical help and information, and stay on top of what's happening during this conference. On top of that, you can converse with people from all over the world.

To get started using Discord:

1. We wish to make sure that you are clearly identified. Please change your nickname to the surname and name you used to register to the conference.
2. Start exploring the channels on the left side and enjoy the conference!
3. The discord server is meant to allow interaction and discussion between participants of the conference. General messages can be posted in the smef-general channel
4. For each poster or talk presentation. The server consists of a collection of text channels (listed on the left-hand side, marked respectively with hash). Just click on the relevant channel to join it and post a remark or a question.
5. You can see the list of members, i.e. other participants to the conference, on the right-hand side panel.
6. You can message other participants directly from the list. "Crew members", who are part of the organizing team are listed at the top.
7. If you need help with navigating around the server, posting and interacting with other users, please head to the helpdesk channels or contact a crew member. If you need to send a file or a picture, just send me a private message at julienclaude in discord.

We ask authors of papers to regularly watch at their proper chatroom so that they can answer participants's questions even well after their presentation. The discord server will be available until july 5th.

Discord works well, but it is possible that you do not have access to it if your university has a strong firewall. Then you can still use the general discussion slots during the congress to ask your questions. Feel free to contact us (julien.claude@umontpellier.fr, allowen.evin@umontpellier.fr) if you encounter any problem.

Presentation formats and rules

Oral presentations

Try to make sure that your presentation goes well on your computer. We encourage you to use pdf as it is more stable and easier to display (no surprise !!). Reserve 15 minutes for the presentation itself, 5 minutes for questions. Go to the zoom and discord section of this book to make sure that you can correctly use these applications before the congress. One discord channel has been created for each presentation, you should be able to easily find yours once connected on discord.

Instructions for posters

Poster will be on display on authors channels in the poster section of discord. The poster will be installed on these channels before the congress. The poster must therefore be sent to Allowen Evin (allowen.evin@umontpellier.fr) by June 28. The poster should be in pdf or jpg format and should be compressed and not exceed 6 Mo. If you have problems with compression, you can ask us. We do not impose rules regarding the size of the poster as it is posted online (the poster can be on one or several pages).

A four minute slot will be alloted during the zoom session to present the main feature of your poster. Participants must go to poster channels in discord to later interact with poster presentation and ask questions. If you have posted a poster, we ask you to regularly check your room and to actively participate in our discord channels, it will make the conference more pro-active.

Workshop sessions

SlicerMorph - Murat Magat

SlicerMorph (https://github.com/SlicerMorph/SlicerMorph) is an extension to the open-source biomedical visualization and image processing platform 3D Slicer (https://slicer.org). Two primary goals of SlicerMorph are: (1) to simplify common digital morphology tasks (import, segmentation, visualization, and animation) for biologists working with non-clinical 3D datasets; (2) to facilitate geometric morphometrics data collection and exploratory data analysis from these datasets. Further GMM analyses (particularly inferential analyses) can be accomplished by importing the results from SlicerMorph into R ecosystem.

In this workshop, we will demo all the functionality SlicerMorph offers using the sample data bundled. We will also show where to find step-by-step written and video tutorials, SlicerMorph documentation, and seek help from the Slicer user forum.

MorphoDig - Renaud Lebrun

MorphoDig (https://morphomuseum.com/morphodig) is an open-source VTK based freeware that provides a set of tools for editing, positioning, deforming, labelling, measuring and rendering sets of 3D surfaces. MorphoDig also provides tools for opening, editing and visualizing 3D volumes, and to extract 3D surfaces out of 3D volumes.

Features include :

1. Undo-Redo most actions
2. Retro-deformation for un-deforming fossils/deformed specimens
3. Point and curve primitives for placing the exact type of landmark points you're interested in
4. Surface tagging, labelling and coloring (to allow for the creation of anatomy atlases)
5. Surface scalar computation and coloring (based upon curvature/thickness/complexity/volume/area)

As MorphoDig uses VTK, and as such most input and output files are compatible with other VTK based software such as 3DSlicer and SlicerMorph.

An overview of MorphoDig functionalities will be presented and a I will explain interactively with the audience how to open data and digitize landmarks will morphodig (tutorial data can be downloaded at https://morphomuseum.com/tutorialsMorphoDig).

The session will use the conference zoom canal and material will be posted on discord.

R - Multiple panelists

Resources for Morphometrics in R : past, present, future - Julien Claude

In that section, I will provide a rapid comparison of packages performing morphometrics in R. I will show in practice the behaviour of sliding semi landmark using a single data set but different packages. I will also show how to easily compute and display BOAs as they might interest people interested in evo-devo studies.

Morpho and Rvcg - Stefan Schlager

The R-packages Morpho and Rvcg provide various tools for applying Geometric Morphometrics methods and triangular mesh processing. This includes (among other stuff) mesh deformations based on reference points, permutation tests, detection of outliers, processing of sliding semi-landmarks and semi-automated surface landmark placement. In this session we are going to look into some functionality and explore the scope of these packages.

Momocs and MomX - Vincent Bonhomme

Momocs is an R package mostly used for outline analyses. MomX, under development, aims at generalising its approach by provingan ecosystem of R packages for everything 2D morphometrics, that is the statistical description of shape and its (co)variation. MomX is intended to provide a complete, comfortable, powerful, and - last but not least - open-source workflow for morphometrics. MomX packages share common principles and work together well. This architecture is largely inspired by the tidyverse. In this session, I will show Momocs in action and how MomX will extend its philosophy..

digit3DLand - Nicolas Navarro and Remi Laffont

digit3DLand is an R package for digitizing 3D landmarks and curve semilandmarks on meshes. It provides a multi-resolution framework for placing landmarks as well as an assistance with the landmarking sequence. In this session, we will show the main capabilities of the package.

ShapeRotator - Marta Vidal-Garcia

The quantification of complex morphological patterns typically involves comprehensive shape and size analyses, usually obtained by gathering morphological data from all the structures that capture the phenotypic diversity of an organism or object. However, 3D morphological data from multiple or articulated structures are usually in different relative positions, as an effect of how they have been preserved. ShapeRotator is an R package that allows joint 3D geometric morphometric analyses of multiple or articulated hard structures as a whole, by removing the effect of rotations and translations of different structures across all specimens. By eliminating the effect of random rotations and translations in these structures we can analyse these data as a single rigid structure. That will also allow us to visualize patterns of morphological variation across multiple structures that span articulations, to better understand complex phenotypic patterns.

prWarp - Anne Le Maître

We will show two applications of the package 'prWarp' on the midsagittal shape of the skull: (1) within humans, to compare the intraspecific patterns of shape variation at different spatial scales, and study morphological integration; (2) across papionin species, to separate the total shape variation into outline and residual shape components, and discriminate between the adaptive and the phylogenetic signal.

Phylogenetic Multivariate Linear Models : fitting, testing, and assessing multivariate models in R. - Julien Clavel

Phylogenetic linear models (e.g., regressions, ANOVA, or ANCOVA) provide a statistically rigorous framework for comparative studies of phenotypic traits across taxa. The R package mvMORPH extends these approaches to the multivariate case and can deal with the high-dimensionality of modern high-throughput phenotypic and morphological comparative datasets (e.g., geometric morphometrics) through the use of penalized likelihood techniques. Here I will provide a short introduction and some guidance on how to fit phylogenetic multivariate linear models (e.g., multivariate regressions, MANOVA, MANCOVA) in mvMORPH. The session will use the conference zoom canal and material will be posted on discord.

Abstracts

Morphological evolution in the pelvis of Didelphidae marsupials : phylogeny, size and function effects

Diego Astua * [1]

[1] Universidade Federal de Pernambuco, Recife – Brazil

Newborn marsupials crawl independently to the teats using their forelimbs at a very early developmental stage, and this is believed to impose developmental constraints in their shoulder girdles. Marsupial pelvic girdles are morphologically more diverse than their shoulder girdles, possibly because the former are not under such constraints. These diversity differences were, however, assessed across several marsupial orders, with very different locomotor modes. New World opossums of the family Didelphidae are a taxonomically and ecologically diverse marsupial group considered morphologically conservative, and they have been assessed for scapula shape diversity, but not for pelvis shape diversity. Here I assess shape variation in the Didelphidae pelvis and possible factors influencing it, using 2D geometric morphometrics. I digitized 19 landmarks of the lateral view of the pelvis, in a sample of 953 specimens (14 genera, 55 species). and assessed shape variation through a Principal Component (PC) Analysis on Procrustes Coordinates, using an independent phylogenetic hypothesis to establish a phylomorphospace and test for phylogenetic signal. I also assessed the influence of size by regressing shape variables or selected PC scores onto centroid sizes. There is a continuous variation in pelvis shapes with no distinct groups identifiable in the PCA, although there is no overlap between specific clades (*e.g.* Metachirini x Thylamyini). PC1 is correlated with size ($r=0.78$, $p< 0.001$), and it ranges from robust pelves with dorsally inflexed ilia and ischial tuberosities and broad pelvic symphyses in large taxa, to delicate pelves with ilia aligned with the dorsal portion of the ischium and narrower pelvic symphyses in smaller opossums. There is a significant but weak allometric effect of size on overall pelvis shape, and a significant phylogenetic structure in the data ($p< 0.0001$). Inspection of phylomorphospace shows that taxa within genera are clustered together with little overlap between species means (except for *Marmosa* and *Marmosops*) and that *Lutreolina* diverges away from the other Didelphini and converges towards the highly terrestrial *Metachirus*. Phylomorphospace is structured by size along PC1, and by locomotor habits along PC2, with divisions between arboreal and terrestrial taxa in large and small taxa, even within tribes (in Monodelphini and Thylamyini). Observed shape variation in the pelves suggests increased strength for movements directed forward or upward in larger taxa, quicker extensions in more terrestrial ones, and stronger adduction in more arboreal ones. Despite differences in developmental constraints, these results are similar to those found for the scapula in Didelphidae.

Keywords: marsupial, pelvis, morphological evolution, functional morphology, locomotion

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*Speaker

Are petrous bones just a repository of ancient molecules? Investigating biosystematic signals in caprine petrous bone using 3D virtual morphology

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The petrous bone is the densest bone of the skeleton and fully develop *in utero* without remodelling throughout the life, making it the ultimate repository of ancient biomolecules, especially endogenous ancient DNA. As such, it has been used widely for biomolecular archaeological studies on human and non-human animals. However, the extent of the demand for destructive analysis of these ancient remains has led to recent pleas for greater caution in the sampling strategy and more ethical curation to safeguard these precious bioarchaeological archives. Beyond their value as ancient molecules locker, physical anthropology has explored the potential of petrosal bones for sexing and to estimate the foetal age at death, but the use of petrosum in the field of Zooarchaeology has been less explored. Its specific anatomical characteristics have proven useful to reach morphoscopic identification at the species level for closely related species using multivariate morphometrics. However, the intraspecific component of the petrosal bones morphological variation has not been explored yet. Here we propose to investigate the intraspecific taxonomic signal in the petrous bone by using a cross sectional study of its morphological variation in modern populations of sheep breeds and landraces (including wild sheep relatives as well as domestic goats as outgroups), using a 3D Geometric morphometrics protocol on the petrous bone surface to collect size, shape and form datasets. We show here the form is able to detect significant taxonomic signals at both the intra-generic and intra-specific level suggesting that 3D surface capture and GMM analysis of petrous bones could be a prerequisite before destructive biomolecular analysis.

Keywords: Caprinae, Petrous Bone, 3D Geometric Morphometrics, Zooarchaelogy

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[*] Speaker

"Confounded variation"? Assessing the impact of intra-specific morphological variability on inter-species comparisons: a case study using petrous bones of extant and extinct suids (Mammalia, Artiodactyla)

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Taxinomic delineation of morphospecies relies on our capacity as taxinomists to disentangle interspecific and intraspecific morphological variability. The petrous bone displays a complex morphology and is an important source of taxinomic and phylogenetic characters in extant and extinct vertebrates, but their use is hindered by a poor understanding of intraspecific variability. We developed an original protocol to quantify morphological variation of the petrous bone by combining 3D traditional morphometrics on surface models and 2D geometric morphometrics on standardized views. We applied this protocol to 72 petrous bones encompassing nine taxa of extant and extinct Suidae to quantify intraspecific and interspecific variability of main morphological structures (bone outline, position and shape of main foramina on lateral and medial faces). We conducted a multiple factor analysis (MFA) of the first 5 PC axes of each geometric morphometrics-based shape analyses (bone outline, medial and lateral faces; a total of 15 variables) to study the degree of similarity between each taxon. Using two reference taxa with more than twenty specimens, the extant wild boar (*Sus scrofa*) and an extinct suid from Ahl al Oughlam, Morocco, we identified some characters that strongly vary within species (e.g., length of medial process of *protympanum* in *Sus scrofa*). In general, conspecific individuals have higher morphological similarities with each other than with individuals of other taxa. This improved knowledge of intraspecific variability allows us to test whether the morphometric differences observed between each pair of specimens are congruent with inter-species differences when following a model of intraspecific variability based on *Sus scrofa.* It appears that *Phacochoerus africanus* is the most similar in petrosal morphology to the Ahl al Oughlam suid, which would be congruent with a close phylogenetic relationship between those taxa as inferred from craniomandibular and dental data.

Keywords: Petrous bone, taxinomy, morphometry, Sus scrofa, Kolpochoerus, Phacochoerus

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*Speaker

Morphological diversification and decline of Devonian trilobites from North Africa

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The Devonian was a key period in the evolutionary history of trilobites. They experienced several ecological changes, which influenced their morphologies. This was particularly the case for the abundant trilobite communities from North Africa. . Using a geometric morphometrics approach based on the acquisition of 2D landmarks, semi-landmark coordinates and disparity indices, a dataset was compiled to investigate the trilobite exoskeleton shape. Analyses were carried out on three typical structures: cephalon, cranidium and pygidium. Based on empirical morphospaces, the morphological changes were quantified through the Devonian stages. The results reveal significant variations of the morphological disparity concerning the glabella shape, the facial suture location, the pygidial length and the presence of spines.While the Silurian trilobites showed a reduced morphological disparity, the Devonian began with several innovations and novelties associated with both abiotic and biotic factors. The morphological range extended to the Emsian and the morphospace became denser. As a result of adverse environmental events, including sea-level changes and anoxic events, the morphological disparity dropped from the Eifelian and never recovered thereafter. The non-random extinctions mainly affected the edges of the morphospace and little of its density. The surviving shapes corresponded to those inherited from the Silurian which were maintained throughout the Devonian whereas extinction mainly struck the Pragian and Emsian novelties. Persistent shapes were more versatile and ecologically better suited to changes in bathymetry, feeding habits and visual abilities that helped them survive to environmental events. Phacopida and Proetida, the only orders that survived until the end of the Devonian, had the greatest morphological occupancy.

Keywords: Shape, Trilobite, Devonian

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*Speaker

Shall we measure more in morphometrics? ... By the way, more of what?

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Morphometrics was developed to measure continuous variation and differences which are generally moderate or small. For statistical power, large samples should therefore be important in most morphometric studies. Morphometricians also agree that one should measure only what is relevant for a specific study question. Yet, with geometric morphometrics, increasing the number (p) of measurements (landmarks or semilandmarks) is easier than increasing sample size (N). This makes poor sampling potentially even more problematic. Expanding previous work on p/N but mainly focusing on N, I will use cranial shape variation of adult mammals to explore whether large samples are really crucial for accurate and robust results in studies at the boundary between micro- and macro-evolution.

Keywords: dimensionality, mammals, Procrustes, sampling error, within, between species variation

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[*] Speaker

Outlining the dental evolution among Miocene Cricetids.

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The family Cricetidae (Rodentia, Mammalia) is one of the most specious groups of mammals and an important part of faunas during the Miocene. Here, we study several taxa with large geographical ranges during the Miocene and with relevance for paleoecological reconstructions and biostratigraphy. Particularly we focused on the genus Megacricetodon and representatives of the tribe Cricetodontini (Cricetodon, Hispanomys, Ruscinomys, and Byzantinia), which present wide stratigraphical and geographical distribution from the late Oligocene to the early Pliocene all over Eurasia. As in other extinct small mammals, the main characteristics to identify these species are the dental traits they present. Here, we aim to assess the dental morphological differences between those genera by applying geometric morphometrics and describing the evolution along with their stratigraphic range. We performed an Elliptic Fourier Analysis as implemented in Momocs R package on 1281 upper first molars of these five genera. After Generalized Procrustes Analysis and Elliptical Fourier Transformation, we obtained 9 harmonics describing the outlines. We run the Principal Component Analysis to summarize the morphological variation. The first two principal components (PC1 and PC2) explain 77% of the total variation. The PC1 distributes the genera in two groups: Megacricetodon and tribe Cricetodontini. The PC2 describes two outline morphologies on the labial region: straight and trilobed. Straight outline morphology is distinctive of brachydont teeth typical of primitive genera (Megacricetodon and Cricetodon). Trilobed outline morphology is characteristic of hypsodont molars, a derived trait present on some Cricetodontini (Hispanomys, Ruscinomys, and Byzantinia). A Canonical Variate Analysis was able to identify the different tribes with an overall accuracy of 91%. This work provides the basis for further analyses to evaluate if the change from a straight to trilobed outline is linked to environmental changes related to the expansion of the grasses during the Miocene.

Keywords: Paleontology, mammals, rodents, Fourier, dentition

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*Speaker

Filtering out spurious effects of pitch, yaw and roll when digitizing on pictures of 3D objects.

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The orientation of biological objects under the camera can be a source of important error in morphometric studies, especially regarding the study of shape variation. The induced variation is related to effects of pitch, yaw and roll of the camera axes or object main axes. This variation can be dramatic in terms of error variation when other factors affecting shape variability are explored. Therefore, users want to filter it out. We use here two datasets where objects and camera orientations are well known to produce an important source of error: rodent teeth and *Drosophila* compound eye outlines. The effect of yaw, roll and pitch can be filtered by sending shape variation in an orthogonal space against to the error subspace produced by these effects using the Burnaby procedure (Burnaby, 1966). The subspace can be appreciated by using replicated measurements, and its eigenvalues can eventually be exaggerated by generating more variation due to orientation than there is in practice. We empirically show that the effects of pitch, yaw and roll determine a subspace spanning two major axes of variation as it is expected from the theory. We also generated in-silico variation in pitch, roll and yaw using geometric operations on the mean shape and sent morphometric data orthogonal to that subspace. Both approaches showed similar results, demonstrating that even without replicated measurement, there are reasonable ways to filter out variation due to camera and object orientation. In most instances, these approaches will filter out the uniform component of shape variation (as the relative warp approaches do) except when homology is lost between replicates (which sometimes happens for outllines). It is recalled here that Burnaby correction can have a large range of applications for reducing other spurious or confounding biases such as variation due to photography (e.g focal distance variation) or variation due to undesired biological factors (tooth wear).

Keywords: orthogonal space, measurement error, Burnaby correction

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*Speaker

Pattern and magnitude of outer enamel surface (OES) and enamel-dentin junction (EDJ) shape covariation in upper molars among living hominoids

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The investigation of external and internal tooth structures of extant and extinct hominoids has provided interesting clues on primate dental evolution and diversity. Given their morphological complexity, a number of studies have focused on the outer enamel surface (OES) and the enamel dentine-junction (EDJ) of upper and lower molars in different primate taxa, including fossil hominins. The EDJ is believed to be the developmental precursor and primary contributor to both *gross* and minor morphology of the OES. However, species-specific differences suggest that the strength of the EDJ/OES association varies among primate taxa. This study aims to explore, through 3D geometric morphometric methods, the strength of shape variation and covariation between the EDJ and OES of upper molars in living hominoid species. OES and EDJ models, obtained through micro-computed tomography (μCT), for 40 upper second molars from four living hominoid species *Homo sapiens* (n=10), *Pan troglodytes* (n=10), *Gorilla gorilla* (n=10), and *Pongo pygmaeus* (n=10) were investigated. Landmarks/semilandmarks (n=250) were digitized on each OES and EDJ model and standard GPA and PCA were performed. The pattern of covariation between the EDJ and OES was investigated through a two-block partial least squares (PLS) analysis and the magnitude of covariation was investigated through the covariance ratio (CR). Additional methods were used to evaluate developmental constraints and evolutionary flexibility in both structures. The results show distinct patterns of shape variation/covariation between the EDJ and OES in the species investigated, where modern humans present a distinctive pattern of association. The magnitude of EDJ/OES covariation also differs among living hominoids as well as the level of evolvability and developmental constraints in both structures. Overall these results suggest a major role of the EDJ in the OES morphology among living hominoids nevertheless, the differential pattern and magnitude of shape covariation reveal the important influence of enamel deposition in molar occlusal diversity in some species.

Keywords: OES, EDJ, living hominoids, shape covariation, dental evolution and diversity

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*Speaker

Advancing Ancient Mollusk Shells as Multi-Proxy Archives of the Past

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Mollusk shells were recently revealed as metagenomic archives of the past, potentially covering the last 100,000 years. This has not only opened new avenues for ancient DNA research but also added DNA to the list of morphological, structural and biogeochemical shell proxies that provide a wealth of information about the evolution, life history, stress responses and past environments of mollusks. Multi-proxy studies thus offer the unique opportunity to characterize, at high resolution, the dynamics of their different biological responses to environmental changes. We present here a multi-disciplinary approach combining 3D computed tomography imaging, statistical shape analyses, diffeomorphometry, paleo-environmental reconstruction and ancient genomics to investigate the relationships between the phenotype and genomic composition of wild Mytilus mussels across environmental gradients at both the spatial and temporal scales. Our novel methodological framework is highly relevant to address the on-going and future environmental challenges faced by our societies, such as global warming and pollution intensification, and their damaging consequences on biodiversity. Other goals include advancing responsible ancient mollusk DNA research by maximizing information output while minimizing destruction of shells.

Keywords: mollusks, shell, morphology, ancient DNA

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*Speaker

Phenotypic diversification of extinct and endemic Lesser Antillean rice rats (Oryzomyini tribe): combined geometric morphometrics analysis of archaeological teeth and mandibles

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Nowadays, rice rats (Oryzomyini tribe) have a large taxonomic diversity on the American continent. Yet, they used to be present in the Lesser Antilles before their disappearance following the European colonisation. These extinct insular representatives have been the subject of numerous studies including genetic and morphometric, and anatomical descriptions aiming to understand their past diversity. Three genera specific to this area are now known that could be associated with a geographically structured phenotypic diversity. In our study, the combined analysis of morphometric signals (sizes and shapes) from the teeth and mandibles of 215 specimens from 33 archaeological sites on 11 islands, highlights the presence of an even larger diversity composed by 6 morphotypes and 11 sub-morphotypes. These groups, which subdivide the three previous clusters, help to clarify the archaeobiogeography of oryzomyine in the Lesser Antilles. These morphotypic differences, which respect a geographical organisation, favour the hypothesis of differentiation induced by population isolation within islands. However, the coexistence of several sub-morphotypes on some of the islands may reveal ecological differenciation. All together our data revealed a greater diversity than known before for an extinct group of rice rats in the Lesser Antilles archipelago only allowed by a bioarchaeological study combining multiple lines of evidence.

Keywords: Archaeobiogeography, Rodents, Oryzomyini, Lesser Antilles archipelago, Teeth, Mandibles

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[*] Speaker

Ecomorphological changes of the mandibles of two living caiman species in the post-hatching ontogeny

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Ontogenetic morphological transformation of the mandible of living crocodiles has been poorly studied. We have explored the inter- and intraspecific variation of the mandible in two extant caiman species, exploring the relationship between these morphological changes and diet, from a quantitative approach. We applied three-dimensional geometric morphometric methods on post-hatching ontogenetic mandibular series of *Caiman latirostris* and *C. yacare.* We performed interspecific Principal Component Analysis (PCA), and intraspecific Regression and Partial Least Squares (PLS) analyses using the Morpho package in R software. Only PC1 and PC2 were meaningful (explaining the 33.08% and 16.36% of the variance, respectively). Species were segregated along the PC1 with *C. yacare* located on the positive values (slender mandibles) and *C. latirostris* on the negative ones (robust mandibles). Both the PC2 and the regression analyses showed shape changes along the ontogeny (common and specific pattern, respectively) with juveniles of both species in the negative values and adults towards positive ones. Allometric scaling explains 19.01% of variation in *C. yacare* and 22.31% in *C. latirostris.* The adult mandible is longer, wider and taller than the juvenile (more conspicuous in *C. yacare*). The PLS analysis of both species shows a significant relationship between ontogenetic shape variation and diet. Although proportions and feeding items are similar in the two caiman species (e.g., adults of both species feed mainly on vertebrates), crustaceans are a very important component of the diet in the juveniles of *C. latirostris* whereas snails are for *C. yacare.* Summarizing, common morphological changes occurring during ontogeny seems to reflect the same mechanical requirements for crushing and killing in both species, driven by ontogenetic changes in the diet from invertebrates to vertebrates. Additionally, differences in the mandible morphology (gracile and robust) could be related to different feeding mechanical requirements (stiffness and toughness) and to different habitat preferences.

Keywords: Caiman latirostris, Caiman yacare, Crocodylians, Diet and mandibular shape covariation, Tridimensional geometric morphometric approach

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*Speaker

Sex differences in the pelvis did not evolve de novo in modern humans

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The pelvis is the only part of the human skeleton for which females have larger average dimensions than males. Compared to males, females have a larger pelvic canal, a wider subpubic angle and a wider sciatic notch. In this study, we present new results that shed light on the evolutionary origin of these sex differences. We conducted a geometric morphometric analysis of individual pelvic variation in modern humans and chimpanzees (Pan troglodytes). Our study sample comprised 34 adult chimpanzee pelves and 99 adult human pelves. On each pelvis, 109 3D landmarks were collected (44 anatomical landmarks and 65 curve semilandmarks). We quantified similarities and differences in pattern and magnitude of sex differences in humans and chimpanzees. Surprisingly, the pattern of pelvic sex differences was almost identical despite large species differences in overall pelvic shape. The magnitude of pelvic sex differences, however, was twice as large in humans compared to that in chimpanzees. We conclude that the pattern of sex differences in the human pelvis did not evolve de novo in modern humans, but it must have been present in the common ancestor of humans and chimpanzees. We propose a "facilitated variation" hypothesis to explain this homology: the genetic-developmental machinery underlying the pattern of pelvic sex differences has stayed relatively conserved during primate evolution, but the regulatory switch behind this machinery, which determines the magnitude of pelvic sex differences, has high evolvability and adapts rapidly. We propose that this switch relates to the amount and duration of estrogen and relaxin secretion as well as to the overall reactivity of the corresponding receptors in the pelvic bones. We predict that the pattern, but not the magnitude, of pelvic sex differences is largely conserved across primates and non-primate mammals, despite very different obstetric and biomechanical requirements.

Keywords: obstetrics, childbirth, pelvis, pan troglodytes, anthropology, homology

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*Speaker

Discrimination of the red dwarf honey bee populations using wing geometry in southeastern Iran: Kerman province

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The red dwarf honey bee, *Apis* (*Micrapis*) *florea* Fabricius, 1787, as a keystone pollinator, is distributed in some parts of southern Iran. In the present study, wing geometry was used to characterize the population structure of *Apis florea* in southeastern Iran; Kerman province. We collected the bee samples from four different populations (Bam, Jiroft, Faryab, and Rudbar) to measure 19 landmarks on the digitized images of the right forewing of the worker honey bees from each colony (213 wings in total). Differences between regions were well demonstrated by a CVA plot and multivariate analysis of variance (MANOVA) illustrated that the four populations were significantly different from each other ($P < 0.0001$). A cluster analysis of phenetic relationships between the populations separated the samples of Bam from other counties. The lowest and highest distances were detected between Jiroft and Faryab (2.69) and Bam and Jiroft (4.29), respectively. We conclude that geometric morphometric can also be successfully used to separate different populations of *A. florea* with short geographical distances.

Keywords: *Apis florea*, wing geometry, population, MANOVA, Kerman province.

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[*] Speaker

Cranial shape variation in mink: Separating two highly similar species

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European and American minks are very similar in their ecology, behavior and morphology. However, the American mink is a generalist predator able to thrive in anthropized environments. Thus, when introduced in Europe, it outcompetes the native species, threatening its survival. To assess whether differences in the masticatory apparatus allow American mink to exploit a wider range of prey than European mink, we analyzed cranial shape variation in both species using 3D geometric morphometrics. Sexual dimorphism in both size and shape was also studied. Significant differences between species were found in cranial shape, but not in size. Relative to American mink, European mink have a shorter facial region, a longer neurocranium with smaller crests and processes, and an anteriorly expanded tympanic bullae shifted antero-medially. Interspecifically, size-related sexual dimorphism is highly significant, but sexual dimorphism in shape is only significant in American mink. Additionally, two trends common to both species were discovered, one related to allometric changes and another to sexual size dimorphism. The former can be subdivided into two, probably related, trait sets: increased muscle force and growth, with the first somewhat paralleling interspecific differences, while the second includes an anterodorsal expansion of the face, and the neurocranium shifting from a globous shape in small individuals to a dorsoventrally flattened ellipse in the largest ones. Finally, the sexual dimorphism trend, while also accounting for differences in muscle force, seems to be related to the observed dietary differences between males and females. Overall, differences between species, sexes and sizes, mainly relate to differences in masticatory-muscle volume and therefore muscle force and bite force, which in turn relate to a wider potential prey range. Thus, muscle force (and dietary range) would be larger in American mink than in European mink, in males than in females, and in larger individuals than in smaller ones.

Keywords: European mink, American mink, cranium, shape variation, geometric morphometrics, sexual dimorphism

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*Speaker

Assessing the usefulness of wing morphometrics to identify three forensically important fly species (Diptera: Muscidae) from Colombia

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Muscidae is a family of Diptera of great forensic interest because some of its species are attracted to a corpse during the decomposition process. Accurate identification at species level of this entomological evidence is essential for the effective application of forensic entomology in criminal investigations. However, this task is challenging, as some forensically important species can be barely distinguished based on traditional morphology. Here, we assessed the potential of the landmark-based geometric morphometric analysis of wing size and shape to discriminate three morphologically identified species of field-collected flies from Colombia: *Musca domestica*, *Atherigona orientalis*, and *Biopyrella bipuncta*. Wing shape was able to separate species of the three muscid flies with a highly significant difference in Mahalanobis distances. The results showed significant differences in wing shape among species, with a cross-validated classification score of 100%. Further, wing shape was able to separate sexes in some species. Our preliminary results indicate that wing geometric morphometrics seems to be a very useful, low-cost tool to distinguish among muscid species. Further studies are needed including other species of the Muscidae family.

Keywords: Morphometrics, Species identification, Colombia, Muscidae, Wing.

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*Speaker

Regional differentiation of the axial skeleton during the development of the nine-banded armadillo (Dasypus novemcinctus)

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Xenarthrans (armadillos, anteaters, sloths and their extinct relatives) are unique among mammals in displaying a distinctive specialization of the posterior trunk vertebrae - supernumerary vertebral xenarthrous articulations. This study seeks to understand how xenarthry develops through ontogeny and if its development impacts regionalisation patterns (thoracic vs lumbar). Using 3D geometric morphometrics on the neural arches of vertebrae, we explore phenotypic, allometric, and disparity patterns of the different axial morphotypes during ontogeny of nine-banded armadillos. Shape-based regionalisation analyses showed that adult thoracolumbar column is divided into three regions according to the presence or absence of ribs and the presence or absence of xenarthrous articulations. A three-region-division was retrieved in almost all specimens through development, although younger stages (e.g. embryos, neonates) have more region boundary variability. In size-based regionalisation analyses, thoracolumbar vertebrae are separated into two regions according to the presence or absence of xenarthry. We show that xenarthrous thoracic vertebrae grow at a slower rate, while anterior thoracics and lumbar grow at a faster rate relatively, with rates decreasing anteroposterioly in the former and increasing anteroposterioly in the latter. We propose that different proportions between vertebrae and vertebral regions might result from differences in growth pattern and timing of ossification.

Keywords: Vertebrae, Xenarthra, growth, ossification

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[*] Speaker

The South American camelids domestication at the south-central Andes through the morphogeometric evaluation of the phalanges

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The domestication of South American camelids took place independently in different sectors of the Andes around 4600-3600 BP., and produced behavioral, physiological and morphological changes on wild populations (*Vicugna vicugna* and *Lama guanicoe*) and their domestic morphotypes (*Vicugna pacos* and *Lama glama*). Due to the morphological changes derived from the domestication process, this domestic species of camelids shows larger sizes than wild ones.
In archaeology, traditional morphometrics studies of postcranial bones have been used to differentiate camelid species based on their size. This technique distinguishes small camelids (*Vicugna vicugna*, *Vicugna pacos*) from large camelids (*Lama guanicoe*, *Lama glama*). Each set includes a domestic and a wild species with low magnitude of the morphological change within each group, so differentiating wild and domestic forms from their bones is a challenge.

At the beginning of late Holocene, in the Argentine Northwest only the *Lama guanicoe* (guanaco) was domesticated. For this reason, the main difficulty of zooarchaeological studies in this area is to discriminate between the domestic and wild species of large camelids that have similar body sizes. To address this, we employed two-dimensional geometric morphometric techniques in order to identify shape differences between modern guanacos and llama (*Lama glama*) phalanges. Subsequently, we used this data to classify archaeological specimens from northern Quebrada de Humahuaca (Argentina) with the wild or domestic morphotype.
We used landmarks and semilandmarks configuration to study first and second phalanges. After a generalized Procrustes analysis, shape variables were studied with Principal Component Analysis and Discriminant Analysis. Results show variations in the phalange's shape between the larger wild and domestic species. Geometric morphometric techniques constitute a new methodological approach to the study of the intra and interspecific morphological variability of Camelidae family. Therefore, it contributes to the knowledge of the large South American camelid domestication process at South-Central Andes.

Keywords: 2D geometric morphometric techniques, domestication process, large camelids, South Central Andes

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*Speaker

Geometric morphometrics of leaf phenotypic plasticity: linking bioclimatic variables and leaf phenotypes in European goldilocks buttercups

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Phenotypic plasticity of vegetative organs is essential for sessile organisms like plants in a steadily changing environment. Whereas in woody plants numerous studies have shown that leaf phenotypes reflect ambient temperature, herbs remain poorly investigated so far. Our model group is goldilocks buttercups (Ranunculus auricomus), a complex of hundreds of morphospecies, which are distributed across several climatic zones of western Eurasia. Goldilocks buttercups show striking phenotypic plasticity of basal leaves among which two extreme phenotypes can be distinguished (non-dissected leaves vs. deeply dissected leaves). The vast majority of natural populations show hybrid forms and here we ask whether these polymorphic forms possibly reflect bioclimatic conditions of their habitats. Our sampling of preserved leaves from 512 herbarium sheets covers sampling sites spread across western Eurasia. Leave shapes were captured using 2D landmark geometric morphometrics and bioclimatic variables at corresponding sampling sites were derived from the WorldClim database. Finally, an association between phenotypes and climate was tested using regression models. Species distribution models showed that plants with non-dissected leaf blades had slightly different optimal distribution than plants with dissected leaf phenotypes. Regression models showed significant effects of temperature-related bioclimatic variables. Both temperature seasonality (BIO4) and mean temperature of the driest quarter of the year (BIO9) were negatively associated with the extent of leaf dissection. We conclude, that rising continentality eastward goes hand in hand with decreasing leaf blade outline to surface ratio. This observation might have an ecophysiological explanation related to effective plant thermoregulation in the driest seasons, i.e., less dissected leaf phenotypes might have a lower ability to transfer excess heat to the surroundings due to the thicker leaf boundary layer.

Keywords: phenotypic plasticity, leaf, bioclimatic variables, geometric morphometrics, goldilocks buttercups

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[*] Speaker

Sheep or Goat ? Identifying isolated teeth and mandibles using geometric morphometrics

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Sheep and goat are often herded together and show great morphometrics resemblance of their skeleton. On one hand, the use of discrete macroscopic criteria; and on the other hand the recent use of geometric morphometrics, particularly on the talus, have helped distinguishing the two species. However, quantitative approaches are still scarce especially for mandibles and isolated teeth. The aim of this study is therefore to propose a new 2D geometric morphometric protocol in order to distinguish the two species. This protocol is applied on 3rd lower molar and on mandible, using 2D landmarks and slidings semi-landmarks. Our analyses combine modern specimens of known breed, sexe and estimated age, before being applied to archaeological specimens dating from the middle-age and originating from the North-Western Mediterranean bassin. Once the specimens identified, teeth and mandibles size and shape variation can be quantitatively studied through time and space, leading to a better understanding of the bio-cultural drivers of sheep and goat diversity. The GMM results will be contextualised in the framework of ERC-DEMETER project aiming at studying " Eight millennia of changes in domestic plants and animals: understanding local adaptation under socio-ecomic and climatic fluctuations ". This research is part of the DEMETER project (ERC, grant agreement No. 852573)

Keywords: archaeozoology, discriminant analyses, classification, Ovis aries, Capra hircus

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*Speaker

Studying the current diversity of barley using geometric morphometrics on modern seeds: protocol and first results

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Geometric morphometrics is a powerful method to explore intraspecies variation in cultivated plants (Terral et al., 2012 ; Bonhomme et al., 2017). Barley (*Hordeum vulgare* L.) is one of the staple crop of the Mediterranean since the Neolithic (Zohary et al., 2012). While morphological discrete characters are available to distinguish two-rowed from six-rowed barley, and naked from hulled barley (Jacomet et al. 2006), quantitative approaches still need to be developed at a large scale. The aim of this study is to explore the morphometric grain variation between barley varieties, six- and two-rowed types, naked and hulled types and spring and winter varieties. Size and shape of 2950 modern barley seeds from 84 current varieties provided by the Small grain cereals Biological Resources Centre (INRAE, Clermont Ferrand, France) were quantified using Elliptic Fourier Transforms (EFT) applied to gain outlines 2D coordinates. Results open interesting perspectives for investigating archaeological barley seeds and trace barley evolution in the western occidental Mediterranean basin since the Neolithic. This perspective will be realized in the framework of the ERC project DEMETER (grant agreement No. 852573). .

Keywords: Elliptic Fourier Transforms, archaeobotany, Hordeum vulgare, cereals evolution

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*Speaker

Claws Of The Caribbean

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Claws are common biological attachment devices that can be found in a wide variety of animal groups. Their curvature and size are supposed to be parameters related to ecological aspects. Mites, known as very small arthropods, occupy a wide range of ecological niches and are a perfect model system to investigate correlations of claw morphology with ecology. We performed the first geometric morphometric investigation of arthropod claws using different Caribbean intertidal oribatid mite species living in three different habitat types to determine if claw shape is correlated with ecology. Furthermore, we tested for phylogenetic signal within this morphological trait and checked if a potential habitat specific claw shape is already present in juvenile stages of those mite species. Our results show that species living on rocky shores show remarkably high and strongly curved claws while species from mangrove habitats show significantly lower and less curved claws. Even in closely related populations, we find clear claw shapes for hard versus soft substrate, confirming previous findings. Surprisingly we do not detect any phylogenetic signal within the trait and even juvenile mite specimens already show habitat specific claws. Here we demonstrate that ecology (different surfaces and substrates) has acted as one of the primary selective forces in the diversification of claw shapes. Considering that the basic claw design may be the same in the majority of arthropods, our results have important implications for further investigations of claw morphology and its ecological relevance within this phylum.

Keywords: Acari, Oribatida, Geometric morphometrics, Ecomorphology, Semilandmarks, Adaptation, Littoral

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*Speaker

Decomposing morphological variation at different spatial scales: Application of the package prWarp to the primate skull

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In the last decades, the development of geometric morphometrics enabled quantitative description and analysis of complex shape patterns. However, this method has several limitations to handle different landmark densities along a structure, or to separate the biologically relevant signal from the noise in morphological variation. In order to deal with these issues, we propose a novel method for geometric morphometric data: decomposing shape variation into large-scale and small-scale shape components. Two different approaches are possible: (1) a mathematical decomposition of the non-affine shape variation into *partial warps*, namely the partial deformations for increasing spatial scales; and (2) an informed decomposition of the overall shape variation into outline and residual shape components. We applied this method to the analysis of the midsagittal skull morphology in papionin primates ($n = 61$), quantified by the 2D Cartesian coordinates of 70 landmarks. Our hypothesis was that the small scale features of the skull are, relative to large scale features, functionally less important, hence more variable and more prone to drift. Using our new R package prWarp, we performed the analyses for both approaches. As expected, our results show that independently of the approach, small-scale shape variation is more consistent with papionin phylogeny, whereas large-scale shape variation better reflects an adaptive signal. This new method has multiple applications in fields as diverse as ecology, palaeontology, evolutionary biology and developmental biology.

Keywords: partial warps, geometric morphometrics, spatial scale, papionin, prWarp, phylogenetic signal, adaptive signal

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*Speaker

Gliding in the Amazonian canopy: adaptive evolution of flight in Morpho butterflies

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The diversity of flying animals suggests that countless combinations of morphologies and behaviors have evolved with specific lifestyles, thereby exploiting diverse aerodynamic mechanisms. Elucidating how morphology, flight behavior and aerodynamic properties together diversify with contrasted ecologies remains however seldom accomplished. Here, we studied the adaptive co-divergence in wing shape, flight behavior and aerodynamic efficiency among Morpho butterflies living in different forest strata, by combining high-speed videography in the field with morphometric analyses and aerodynamic modelling. By comparing canopy and understory species, we show that adaptation to an open canopy environment resulted in increased glide efficiency. Moreover, this enhanced glide efficiency was achieved by different canopy species through strikingly distinct combinations of flight behavior, wing shape and aerodynamic mechanisms, highlighting the multiple pathways of adaptive evolution.

Keywords: wing shape, flight behaviour, aerodynamics, habitat specialization, Morpho butterfly

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[*] Speaker

Comparison of ontogenetic and static allometry among three phylogenetically distant species of armadillos.

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Allometry, *i.e.* size-related changes of traits, represents a pervasive pattern in morphological evolution. Size-related shape changes within one species are not sufficient to infer allometric patterns within other species or within an entire clade. Consequently, recognition of a common allometric pattern among species requires analyses and comparisons of allometric patterns and/or trajectories at the intraspecific level in several species.
Our recent detailed study of ontogenetic and static allometry for the entire skull as well as cranial subunits in the nine-banded armadillo (*Dasypus novemcinctus*) has provided the first in-depth investigation of cranial allometric patterns within a cingulate species.

In this work, we first tested the hypothesis that the allometric patterns detected in *D. novemcinctus* are similarly present in two other series of phylogenetically distant armadillo species, *Zaedyus pichiy* and *Cabassous unicinctus*.

Applying 3D morphometric geometrics at different skull scales, we demonstrate that several allometric patterns are common to all three species. At the entire skull level, the strongest common allometric pattern corresponds to the craniofacial allometry (*i.e.* relative snout elongation and reduction of braincase proportions) although it appears weaker in *Zaedyus* and *Cabassous*. We suggest that this difference is due to the shorter snout in the latter. At the level of the cranial subunits, several common allometric patterns are detected such as a stronger and more posterior postorbital constriction and a more protruding mastoid process when size increases.
Comparison of the allometric patterns obtained at different levels enables us to highlight size-related shape changes that appear to be present within several cingulate species, and potentially represent common patterns of morphological variation induced by size variation throughout the whole clade. Our comparative study encourages us to consider analyses at the evolutionary level as a promising prospect for further understanding cranial allometric patterns within both extant and extinct cingulates.

Keywords: Allometry, Ontogenetic, Static, Armadillo, Cranium, Entire skull, Cranial Subunit.

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*Speaker

Differences in inner ear asymmetry levels between slow-moving and fast-moving primates

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The vestibular system of the inner ear, highly involved in maintaining balance during activities and positional behaviour of animals, has been deeply studied in order to link its morphology with the specific type of locomotion. Previous studies (*e.g.* Perier et al. 2016, Gonzales et al. 2018) have shown that, in primates, the amount of morphological variation is higher in slow-moving species than in fast-moving ones. These results indicate a lower selective pressure and a reduced functional demand for postural adjustments in the former group, and a higher selective pressure for balance and postural capabilities in the latter. In this study, we assessed if the difference in selective pressure are also linked to the fluctuating asymmetry levels of the vestibular system, and to which extent. Fluctuating asymmetry is defined as a non-directional variation between left and right sides of a bilateral character, and it may rise as a result of an inability to control development under genetic or environmental stress. There are very few analyses of the interspecific variation of the asymmetry levels of this organ in mammals in general (Berlin et al. 2013), and to our knowledge none so far at the intraspecific level. Here we analyzed the intraspecific variation of the bony labyrinth (inner ear) morphology and of the fluctuating asymmetry levels of left and right labyrinths among six species of lorisiform primates differing in their activities and positional behaviours of their locomotor repertoires: three being slow-moving (*Loris tardigradus*, *Nycticebus coucang*, and *Perodicticus potto*), and three being fast-moving taxa (*Paragalago granti*, *Galago moholi*, and *Otolemur crassicaudatus*). Our results highlight the difference in amount of intraspecific variation between slow-moving and fast-moving taxa. Furthermore, fluctuating asymmetry levels of slow-moving taxa also tend to be higher than in fast-moving taxa. Based on these results, it may be expected that relaxation of the selective pressure applied to the morphology of the bony labyrinth is the likely reason for this higher amount of intraspecific variation and asymmetry levels in slow-moving taxa, and that it may be related to a decreased demand for rapid postural changes.

Keywords: Inner ear, asymmetry, locomotion, 3D Geometric Morphometrics, primates

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[*] Speaker

Investigating the relationship between diet and mandibular morphology: new insights from a controlled-feeding experiment on domestic pigs

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Numerous previous studies detected a close link between diet and dental morphology in mammals. Conversely, the relationships between diet, feeding behaviour, and craniomandibular morphology are poorly defined, with the exception of the mice model. Here, we investigated in domestic pigs (*Sus scrofa*) whether the consumption of different foods in addition to an overall similar diet influences the mandibular morphology during growth period.

We conducted controlled-feeding trials (APAFiS 155/2015012117162897, INRAE, France) on 27 juvenile pigs that were fed daily from about 4 to 9 months old. We studied one group fed only with cereal flour (n = 6) and four others fed the same flour supplemented with either corn silage at will (n = 4), 30% barley seeds (n = 5), 20% corn kernels (n = 6) or 10 in-shell hazelnuts per day (n = 6). We performed principal component analyses (PCA) using 18 landmarks and 64 sliding semi-landmarks placed on three-dimensional digital surfaces to evaluate the mandibular shape variations and ANOVA on aligned Procrustes coordinates to detect significant differences between dietary groups.

PCAs and ANOVAs show that pigs fed with barley seeds or corn kernels exhibit more U-shaped mandibular arches, higher mandibular rami and narrower mandibular angles than pigs fed on softer foods (flour only or supplemented with corn silage), or on harder and bigger seeds (hazelnuts). These results suggest that the supplemental consumption of a significant amount of relatively hard and small seeds for a short period, even though the diet is overall similar, significantly influences the mandibular morphology in domestic pigs. These results represent important new insights on the relationships between diet and mandibular morphology.

Keywords: Jaws, Suids, Geometric Morphometrics

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[*] Speaker

Analysis of intraspecific variation in the bone microstructure of *Sciurus vulgaris fuscoater* humeri

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Computer tomography offers an unprecedented way for investigating internal structures such as bone tissue and organs without disruptive methods. In a biological sense bone structure and composition provides information about health, growth stage, evolutionary relationships as well as the lifestyle and behavior of an organism and can portray intra- and interspecific variation. In this study sexual dimorphism, laterality, seasonal variation, growth stage and differences between the proximal and distal epiphysis of bone parameters in the humerus of *Sciurus vulgaris fuscoater* were analyzed digitally.

A total of 39 humeri were used for scanning and analysis, belonging to 27 specimens. The scans were obtained in a CoreTOM with a voxel size of 0.026 mm. The CT scanned humeri were segmented using ORS Dragonfly and subsequently 6 bone parameters were calculated (bone volume (BV), total volume (TV), bone volume fraction (BV/TV), trabecular thickness (Tb.Th.), trabecular separation (Tb.Sp.) and cortical area (Ct.Ar.)). Additionally, trabecular parameters were calculated separately for the proximal and distal parts of the bone.

Statistical analysis showed neither a difference between males and females nor a significant laterality in the humeri. Growth stage, as well as seasonal changes, seem to have an impact on bone parameters in the case of Ct.Ar., (subadults/adults) or BV/TV and Tb.Sp. proximal (seasonal variation). The observed variation can be connected to bone ontogenesis and nutrient intake (most notably calcium) respectively. Furthermore, a significant difference was detected in the trabecular parameters of the distal and proximal epiphysis, as a result of differences in loading patterns during locomotion. The findings of this study suggest that intraspecific variation should be taken into account when investigating interspecific variation in bone parameters.

Keywords: intraspecific variation, bone microstructure, trabeculae, humeri, Eurasian red squirrel

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*Speaker

Shape changes of the diaphragmatic domes during breathing in COPD patients: a 3D geometric morphometrics analysis

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The impact of COPD on the geometry of diaphragm has been previously reported as a shortening of its cranio-caudal extension and a flattening of the diaphragmatic domes. Although both conditions lead to breathing difficulties in COPD patients, probably more acute in females due to their particular lung anatomy, there are no studies quantifying the extent of these parameters using precise digital techniques. Thus, the objective of this research is to analyse shape changes in the diaphragmatic domes during forced respiration using 3D geometric morphometrics. Computed tomographies were taken in maximal forced inspiration (FI) and expiration (FE) in a control group 36 healthy individuals (18 males and 18 females) and 33 stable COPD patients (18 males and 15 females). Then 161 (semi)landmarks were digitized on 138 virtual lung models for comparative quantification of the diaphragmatic domes shape during breathing. Firstly, the obtained 3D coordinates were subjected to a Generalized Procrustes Analysis (GPA) and shape variations were explored and visualized by a Principal Components Analysis (PCA) (**Figure 1**). The distribution of the PC scores is statistically analysed in **Table 1**.

To further test for shape differences in breathing kinematics between control and COPD groups, we performed a mean shape comparison in full shape space (**Figure 2**). Shape difference between the FI and FE diaphragmatic domes of each subject was quantified by Procrustes distance between both configurations of shape coordinates and statistically analysed in **Table 2**. Our results suggest that COPD patients present significantly flattener diaphragmatic domes (**Figure 1, Table 1**) and a smaller shape variation during breathing (**Figure 2, Table 2**). As expected, these effects are more pronounced in females than in males (**Table 2**).

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Keywords: COPD, diaphragmatic domes, breathing, 3D geometric morphometrics

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*Speaker

Deciphering the mandibular shape variation in a group of a Malagasy primates using Fourier outline analysis.

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The analysis of morphological variation is a powerful tool with major applications, both for the estimation of biological diversity and for the understanding of the fundamental parameters of a species' ecology and, therefore, for the implementation of conservation measures. While several morphometric analyses of malagasy primates have focused on the craniofacial complex, the characterization of their mandibular morphology has received less attention, especially in the last decade. Thus, if studies exist to understand the morphological variation of the mandible at the macroevolutionary scale, this is less the case at a smaller taxonomic scale. The interest of this work is to characterize the morphological variation of the mandible within five genera (Lemur, Eulemur, Hapalemur, Prolemur and Varecia) of the same family, the Lemuridae. This family has previously been recognized as presenting a higher morphological variation than in other families of Malagasy primates, at the origin of a controversial taxonomy (Raveloson, 2007). For that purpose, we adopted Fourier outline analysis on the left mandible of 193 specimens covering the five genera of the family. The influence of physiological (such as sex, age, body mass, diet...) or ecological covariates (home size, group size, distribution, sexual behavior, habitat,...) and the interactions of these factors was examined in order to quantify the role played by each covariate for structuring the morphological variation. Our results indicate that diet and habitat play a major role in the structuration of mandibular shape variation. These results highlight the importance of conservation and management measures to avoid habitat loss of the members of this family, already widely threatened.

Keywords: Mandible, diet, Fourier analysis, Geometric Morphometrics, primates

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*Speaker

Skull and mandible shape variation in mouse opossums, genus Marmosa (Didelphimorphia, Didelphidae): a preliminary assessment

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Mouse opossums of the genus Marmosa Gray, 1821 are currently divided in 5 subgenera. With 25 species, *Marmosa* can be considered the most species-rich genus of didelphid opossums. Recent advances in phylogeny and taxonomy are revealing a group more diverse than initially thought. However, a comprehensive quantitative analysis of cranial and mandibular shape variation within *Marmosa* has not been conducted. Here we provide initial results of the diversity and variation observed within the genus and related it to the current phylogenetic knowledge. To do so, we used images of the dorsal view of the cranium (432 specimens) and lateral view of the mandible (445 specimens) of 12 species, where we placed 35 and 19 landmarks, respectively. Landmark configurations went through a Generalized Procrustes Alignment and resulting shape variables were analyzed through Principal Component Analyses. An independent phylogenetic hypothesis was also used to generate a phylomorphospace and test for phylogenetic signal. All analyses were conducted in MorphoJ. Overall, there is considerable overlapping among most species, indicating little interspecific shape variation . We also found a significant phylogenetic signal for both the cranium and mandible ($p=0.0384$ and $p= 0.0060$, respectively). The most divergent species in cranium phylomorphospace are *Marmosa tyleriana* (with wider nasal bones and narrower zygomatic arches) and *M. lepida* (with a more globose braincase and shorter nasal bones), whereas most other species show a conservative or convergent cranial shape. In contrast, *Marmosa rubra* and *M. xerophila* converge in their more robust mandibles, and *M. tyleriana* remains the most distinctive in mandible shape, with a narrower mandible. These preliminary results will be completed with the inclusion of additional species of *Marmosa.* This will help to understand better the morphological diversificationof the genus.

Keywords: Didelphidae, Marmosa, Morphological evolution, Cranium, Mandible

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[*] Speaker

Mazama insulae: an extinct dwarf deer from Playa don Bernardo, Panamá (6000 cal. BP)

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The archaeological site of Playa don Bernardo (PdB) is located on Pedro González island at Pearl Island Archipelago in Panama. This site was inhabited between 6200-5600 cal yr BP. They were farmers who cultivated maize and root crops. When they reached the island they found a local dwarf deer ($<$ 7 Kg) population. The archaeological record evidence that dwarfed deer was the most abundant terrestrial mammal in the assemblage. Also that, the island's inhabitants consumed venison and used deer bones to make ornaments and tools. Deer remains decreased across time, with none remaining at the end of the human occupation. The taxonomic identification of the dwarf deer is not clear, collagen fingerprinting analysis shows that the archaeological deer fingerprints do not derive from extant Panamanian *Mazama temama* but from a group of taxa that includes the *Odocoileus virginianus* and Colombian populations of *Mazama americana*. The PdB fingerprint match whit the collagen samples from San José Island (Pearl Island Archipelago), where an extant population of deer inhabits. This population is thought to be *Mazama nemorivaga*, however, this determination was made intuitively. In general, the taxonomy of deer in Central and South America, despite the works in the last years, is still unknown. In part because *Mazama* genera represent separate radiation events with high levels of molecular and cytogenetic divergence being a polyphyletic genus. The aim of this presentation is to explore the taxonomy of this dwarf deer through the use of geometric morphometrics by comparing the lower third molar of the archaeological samples with extant *Mazama americana, Mazama temama, Mazama nemorivaga* and *Odocolileus virginianus* from museum collections. The results suggest that the species of deer that inhabited PdB was related to *Mazama americana.* It is possible that PdB deer was the dwarf form of this species. We suggest a new species based on the geometric morphometrics results call *Mazama insulae.* In the near future, we expect that genetic analysis of the Neotropic cervids brings more information about this extinct species that inhabited Pearl Island Archipelago.

Keywords: Dwarf deer, Preceramic, Panama, Pearl Island Archipelago, Geometric morphometrics

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*Speaker

A landmark-free approach to quantify climate-related variation of the human nasal airway

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The morphology of the human craniofacial skeleton is the result of the complex interaction between genetic, physiological, biomechanical, and environmental factors. The latter include climatic factors such as air temperature and humidity, that might have played a significant role in the evolution of craniofacial morphology. Previous studies have tried to disentangle these factors and focus on climate-related variation of the skull. Particular attention has been paid to the nasal cavity, which constitute the interface region between humans and their environment. These studies have shown that, depending on the type of climate in which they live (hot/cold, humid/dry), humans tend to have morphologically different bony nasal cavities. Less is known about the climate-related variation of the associated soft tissues. Indeed, the nasal cavity is covered with a respiratory mucosa that produces heat and moisture exchanges and that is therefore crucial in respiratory energetics and air conditioning. Few studies have focused on understanding the impact of temperature on nasal airway (NA) morphology, yet this is very important for studying nasal morphology in a more structural and physiological prospect. Our research focuses on these issues. For that purpose, we study CT-scans of modern individuals living in five different regions (France, South Africa, Russia, Cambodia and Chile). Using diffeomorphism, a landmark-free approach, we quantify the variability of the NA among and between these populations. Preliminary results highlight that the most variable areas of the NA are the anterior part (i.e. the nasal aperture), the middle meatus, the superoposterior part and the choanae. This study provides clues to better understand nasal shape variation in relation with demographic data and, more extensively, with climatic factors. Our results will ultimately allow us to discuss the role of climate adaptation in human evolution.

Keywords: Biological anthropology, Environmental adaptation, Respiratory function, Diffeomorphism

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[*] Speaker

Effect of Low Frequency Electromagnetic Field (50 Hz, 1.5 mT) on Wing Shape and Fluctuating Asymmetry of *Drosophila melanogaster* in Five Generations.

Farzaneh Morovat * [1], Saber Sadeghi [1]

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Electromagnetic waves affect the stability and health of various organisms, including insects, such as *Drosophila melanogaster*. In this study we were examine the effects of the applied electromagnetic waves to investigate the shape and asymmetric fluctuations of the left and right wings of this insect as a criterion of developmental instability. Around 120 wild-type *D. melanogaster*, were collected and grouped into control and treated groups. Both groups were at room temperature (25◦C) but the treated group was exposed to the electromagnetic field (1.5 mT, 50 Hz) using a Helmholtz coil *as a magnetic field source.* The study was performed five generations. The wings of the adult flies in each generation were utilized for photographing and landmarking by geometric morphometrics softwares. The results indicated significant wing shape differences and remarkable fluctuating asymmetry in some treated groups especially 5th generation. Besides, the observed flies in treated groups exhibited asymmetrical wing shape, longer growth times and larger size of wings in comparison with the control group. Our results imply that electromagnetic field probably affects the wings development and natural growth time of this insect and may cause an abnormal form of the wings or harmful destruction.

Keywords: EMF stress, geometric morphometrics, wing shape, fitness, developmental instability

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*Speaker

Filter criteria for the profitable use of digital images, taken under field conditions, and augmentation in Machine Learning

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Digital photography of wild animals has become inexpensive these days. The research community has shown many interests in *in-situ* measurements (Mahendiran *et al.,* 2018). However, digital images possess object-orientation issues and have always been the primary cause of hindrance, particularly in size and shape analyses. Object orientation often occurs in fossil specimens or natural history collections that produce shape deformations and distortions from its natural shape and size. Using Keras, the deep learning neural network library, augmentation of a digital image is essential for machine learning problems that create image manipulation functions such as rotations of the images in different axes. However, the above augmentation method lacks the acceptable level of object-orientation issues that ensures the non-distortion of specimens' shapes. Therefore, we developed a model that ensures the acceptable level of object orientation in the digital images taken under field conditions with ±20○ towards or away from the image plane, ensuring non-distortion of shapes and reduced errors. Here, we provide empirical shreds of evidence using Cardboard Model Fish (CMF) that (a) Object-orientation produces shape variations. (b) Generalized Procrustes Superimposition (using least square fit) reduces the non-shape variation and the object-orientation issues. We show that the generalized least square (GLS) algorithm partitions the overall shape variation to all landmarks and reduces non-shape variation, particularly the specimens orientated up to ±20○. Though the corrections of the object orientation by the GLS superimposition were limited to a small range, it assumes significance. Thus, we expand the scope of Procrustes' application with appropriate filter criteria for using digital images taken under field conditions and the augmentation of digital images for machine learning problems.

Keywords: Object orientation, Procrustes Superimposition, Filter criteria, Cardboard Model fishes, Digital images, under field conditions

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*Speaker

The longevity of the crop reflects on their seed characters (size and shapes) in selected rice varieties of Tamil Nadu

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2

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The size and shape of the rice seed varieties are essential characteristics for crop improvement and, at the same time, directly related to consumer preference and milling quality. However, even trained farmers often fail to distinguish the morphological difference among rice seed varieties and tricky for the commoner. Therefore, we used the traditional liner and 2D Geometric Morphometrics tools to study the size and shape variation of the selected rice seed varieties. We photographed 640 rice seeds of 16 varieties using the stereo zoom microscope with a photography attachment. From those rice seed images, we estimated the size *viz.* length, width. The results of one-way ANOVA confirmed statistically significant differences between the 16 rice seed varieties for length and width.

A tps file was created for the rice images *viz.,* ADT47 (short), ADT46 (medium), and CR1009 (long duration) using TpsUtil (Rohlf 2015) and 30 landmarks (discrete homologous points) were marked with TpsDig2 (Rohlf 2015). Then, TpsRelw (Rohlf 2015) was used to facilitate the statistical analysis of landmark data in rice seed morphometrics. The average shape of rice seed varieties was computed and aligned all the digital images using a Generalized Procrustes Analysis (GPA). Our results showed that the rice seed size classified the rice varieties based on duration *viz.*, Short, Medium, and Long. The Principal Component Analysis (PCA) plot revealed significant variations based on duration.

In addition to the landmarks, we extracted the outline shape of the seed using the Elliptic Fourier Descriptors (EFDs) with the SHAPE software (Iwata and Ukai 2002). The PCA plot revealed significant shape variations among ADT46 (medium), ADT47 (short), and ADT 44 (long duration), which closely reflected the landmark results.

Further, we used the entire image of the rice seed for the classification and prediction, using Deep Neural Networks with TensorFlow and Keras in R with 85% accuracy. The Weka provides access to Dl4jMlpClassifier using the Deeplearning4j library, which results in 90% accuracy. Thus, it is evident from all the results that longevity (crop duration) preferably decides the rice grain shape.

Keywords: Rice Seed, Crop Duration, Digital Images, Geometric Morphometrics, Deep Learning

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*Speaker

Investigation of the covariation patterns between the respiratory turbinates the incisor and the skull

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The cranium is a structure involved in a large number of functions. Due to the interaction of different factors such as phylogenetic relationships, adaptation to a particular ecology or biomechanical constraints, the different cranial regions tend to covary to different levels. The respiratory turbinates and incisors are functionally important cranial structures. Incisors are part of the masticatory apparatus and therefore play an important role in feeding. Respiratory turbinates are bony structures hosting epitheliums that play a key role in temperature and moisture conservation. Despite their importance, the covariation of these structures with each other and with the skull has never been investigated. Rodents represent a very interesting clade for such studies due to their very high ecological and morphological diversity. A protocol of 179 landmarks describing the skull, the incisor and both the respiratory turbinates was realized on 34 rodent species including curve sliding semilandmarks for the incisor and the turbinates. Using geometric morphometrics methods, we first quantified the shape variations of these three structures using PCAs. Then we quantified their covariation patterns using two-block PLS. Our results indicate variable effects of the phylogeny, ecology, and size on shape variations and covariations of these structures. We also demonstrated a lack of covariation between the shape and the surface data classically used to quantify turbinate morphology. Therefore demonstrating the importance of this new proxy.

Keywords: Geometric morphometrics, covariation, comparative analyses, turbinal bones, incisors, skull, rodents

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*Speaker

Biomechanical constraints associated with captivity alter craniomandibular shape and integration

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The process of animal domestication is a key evolutionary transition in human history, within which the control of wild populations is considered a crucial first step. Yet, phenotypic changes associated with animal captivity remain challenging to document in the archaeological record. Using an experimental approach, we explored whether such environmental constraints can leave an anatomical print, i.e., morphological changes induced specifically by captivity, on the musculoskeletal system beyond the phenotypic variation range observed in animals in their natural habitat. We used wild boar (*Sus scrofa*) as model and we focused on the skull as a phenotypic marker. We compared the craniomandibular shape and morphological integration of wild boar populations raised in the wild and in captivity using geometric morphometric methods based on homologous landmarks and sliding semilandmarks on digital representations of crania and mandibles. We explored the differences among the populations in their response to captivity using Principal Component Analyses and Partial Least Squares Analyses. Our results highlight significant shape differences between wild and captive wild boar populations. Morphological constraints associated with captivity also result in a reduction of craniomandibular integration underscoring that plastic responses to captivity also affect the magnitude of integration. These results support the hypothesis that captivity has a major effect on the development of bones, and his therefore one of the preeminent features acting on the shape changes occurring during the domestication process. These observed new features will be used as proxies for the identification of early processes of animal control. They will provide future new markers of the domestication process that will be explored in the archaeological record.

Keywords: domestication, experimentation, morphological integration

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[*] Speaker

The Borrowing of Concepts from Geometric Morphometrics to Archaeology: Homology, Landmark Types, Modularity, and Allometry

Mercedes Okumura * [1], Astolfo Araujo [1]

[1] Universidade de São Paulo – Brazil

Geometric Morphometrics (GM) is a method originally created in Evolutionary Biology studies, using the analysis of change in size and shape in order to better understand ontogenetic sequences, phylogenetic relations, among other issues. The uses of GM in archaeological materials have seen a strong increase in the last decade, mostly associated with theoretical approaches from Evolutionary Archaeology. This is not an isolated case, since most methods used by Evolutionary Archaeologists have been borrowed from Biology, provoking discussion regarding the future development of Evolutionary Archaeology and its methods. This presentation aims to discuss some concepts that have been directly borrowed from GM in the context of Biological Sciences and that have not been subject to much thought when used in Archaeology. Such concepts include homology and landmark types, the concept of modularity, as well as the idea of allometry. As much as archaeologists using GM can learn from past discussions held by biologists regarding the above-mentioned concepts, it is a good time for researchers to further examine ideas regarding the use of these in archaeological studies. We will also present a case study where geometric morphometrics is used to understand the patterns of temporal and spatial variation in the archaeological record of southern Brazil.

Keywords: Archaeology, Brazil, projectile points, Evolutionary Archaeology

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*Speaker

Computer vision meets morphometrics: the virtue of challenge

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Over the past decade, computer vision and deep learning in particular led to advances for morphometrics. Most often, the aim was to mitigate acquisition effort, for automated digitalization of landmarks and/or of measurements. From pioneer works (Palaniswamy et al, IET Comp Vis, 2011) to the most recent developments (e.g. Kwon et al, IEEE Access, 2021; Thevenoux et al, Comp Ag, 2021), a jungle of computer vision approaches and algorithms could now be useful for morphometrics.

Since these methods promise to ease, fasten, improve and massify the datasets under investigation, they seem to be of universal interest. Yet their use remains uncommon and their publication record scarce. We identified a non-exhaustive list of barriers that impede morphometrics to advance towards such appealing horizon:

1. Overall reproducibility: "our method happened to work once and here are our conclusions"
2. Datasets availability: "oh, the authors published their 5000 raw images on which I can re-digitalize their 48 landmarks myself"
3. Methods availability: "well, it works on my computer"
4. Methods genericity: "well, it works with my landmarks"
5. Metrics accuracy: "this method is very good... if you look at it my way""
6. Metrics usefulness: "once the two million parameters of my model are finely adjusted, the identification is slightly better than chance alone"
7. Methods benchmarking: "I beat existing baseline, I guess"

Morphometrics could draw inspiration from computer vision where "challenges" and curated platforms are customary and overcome, by construction, these limits. Challenges allow participants to test their algorithms in a double-blind study against shared datasets and then discuss their results (e.g. https://www.imageclef.org/LifeCLEF2020). Curated platforms provide access to codes, tutorials, datasets and, overall, a forum to the interested community (e.g. and https://gitlab.com/ecostat/imaginecology). Sometimes, challenges and platforms are combined (e.g. https://www.kaggle.com/).

We propose to discuss, and hopefully ignite such coordinated effort with scientists from different fields gathered at SMEF 2021.

Keywords: computer vision, automated digitalization, automated measurements, challenge

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[*] Speaker

Geometric Morphometrics provinding new insights into the study of lithic form in Brazilian archaeology

Renata Pedroso De Araujo * [1]

[1] Museum of Archaeology and Ethnology at the University of São Paulo – Brazil

This poster proposal regards my doctoral research. I am a Ph.D candidate in Archaeology from the Museum of Archaeology and Ethnology at the University of São Paulo (Brazil), and I am currently developing a project on the application of geometric morphometrics to two classes of formal lithic artefacts from prehistorical sites and collections located in the State of São Paulo (Southeastern Brazil): bifacial projectile points and plane-convex artefacts.
The idea for this poster is to present to the public the aims of this project regarding the application of 2D geometric morphometrics to lithic artefacts from Southeastern Brazil and to show how geometric morphometrics consists in a robust and effective quantitative method for the analysis of shape of archaeological material culture. Moreover, it seeks to state that geometric morphometrics is at present an uncommon approach used by Brazilian archaeologists who study artefact morphology. This research, together with some previous work on lithics published by two Brazilian archaeologists, is pioneer in Brazil regarding lithic analysis, so my idea for this conference proposal is to present how this project can offer an important contribution to the understanding of the variability of lithic form which will provide new insights and scientific evidence for questions related to the definition of archaeological cultures and the conformity of cultural frontiers during the Holocene in South America.

Keywords: 2D geometric morphometrics, lithic analysis, formal lithic artefacts, Southeastern Brazil, Prehistory; Holocene

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*Speaker

Understanding the genetic architecture of Drosophila melanogaster wing shape is complicated by genetic and environmental effects in artificially selected and wild caught populations.

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[2] University of Melbourne – Australia
[3] Florida State University – United States

Dissecting the genetic architecture underlying complex traits remains challenging because of the joint contributions of many alleles of small effect, genotype-by-environment interactions, and other factors. With advances in sequencing technology and methodologies to detect variants, we are only able to identity a subset of the loci contributing to shape variation and many identified loci fail replication in subsequent studies. In part, this reflects low power to identify small effect variants and points to confounding factors such as environment, genetic background and populations' history of selection. Wing shape in D*rosophila melanogaster* is a well-studied trait with over 500 identified polymorphisms influencing variation. Our study asked if we could replicate observed genetic effects in three genes: *dachsous (ds), extra-monochete (emc)* and n*euralized (neur)*, by selecting on shape change and observing responses in allele frequencies using artificial selection and wild-caught contexts.

Using a synthetic outbred population designed to optimize genetic diversity at the *ds* locus, we selected on *ds* shape change for 8 generations. Surprisingly, we observe an allele frequency change at not only *ds* but at a number of other hippo signalling loci. *ds* is a member of the hippo signalling pathway, indicating that genetic effects within this pathway are correlated. Additionally, selection using the same synthetic outbred population based on *emc* shape change, a vector similar in direction to ds shape change but not a member of the hippo signaling pathway, only showed a modest allele frequency change at *emc*. However, we observe a robust allele frequency change at a number of hippo signalling loci, including *ds*, indicating the import influence of genetic variation in a population to selection. We also attempted to replicate genetic effects in wild cohorts by collecting animals from orchards and vineyards in Michigan, USA and selecting outlier individuals based on a 'shape score' calculated by projecting shape data onto shape change vectors then measuring genomic differentiation between extremes. Although we observe a correlation between *ds* and *neur*, the vectors used in this study, shape change and the first three principal components of shape variation, we were unable to identify genetic differentiation at either locus, indicating that other confounding factors influence shape variation in natural populations. Overall, our results demonstrate the complexities of replicating genetic effects in other contexts and the importance of considering the contribution of both genetic and environmental variation in a population when identifying polymorphisms contributing to trait variation.

Keywords: QTL, Genomics, Artificial Selection, Genetic Architecture

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[*] Speaker

Patterns of sexual dimorphism in the modern human fibular extremities: a geometric morphometric approach

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Introduction and objectives

The study of traditional morphometry of the human fibula has revealed differences between males and females. However, the whole morphology of the fibular extremities remains scarcely analyzed in studies of sexual dimorphism. In this work we apply the three-dimensional geometric morphometric approach to investigate sexually dimorphic features in the fibular proximal and distal extremities, with the aim of implementing the methods normally used for human sex determination.

Materials and methods

A sample of 136 left fibulae belonging to 19th-20th century South Africans (N=17) and Italians (Bologna: N=47; Sassari: N=71) were digitized through CT and laser scanning. A total of 142 (semi)landmarks captured the shape of proximal and distal fibular extremities, and two separate Generalized Procrustes superimpositions were performed on each set of Procrustes coordinates of the proximal and distal fibular, respectively. Principal component (PC) analysis was performed to explore differences in shape and form space. Linear discriminant analysis (LDA) with leave-one-out cross-validation testing assessed classification accuracy of sex based on shape variations using shape and PC scores, as well as centroid size.

Results

Females show narrower heads, malleoli, and proximal and distal articular surfaces than males, since both fibular extremities present significant sex variation in form space, except for South Africans. Centroid size differences between sexes emerged for Italians, correctly classifying individuals in the respective sex group for both extremities in 69%-87% of cases, but not for South Africans. LDA on the first three form PCs in the whole sample correctly assigned males and females for both extremities in 68-95% of cases.

Conclusion

While fibular extremities account for subtle morphological changes, significant sex size differences emerged between sexes, with a degree of accuracy that validates the present method for sexing human fibulae in bioarcheological and forensic contexts. A population-based approach is however suggested.

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[*] Speaker

Keywords: Fibular morphology, Lower limbs, 3D geometric morphometrics, Sex variations, Skeletal identified collections

Using morphometrics to understand developmental shifts underlying diversity

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Using morphometric approaches to localize differences in form to specific morphological traits or cell populations facilitates the formulation of hypotheses about processes that underlie morphological variation. We are studying mouse models for craniosynostosis syndromes associated with mutations in the Fibroblast Growth Factor Receptor (FGFR) gene family. These mutations can result in constitutive activation of the receptor associated with up-regulation of osteogenic differentiation, and these syndromes are characterized in part by dysmorphology of the bones of the anterior cranial vault and early closure of the coronal suture. Our work with mouse models for FGFR-related craniosynostosis syndromes shows that the closed coronal suture is only one of many complex traits associated with these mutations. Morphometric approaches have helped to identify new targets of molecular, cell, and tissue research in these mouse models for human disease. For example, morphometric analysis of the neonatal mouse skull led us to study cartilages of the embryonic chondrocranium that develops prior to formation of any cranial dermal bone. Our results reveal that FGFR mutations affect the chondrocyte series in addition to the osteoblast lineage, directly affecting embryonic cranial cartilage, a tissue rarely considered in the pathogenesis of craniosynostosis. Understanding the cellular processes that build morphology is key to understanding the disease process and the development of therapies for these syndromes. Our findings are also useful in interpreting processes underlying variation in skull morphology that has emerged over evolutionary time.

Keywords: Morphometrics, Evolution and Development, craniosynostosis

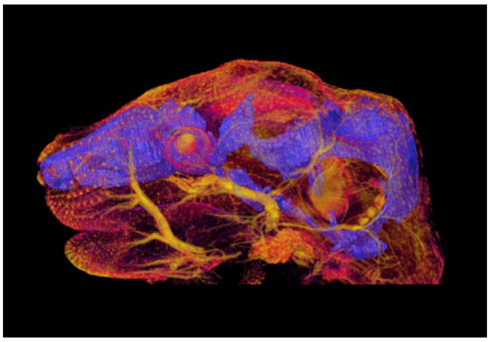

Figure 1: 3D reconstruction of micro-computed tomography images of a mouse embryo stained with phosphotungstic acid to reveal the chondrocranium (purple)

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*Speaker

Longer horns and small eyes: how Onthophagus bidens copes with exaggerate male weaponry development (Coleoptera, Scarabaeidae)

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Polymorphism is a relatively common phenomenon in insects and the coprophagous Onthophagini taxa are a fair and well-known example. In this framework, *Onthophagus bidens* (Olivier, 1789) is an especially interesting and so-far unique case in the dung beetles. Its cephalic weaponry showed a complex allometric relationship to body size, with both male and female polymorphism being recently identified in this species. Differential scaling of the measurements of some anatomical traits (head, eye, epipharynx, elytron, hindwing, foretibia, pygidium and aedeagus) with body size has been here tested in the males within a single African population from Ivory Coast. For each of the abovementioned traits the linear model was the better choice for data fitting. The majority of the examined traits increases at increasing body size, even showing different growth patterns. The only exceptions are the aedeagus (specifically, the phallobase and ventral tooth of paramers) and the eye (commonly subdivided into a dorsal and a ventral portion) which are not significantly related to body size. The relationships of these traits and cephalic horn were then tested, showing how in the aedeagus the phallobase share a common pattern with the ventral tooth of paramers, but not with the paramers on the whole. While the development of the dorsal part of the eye is not affected by either body size or horn, the ventral part decreases at the increasing of the horn length. Likely, males allocating many resources in horn development must use fewer resources in the development of other traits, specifically, the ventral part of the eye. Since the dorsal part of the eye is involved in field of view vision and orientation, while the ventral part in short vision (more focused on partner and food search), our results suggest that the males major gave up a better vision to develop longer horns.

Keywords: Allometry, data fitting, body size, horn length, dung beetles, eye

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*Speaker

A first 3D morphometric analysis to investigate relationship between cephalopod beaks and their ecology

Marjorie Roscian * [1,2], Anthony Herrel [2], Raphaël Cornette [3], Isabelle Rouget [1]

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Cephalopods are cosmopolitan marine molluscs that play a pivot role in all ecosystems. Indeed, they are eaten by meso- and top-predators and are also active carnivorous predators with a diverse range of prey. The coleoids, which are represented by octopuses, cuttlefishes and squids, represent the greatest diversity within the cephalopods with almost 800 species. Unlike all other molluscs, they have hard jaws, called beaks, which are often found in stomach contents of their predators. Their shape and continuous growth allow to identify species and estimate the age of an individual. Previous studies have assumed that the beak shape carries a strong phylogenetic signal and is not related to the ecology of these species. This is partly because these relationships have been assumed a priori to be negligible, but this has never been demonstrated. We conducted the first morphometric analysis on 3D models of coleoids beaks, reconstructed by photogrammetry or micro-CT scanning. Our results show only a moderate phylogenetic signal and suggest that beak shape is related to the environment (i.e pelagic, benthic or demersal) and trophic level, suggesting adaptive variation in beak shape. These results are consistent with our understanding of the beak musculature and provides new hypotheses on the ecomorphological relationships of the beak in cephalopods.

Keywords: geometric morphometrics, cephalopod beaks, 3D models, adaptations

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*Speaker

GMM of featureless surfaces: a case study of the anuran pelvis

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Mantellids are a hyperdiverse group of frogs endemic to Madagascar, showing large variation in morphology and ecological specialization that parallels their phylogenetic diversification. Among them, the genus *Blommersia* comprises several small species of small to miniature frogs, two of which occur in syntopy on the Comorian archipelago, which was colonized in an event of transoceanic dispersal from Madagascar. They have evolved in isolation, which has supposed an evolutionary experiment of morphological and genetic divergence without competition. In mantellids, body size is correlated with dispersal capabilities and these may have allowed colonization of new habitats in parallel to morphological divergence. Consequently, we hypothesized that variation in the *Blommersia* musculoskeletal anatomy would reflect potential differences between species in accordance to their diversification into different ecological niches and lifestyles. To test this, we focused on one of the main components of the anuran locomotor system: the pelvis. We compared the pelvic shape of seven *Blommersia* species, with special emphasis on the Comorian sister species pair and their Malagasy sister taxon. In addition, we mapped the insertion sites of the musculature on the *Blommersia* pelvis by means of a customized contrast staining technique prior to CT-scanning. Morphological distances resulting from the pelvic shape comparison between species correlated to a high extent with their 16S phylogenetic distances. In accordance, we discuss the observed patterns of pelvic shape variation and their relationship with size variation in the context of pelvic musculoskeletal architecture evolution in anurans and its potential interactions with locomotor function in the *Blommersia* genus.

Keywords: CT scan, contrast staining, GPSA, musculoskeletal anatomy, pelvic shape, Mayotte, Mantellidae

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*Speaker

Testing the accuracy of 3D automatic landmarking via genome-wide association studies

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Various advances in 3D automatic phenotyping and particularly in landmark-based geometric morphometric methods have been recently made. A few studies have tested the reliability of such automatic procedures in morphometric analyses. It is generally accepted that automatic landmarking affects analyses comparing sample means, but also the structure of covariance matrices.
However, no studies have directly tested the actual impact of such landmarking approaches in analyses requiring a very large number of specimens and for which the precision of phenotyping is crucial.

Here, we use a recently developed 3D atlas-based automatic landmarking method to test its accuracy in detecting previously found QTLs associated with craniofacial development of the house mouse skull.

For skull and lower jaws shape, the automatic approach generally failed to produce landmarks that would lead to recover the same or major previously found QTLs, but overlaps with the peak SNPs recognized for lower jaws shape were identified. For centroid size, the same general results were recovered for both the skull and lower jaws with the exact same peak SNP being found for the lower jaws.
These results indicate that a geometrically-based phenotyping criterion such as Type II landmarks (i.e. placed at maximum of curvature) exclusively used for an entire structure such as the lower jaws offers an overall fairer comparison between manual and automatic approaches since the automatic method uses a suite of geometric transformations for landmarking. In contrast to the skull which has a mixture of Type II and Type I (i.e. placed at real anatomical locations such as at the intersection between cranial sutures) landmarks with the latter not being treated as such by the automatic method. We conclude that the use of 3D atlas-based automatic landmarking methods requires careful consideration of the experimental question and the cautious interpretation of their results.

Keywords: Automatic phenotyping, atlas based segmentation, 3D landmarking, geometric morphometrics, skull, lower jaws, QTL mapping, GWAS, Mus musculus domesticus

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*Speaker

Preliminary morphometric analyses in the skull and mandible of short-tailed opossums, genus Monodelphis (Didelphimorphia, Didelphidae)

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The short-tailed opossums (genus *Monodelphis*), with 24 species, represent the richest genus of the Didelphidae family. Although our knowledge of *Monodelphis* systematics and taxonomy has greatly improved over the last decade, it has not been quantitatively assessed for its cranial and mandibular size and shape morphological diversity. Here we provide a first assessment of the shape diversity and diversification in its skull and mandible, using 2D geometric morphometrics, and we evaluate the role of phylogeny in the evolution of cranial shape. We set 35 landmarks on the dorsal view of the cranium and 19 on the lateral view of the mandible on a preliminary dataset of 235 specimens from 10 species, performed Principal Components Analyses (PCA) on the shape variables of both structures, and evaluated the phylogenetic signal in both structures. There was a significant phylogenetic signal in both structures (*P-0.0084* for cranium and *P-0.0087* for mandible). The Principal Components Analyses of the skull resulted in overlap in morphospace between some of the species. Cranium PCA shows that taxa of the subgenus *Monodelphis* are close to each other in phylomorphospace, but they diverge from all others, and the two species of the subgenus *Mygalodelphys* are highly divergent. A similar pattern appears in the mandible PCAs: mandibles of species of the subgenus *Monodelphis* are closer in phylomorphospace, and species of the subgenus *Mygalodelphys* diverge from each other.. Additionally, the mandible of *M. adusta* converges in shape with that of *Monodelphiops.* These preliminary results indicate a strong overall effect of phylogeny in structuring shape variation in *Monodelphis* cranial structures, yet with some instances of convergent shapes found in distinct unrelated subgenera, at least with this reduced dataset. We expect a clearer scenario of cranial morphological evolution in *Monodelphis* with the forthcoming inclusion of additional taxa in our analyses that will result in a more complete taxonomic sample that will capture the complete shape variation within the genus.

Keywords: Monodelphis, Didelphidae, Morphological Evolution, Cranium, Mandible.

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*Speaker

Mandible shape diversification in didelphid marsupials (Didelphimorphia: Didelphidae)

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Didelphid marsupials are considered a morphologically unspecialized group with a generalist omnivorous diet, which includes vertebrates, invertebrates, and plant matter. While variation in skull and scapula shape in the family was already analyzed in past studies, variation of mandible shape, sometimes associated with diet or phylogeny in other mammal groups, has not been properly assessed in Didelphidae. Here, we assess the variation in mandible shape in Didelphidae. We analyzed a total of 2,318 specimens (16 genera, 71 species) using 2D geometric morphometrics and a phylogenetic framework. We digitized 16 landmarks and 8 semi-landmarks on mandible images using tpsDig 2.31. Shape variation was analyzed through a Principal Components Analysis (PCA) using a known phylogeny to generate a phylomorphospace on MorphoJ, and we tested for a phylogenetic signal. Effects of size on the structure of the morphospace were tested by regressions of PC scores onto Centroid size to detect possible axis under influence of allometry. Initial results show variation with a significant phylogenetic signal ($p < 0.0001$), with mandibles of *Caluromys*, *Caluromysiops,* and the Didelphini clearly separated from all others. The first two PCs explained 67,95% of the total variation. Along PC1, shape variation ranges from specimens with shorter but wider mandibles, with relatively higher coronoid processes (represent mostly by *Caluromys* species) to all other species overlapping with thinner and longer mandibles. Along PC2, larger species are separated from all small taxa by having more robust mandibles. The phylomorphospace clearly showed the distinctiveness of the Caluromyinae and the Didelphini groups from the other genera. The mandible of *Metachirus* is slender and its shape approaches the morphospace of the small opossums, despite its larger body size. There is an overlap between all the mandible shapes of the small opossums, except for *Hyladelphys*, which is well separated from the others, supporting its phylogenetic distinctiveness from all other mouse opossums. There is another important overlap, between *Glironia* and *Gracilinanus*, although *Glironia* is usually recognized for being closer to the Caluromyinae. No major effects of size were found on the two first PCs, indicating that allometry does not play an important role in shaping the morphological diversity on the didelphid mandibles. These results indicate that the didelphid mandible shape is strongly influenced by phylogeny. Our next steps will be to extend our analyses, assessing the possible role of the subtle variations in diet found within the Didelphidae in the diversification of its mandible shape.

Keywords: geometric morphometrics, mandible, marsupials, morphological evolution, Didelphidae

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*Speaker

Morphological variation of the hominid navicular bone: Implications for behavioral driven divergence

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Morphology of hominid foot bones has received focused attention in paleoanthropological studies because of distinctive traits that are purportedly related to locomotor behaviors. In particular, the navicular is thought to preserve signatures of the medial longitudinal arch that uniquely characterizes the foot of *Homo sapiens* (among extant taxa), as well as distinctive morphological features that reflect habitual locomotor modes of hominids (great apes and humans). However, it is still debated what should be considered uniquely characteristic of human naviculars. This study reevaluates the distinctive traits of human naviculars that are presumably linked to locomotor behaviors by comparing naviculars of 21 *Pongo*, 35 *Gorilla*, 46 *Pan* and 221 *H. sapiens* accounting for different levels of mobility and subsistence strategies. Navicular shape was captured using a 3D template of 85 (semi)landmarks and analyzed through Geometric Morphometric methods. After Generalized Procrustes analysis, differences in shape coordinates were explored with Principal Component analysis and statistically evaluated with Procrustes ANOVA. Centroid size was used to investigate overall size differences and its contribution to shape variation (allometry). Navicular shape significantly differentiates *Pongo*, *Gorilla, Pan*, and *H. sapiens*. Alongside of size variation, it is possible to observe a subtle allometric effect that distinguishes *H. sapiens* from great apes. *H. sapiens* appears unique by showing a proximo-distally broader navicular body, a coronal displacement of cuneiform facets and a less

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*Speaker

medial-laterally elongated talar facet in respect to the navicular transversal length. We suggest that this morphology may reflect the presence of the medial longitudinal arch, therefore may be ultimately linked to our obligate bipedal locomotion. Human and non-human African great apes show a relative larger tuberosity than *Pongo* likely related to terrestrial locomotion. This preliminary contribution can be considered as a source for future studies aimed to investigate fossil hominin naviculars and their inferred locomotor behaviors.

Keywords: navicular, foot bones, hominids, locomotion, longitudinal arch.

Warthogs (Phacochoerus) are peramorphic relative to their presumed ancestor Metridiochoerus modestus based on shape analyses of crania and mandibles

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Extant warthogs are peculiar suids (Artiodactyla, Suidae) whose skulls and dentition display highly derived morphologies that are adaptive traits to their specialized diets of herbaceous plants in open African environments. They are represented by two extant species (common warthogs *P. africanus* and desert warthogs *P. aethiopicus*) whose fossil record is poorly understood. Oldest *Phacochoerus* could date back to ca. 1 Ma and their origin is assumed to stem from a small-sized Pleistocene species called *Metridiochoerus modestus*, occurring in eastern Africa from 2.2 Ma to 0.7 Ma. Here I quantify craniomandibular variability (ontogeny, sexual dimorphism, inter-species differences) in extant warthogs by applying 3D landmark-based geometric morphometrics. A series of specimens at different dental stages allows comparing ontogenetic changes in extant common warthogs to the adult craniomandibular shape of *Metridiochoerus modestus* based on a complete skull from Olduvai (DK site, ca. 1.9 Ma). The adult skull of *M. modestus* is strikingly similar in both shape and size to juvenile specimens of extant *P. africanus*. I therefore interpret extant *Phacochoerus* as peramorphic in shape and size relative to their putative ancestor *M. modestus*. This heterochronic shift could easily explain a geologically rapid origin of *Phacochoerus* from *M. modestus* via a selection of genes controlling timing and rate of growth.

Keywords: Suidae, developmental heterochronies, peramorphy, paleontology

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*Speaker

Computer vision and morphometrics to study quarantine nematodes

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The automatization and standardisation of morphometric studies are expected to make easier the identification of known species and bring evidence about the differentiation inside species complex. Some cyst nematode species belonging to the genus *Globodera* are capable of causing damage on potatoes and are therefore of major economic importance. However, their morphological identification remains complex and requires a high level of expertise. To tackle this challenge, we developed a complete method in order to identify the two quarantine nematode species *Globodera pallida* and *Globodera rostochiensis*. First, we chose discriminative metrics on the stylet of nematodes that are able to be used by algorithms in order to build an automated process. Second, we used a custom computer vision algorithm (CCVA) and a convolutional neural network (CNN) to measure our metrics of interest. Third, we compared the CCVA and CNN predictions and their discriminative power to distinguish closely related species. Results show accurate identification of *G. pallida* and *G. rostochiensis* with the two methods, despite small-scale divergence. We also showed that thanks to these new metrics and the high number of infective juveniles that were analysed, a morphologic distinction can be observed between *G. pallida* and the Chilean populations which are suspected to belong to a novel species. We think these methods represent a promising novel approach to automated morphological identification, of nematodes and *Globodera* species in particular.

Keywords: Automation, Landmarks, Machine learning, Morphometrics, Potato cyst nematode, Nematode taxonomy

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[*] Speaker

Morphological evolution of the *Crocidura poensis* species complex

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A species complex is defined as a group of closely related organisms with low inter-species morphological variability. Therefore, the number and delimitation of species, their geographic distribution, and their morphological features are either debated or overlooked. Such is the case of the *Crocidura poensis* complex, a group of widely distributed Afrotropical shrews, present in a wide array of habitats. Its taxonomy is still uncertain, with 12 species listed in the most recent taxonomic checklist (Wilson & Mittermeier, 2018), against 10 genetic lineages (Nicolas et al., 2019; Konečný et al., 2020). The aim of this study was to investigate the morphological evolution of this species complex, using a geometric morphometric approach on the skull. We tested the existence of clear morphospecies, investigated the amount of phylogenetic signal, and explored the role of various biotic and abiotic factors on the skull shape and size evolution. Here, we present morphological evidence for the complex interplay between climate, geography, habitat and interspecific competition on the shaping of the shrew skull.

Keywords: species complex, morphological evolution, shrews, skull

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[*] Speaker

Biomechanics and morphological patterns in head-first burrowing frogs

Marta Vidal-Garcia * [1,2], Marta Marchini [1], Jordi Marcé-Nogué [3], Josep Fortuny [4], Thomas Semple [2], Paul Cooper [2], Scott Keogh [2]

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Southwest Australia is a biodiversity and endemism hotspot for herpetofauna. Three unusual Australo-Papuan myobatrachid species occur in sandy habitats across semi-arid and arid regions in the Southwest corner, and differ from most other burrowing frogs by burrowing head-first in a forward direction, a behaviour which appears to have resulted in extreme morphological adaptations. Interestingly, the degree of morphological adaptations and fossoriality varies among them, but they are all starkly different from their non-burrowing sister species. Using diffusible iodine-based contrast-enhanced Computed Tomography (diceCT) we were able to extract data of both bones and soft tissue of forward burrowers and non-burrowers to assess morphological adaptation to burrowing across a fossoriality gradient. We used 3D geometric morphometric analyses to identify morphological integration patterns among fore-limb bones. We also assessed 3D muscle architecture associated with forward burrowing behavior. Finally, using Finite Element Analyses we assessed the biomechanical properties of the humerus and radioulna. We discuss their morphological evolution, biomechanics, and soft tissue differences in the context of different soil properties and paleoclimatic events that might have contributed to the morphological adaptations for a fossorial lifestyle in this clade of bizarre frogs. We hypothesize that our results could help to infer behavioural and ecological habits of extinct taxa.

Keywords: morphometrics, geometric morphometrics, biomechanics, Finite Element Analysis, muscle architecture, bone, muscle integration, adaptation

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[*] Speaker

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 associated with the "domestication syndrome" (DS). Although representing an appealing unitary explanation for the generation of domestic phenotypes, support for this hypothesis from morphological data and for the validity of the DS remains a topic of debate. This study used the frameworks of morphological integration and modularity to assess 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, and examples from each of the pathways by which animals entered into relationships with humans. 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) modules, along with 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. Contra to our predictions, however, we find domesticates share similar integration magnitudes to their wild progenitors. Higher disparity in domesticates is not associated with magnitude changes to integration among either neural crest or mesoderm derived elements. Differences in integration magnitude among neural crest and mesoderm elements across species suggest that developmental evolution preserves a framework that promotes flexibility under the selection regimes of domestication.

Keywords: domestication syndrome, modularity, neural crest hypothesis, cranium

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*Speaker

Giants of the Pampean plains (Argentina) during Early Pleistocene (Ensenadan). The case of Panochthus (Xenarthra, Glyptodontidae): comparative descriptions

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During the Ensenadan (Lower to Middle Pleistocene) cold environments prevailed compared to the previous and successive ones. Up to half of the past century, the Ensenadan was characterized by giant taxa, probably following ecogeographic patterns led by the Bergmann's rule. But subsequent systematic revisions have not always confirmed this hypothesis. Two species of *Panochthus* are recorded in the Ensenadan of the Pampean region, both exclusive of this Stage: *P. intermedius* (the type material) and *P. subintermedius.* Additionally, two specimens assignable to *Panochthus* cf. *P. subintermedius* have also been found in Ensenadan sediments of the Pampean Region. These taxa are considerably larger than their cogeneric specimens that lived after the Ensenadan-Bonaerian border. They follow the Bergmann's rule and fulfill the postulate of the Ensenadan gigantism. As well as other Ensenadan megaherbivores, the feeding behavior during this period may account for their large size.

Keywords: Panochthus, Glyptodontidae, gigantism, Bergmann's rule, Ensenadan, Pleistocene, Pampean Region, Argentina

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*Speaker

Changes in form and function of the caudal tubes in Panochthus Burmeister, 1866 (Xenarthra; Glyptodontidae) along the Pleistocene

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Glyptodonts' biochron span from the late Eocene until their demise at the early Holocene. Their palaeobiology has deserved attention lately, including their posture, locomotion and agonistic behaviour. It has been proposed that a bipedal (althouh not erect) posture could have been used in the very large Pleistocene species for using their heavy caudal tubes as weapons, as protection against predators and in intraspecific fights. With 8 species, *Panochthus* Burmeister, 1866 is one of the most abundant and diverse glyptodont genera during the Pleistocene of South America, as well as one of the largest individuals. The relationship between the shape of the tube and its usage as weapons in the species of *Panochthus* is explored here. The morphology of the caudal tube is: (1) ≈ conical -cylindrical and (2) hilt-less viking style sword. The form (1) is represented in *P. subintermedius* Castellanos, 1937 (MACN-Pv 5130), the only full caudal tube known for the time interval early Pleistocene – middle Pleistocene (Ensenadan). On the other hand, the form (2) is present in the specimens from the middle - late Pleistocene (Bonaeran-Lujanian): *P. tuberculatus* (Owen, 1845), *P. greslebini* Castellanos, 1942, *P. florensis* Brambilla, Lopez & Parent, 2020- *P. frenzelianus* Ameghino, 1889 is not considered, since its tube is not known nor are *P. jaguaribensis* (Moreira, 1965) and *P. hipsilis* Zurita, Zamorano, Scillato-Yané, Fidel, Iriondo & Gillette, 2017, whose findings are known from the Pleistocene (*sensu lato*)-. The shape of the caudal tube (1) ≈ conical-cylindrical, allows the glyptodon to perform its blows more effectively in all directions; that is, hitting with less precision. Whereas, the form (2) style of Viking sword, has the greater effectiveness in the blows produced in horizontal direction; these blows require then greater accuracy.

Keywords: Glyptodonts, palaeobiology, Pleistocene, caudal tubes, Panochthus, South America

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[*] Speaker

Morphometric analysis of a well preserved *Machairodus* skull (Carnivora, Felidae) from the late Miocene of Rhodos (Greece) with some taxonomic notes on the *Machairodus aphanistus–giganteus* transition

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A remarkably well preserved cranium and mandibula of an individual belonging to the genus *Machairodus* from the late Miocene of Kalithies, Rhodos (Greece) has traditionally been listed as *M. aphanistus* in the literature. A careful assessment of non-metric characteristics nevertheless shows that the *Machairodus* from Rhodos displays an intermediate morphology between *M. aphanistus* and *M. giganteus*. Additionally, *M. kurteni* appears to be a junior synonym of *M. giganteus*.

Mandibular dental elements of *M. aphanistus*, *M. giganteus*, "*M. kurteni*", and *Panthera leo* (*spelaea*) were measured with a sliding caliper or values were taken from the literature. Boxplots show that the canine dimensions of all *Machairodus* are very similar. The absolute size of the P4 and M1 of the Rhodos specimen is more similar to *M. giganteus*, "*M. kurteni*" and *M. horribilis* than *M. aphanistus*. A preliminary principal component analysis on dental ratios shows that the *Machairodus* from Rhodos is more similar in morphology to *M. giganteus* than to *M. aphanistus*.

The evolution from *M. aphanistus* to *M. giganteus* seems to be controlled by environmental changes: a decrease in humidity near the MN11/MN12 boundary in the late Miocene caused a decrease in forestation resulting in an increase in the size of prey animals and evolutionary pressure on sabre tooth morphology.

Keywords: Sabre tooth cat, evolutionary transition, palaeoecology, MN11/MN12 boundary, late Miocene

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*Speaker

3D analysis of vertebral morphology in Dall's porpoise (*Phocoenoides dalli*): an example of habitat driven morphology-functional adaptation

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Particular vertebral morphologies have been reported for coastal and oceanic cetaceans. Dall's porpoise (*Phocoenoides dalli*) vertebral column is considered one of the most derived among cetaceans. Total vertebral count exceeds greatly that of any other porpoise species, having strongly compressed vertebrae with exceptionally long processes. We employed 3D geometric morphometrics techniques and multivariate statistics to analyze particular vertebral morphology of Dall's porpoise when compared to other four porpoise species (N. phocoenoides, *P. phocoena*, *P. dioptrica*, *P. spinippinnis*), and a pelagic dolphin (*Lagenorhynchus cruciger*) known to show vertebral morphologies associated with fast swimming in an oceanic environment. Principal component analyses (PCA) showed great differentiation of Dall's porpoise with regards to the other species studied here, except when comparing the mid-torso with the oceanic dolphin. PCA results were supported by statistically significant Mahalanobis distances calculated between species. In these small odontocetes, vertebral morphology is distinctive and varies with the differential foraging strategies and habitat of each species. In the oceanic Dall's porpoise, an extremely high vertebral count in conjuntion with vertebrae morphological features (*i.e.*, disk-shaped centra and long strongly bent processes) reveal a vertebral column structure that would be associated with greater stability, particularly adapted for fast swimming in pelagic waters. These findings reveal morphological plasticity among porpoise species and a possible convergence between Dall's porpoise and an oceanic dolphin in the mid-colum, one of the main areas for force production by swimming muscles. Our resulst highlight the importance of habitat use and behavioral coplexity in the evolutionary development of morphological adaptations.

Keywords: 3D geometric morphometrics, vertebral morphology, column stability, Dall's porpoise

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[*] Speaker

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- Thomas Cucchi (MNHN)
- Vincent Debat (MNHN)

- Florent Détroit (MNHN)
- Sylvain Gerber (MNHN)
- Yann Heuzé (Univ. Bordeaux)
- Rémi Laffont (Univ. Bourgogne)
- Ronan Ledevin (Univ. Bordeaux)
- Sophie Montuire (Univ. Bourgogne)
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