ALPACA

Automated Landmarking through Point-cloud Alignment and Correspondence Analysis

Arthur Porto

Louisiana State University

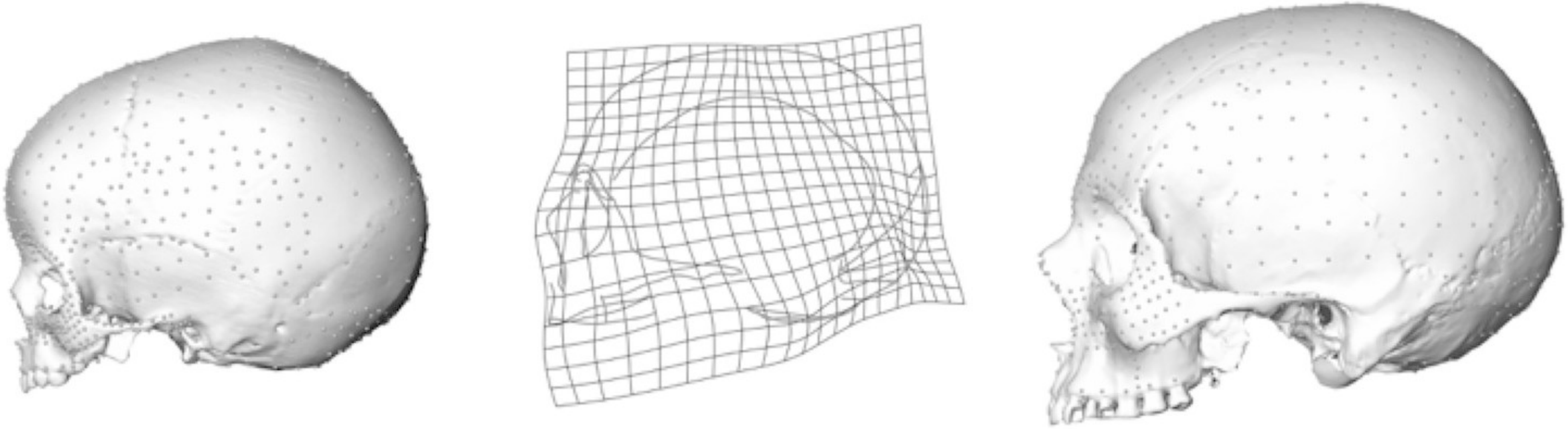
LSU Department of Biological Sciences

LSU CENTER FOR COMPUTATION & TECHNOLOGY

SLICERMORPH

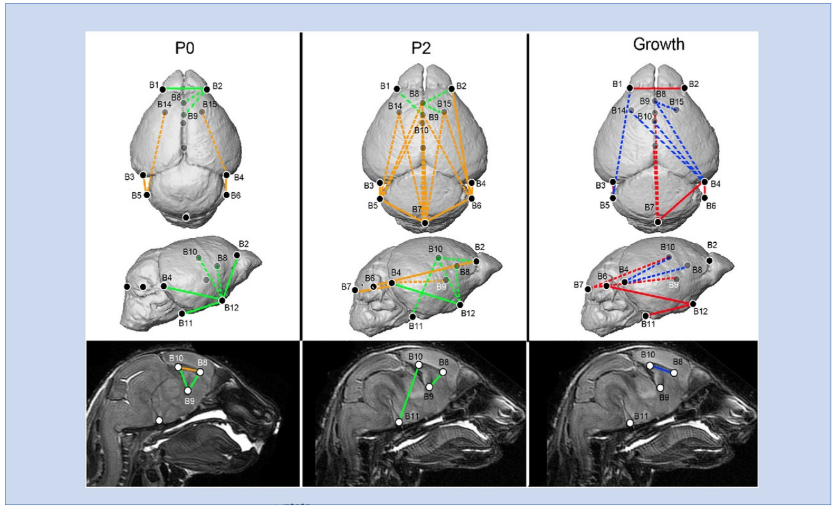
Geometric morphometrics

Suite of analytical techniques aimed at studying shape variation through annotation of landmarks corresponding to anatomical structures of interest

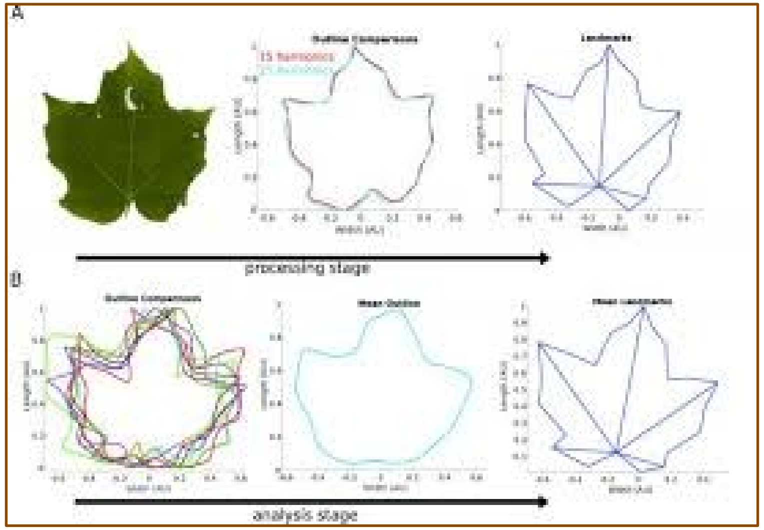


Homo sapiens child | **Thin-plate spline deformation grid** | *Homo sapiens* adult

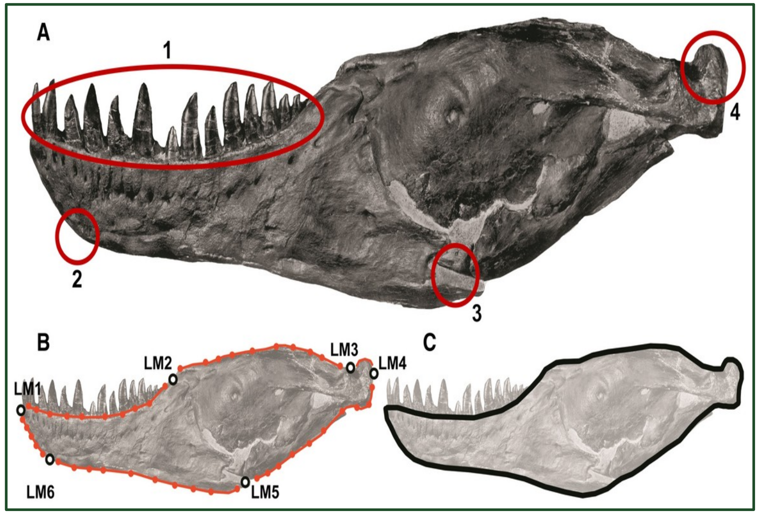
Morphometrics – System agnostic



Genetic contexts
e.g., Apert syndrome



Ecological contexts
e.g., Leaf shape

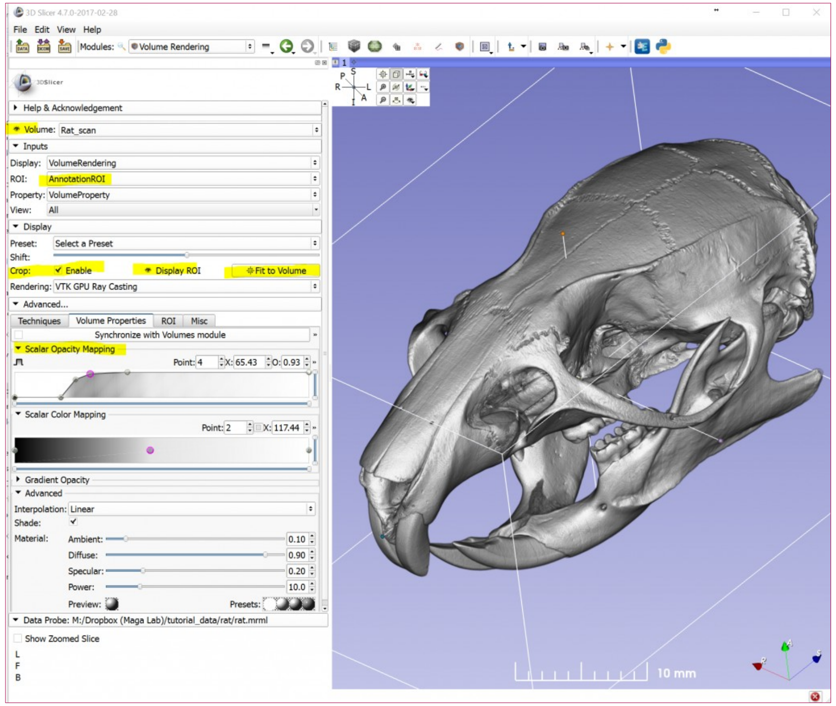


Evolutionary contexts
e.g., Tyrannosaur
Schaeffer et al, 2020

Challenges of Geometric Morphometrics

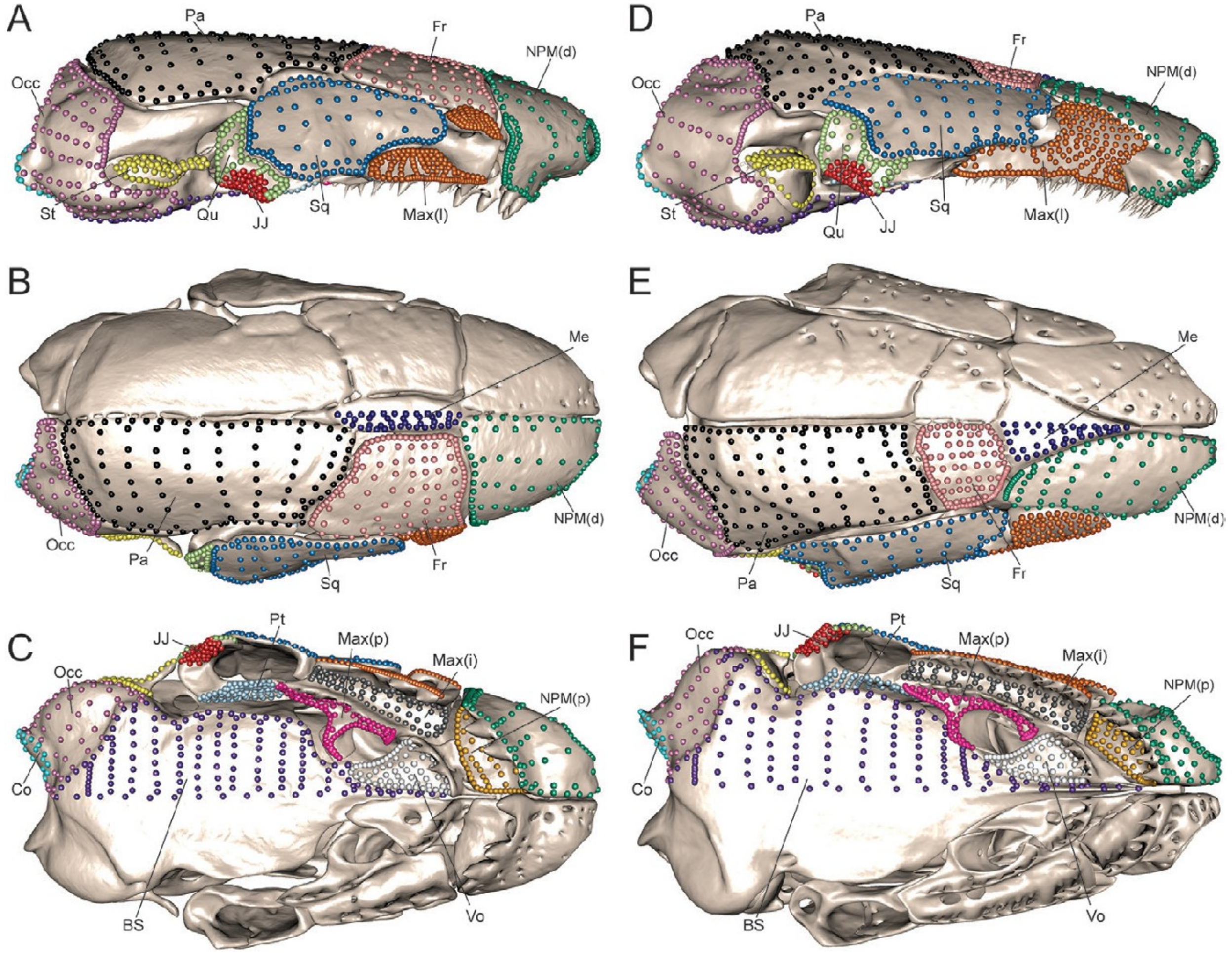
Though popular, geometric morphometrics is nonetheless a labor-intensive process, usually relying on manual annotation of landmarks by a trained expert.

e.g., digitizers



e.g., software

Manual - Time consuming



66 (type 1)
+
336 (sliding)
+
736 (semi)

Marshall et. al., 2019

Manual - Intra- and inter-observer error

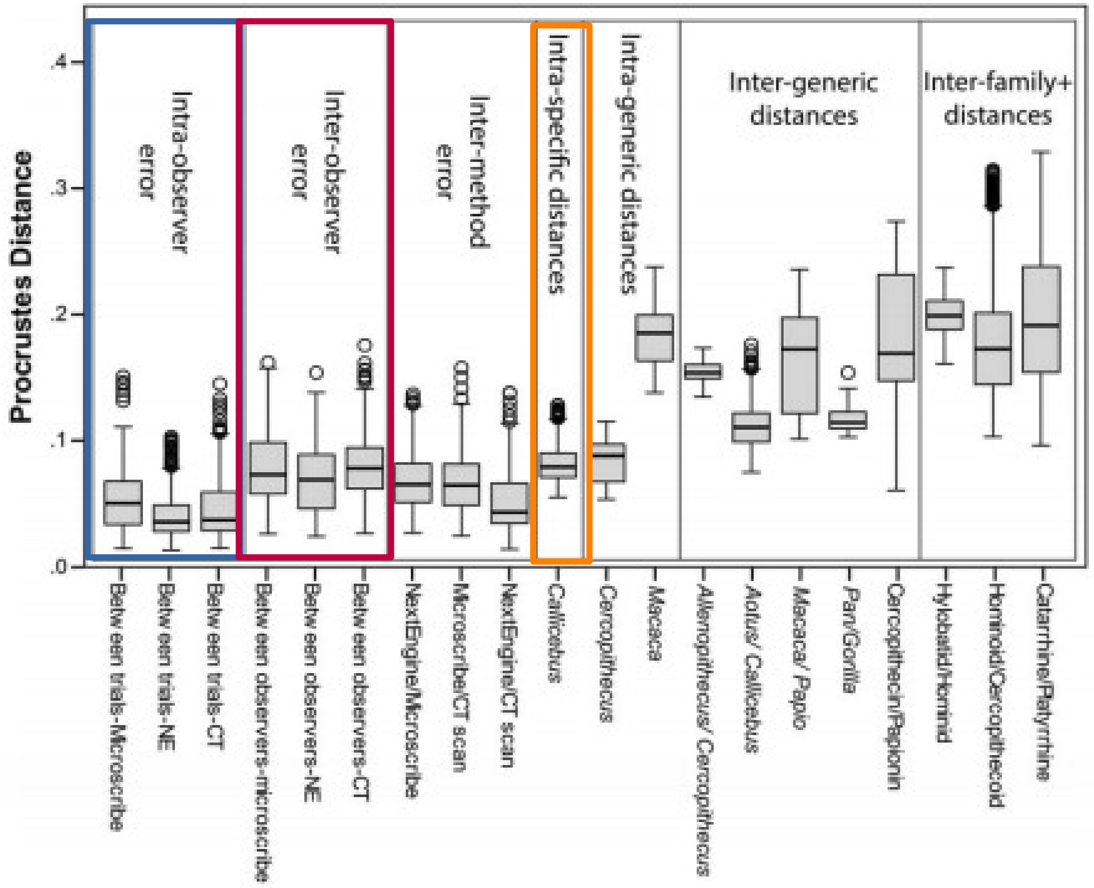


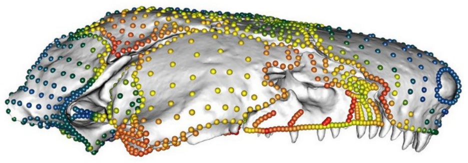
FIGURE 4 Box plot of Procrustes distances within and among observers, methods, and taxa. Darkened bars represent the median value for each group, boxes show the interquartile range (25th to 75th percentile), and the whiskers extend to 1.5 times the interquartile range. Outliers are designated by circles

Robinson and Terhune, 2017

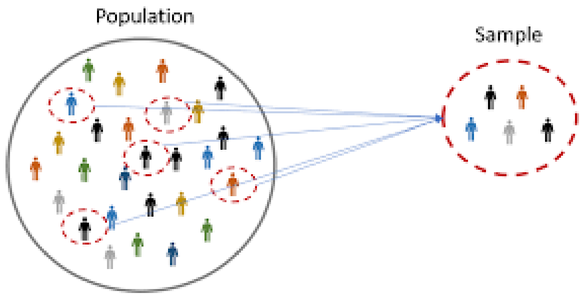
Automated approaches have advantages

Automated methods improve researchers’ ability to sample phenotypes in three ways:

* Increase spatial resolution



* Increase sample size



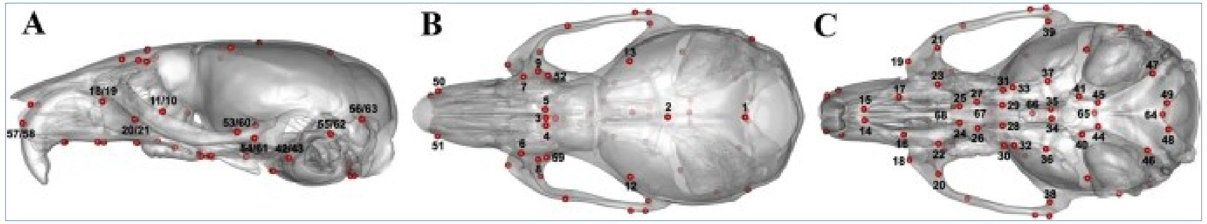
* Reduce subjectivity (reproducible)

Automated approaches face challenges

* Resources

  - Personnel: imaging scientist

  - Hardware: automation = as much as 10 CPU/hours per specimen



e.g. Devine et al 2020

* System-specificity

  - Algorithms: species-specific and hard to generalize
  - Algorithms : hard to deploy

ALPACA

ALPACA

Intuitive

Users with no prior experience in image analysis could use it

Lightweight

Run in minutes (much less time than manual digitization)

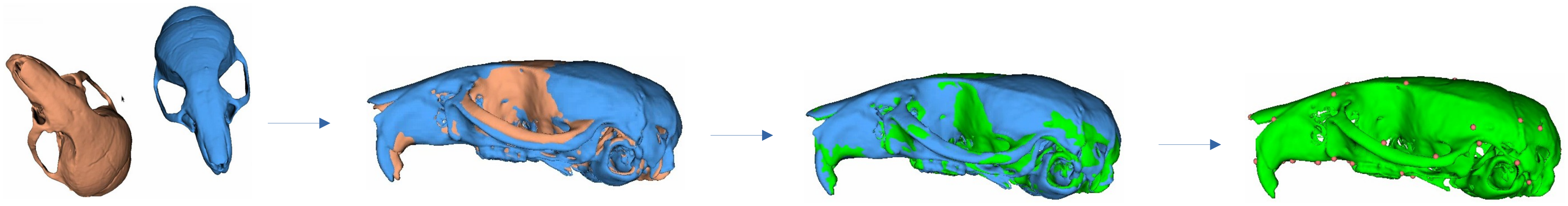
General

Can be applied to any structure of interest, given some limitations in the degree of shape variation

Most automated approaches rely on registration techniques

Registration

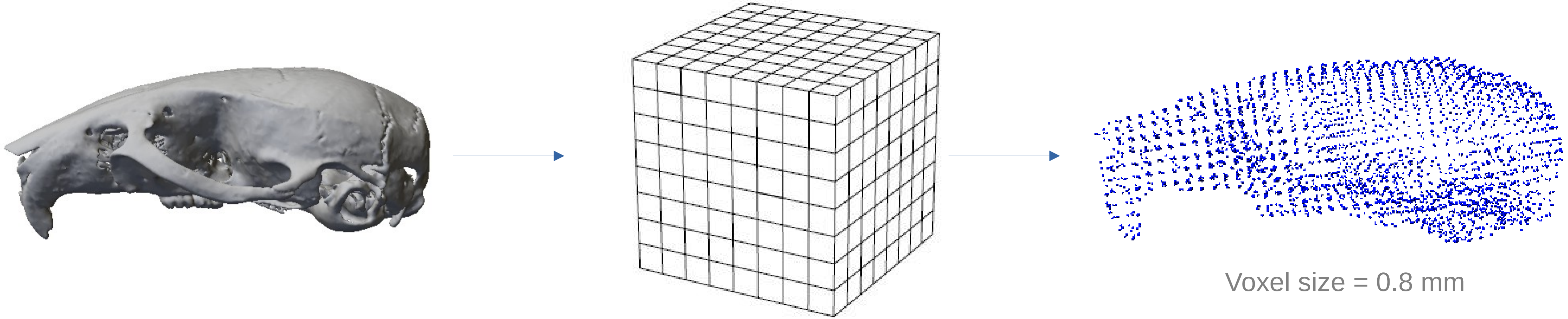
is the process of finding the optimal transformation to maximize correspondence between a template (model) and a specimen



ALPACA is a bit different

Key aspect

Sparse representation can be used to find for alignment



Voxel size = 0.8 mm

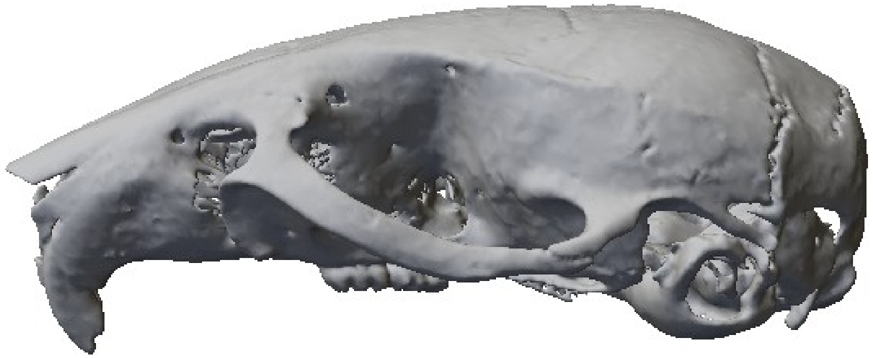
Mesh

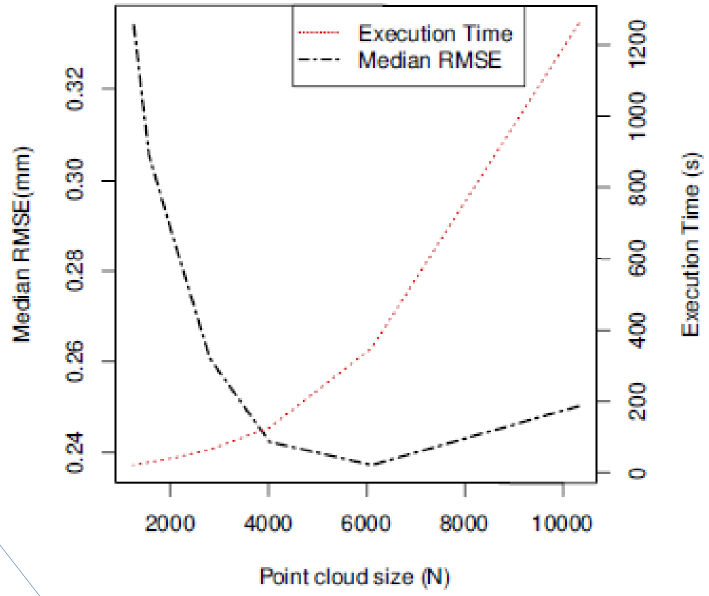
Voxel Grid

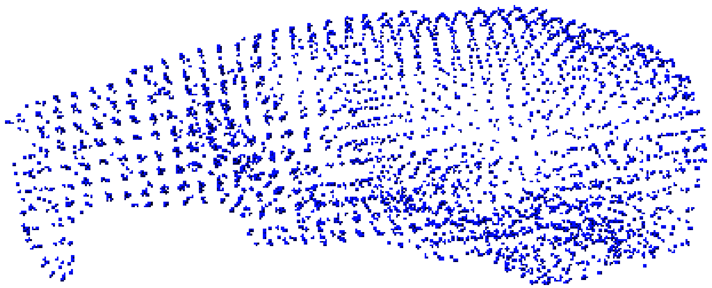
User-specified

Point-cloud

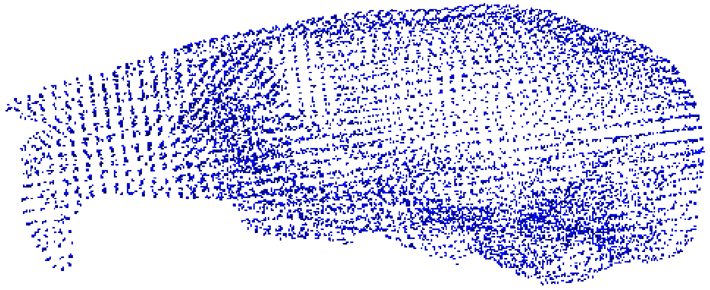
How sparse? User has control over it



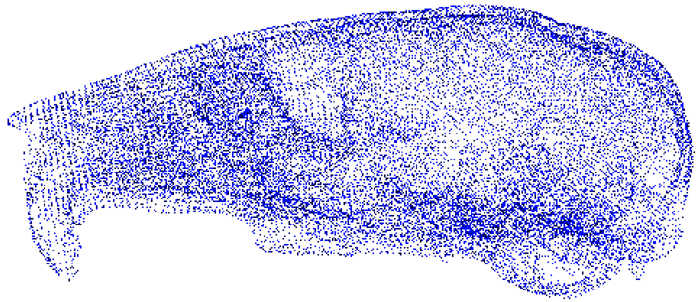




Voxel size = 0.8 mm

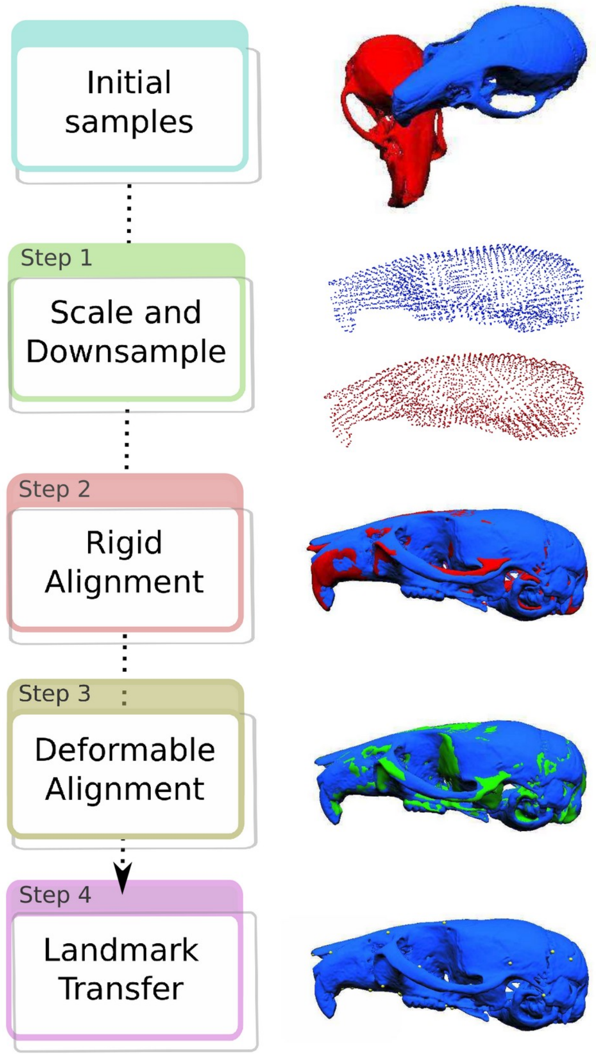


Voxel size = 0.6 mm

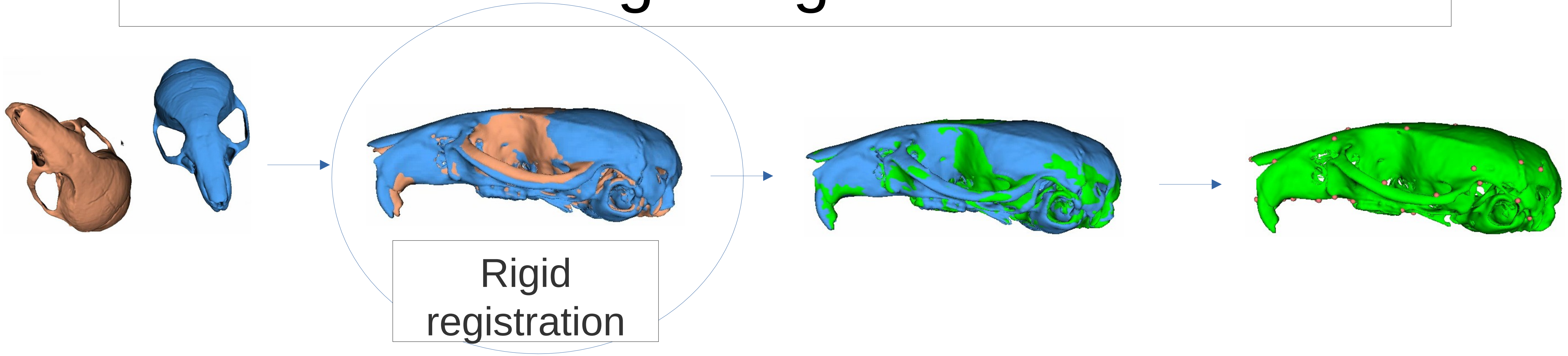


Voxel size = 0.2 mm

ALPACA pipeline overview

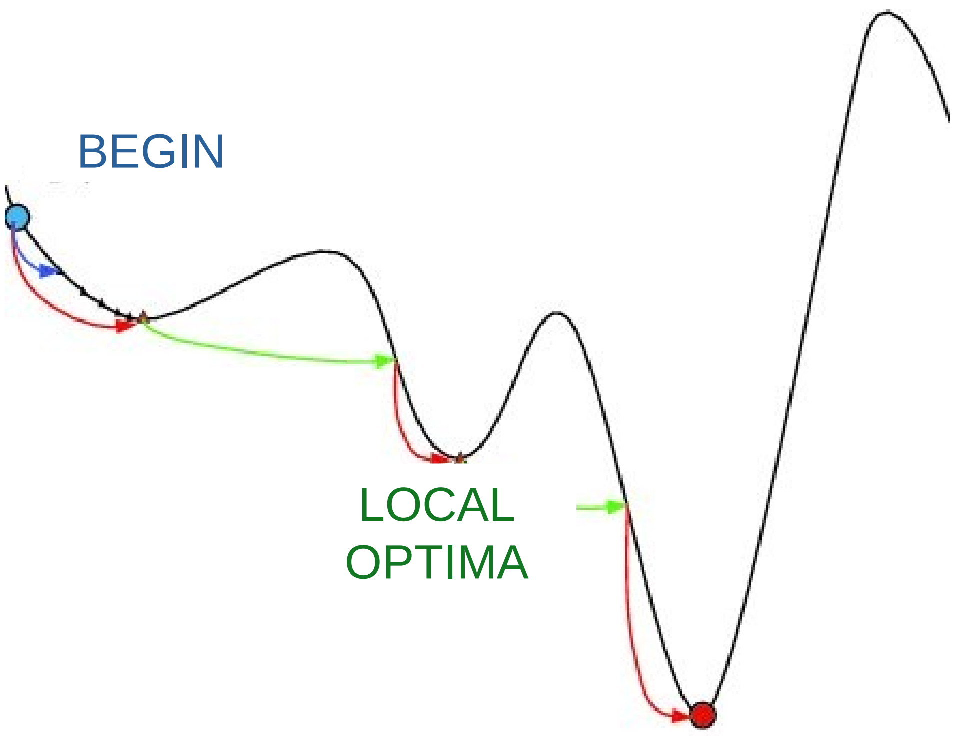


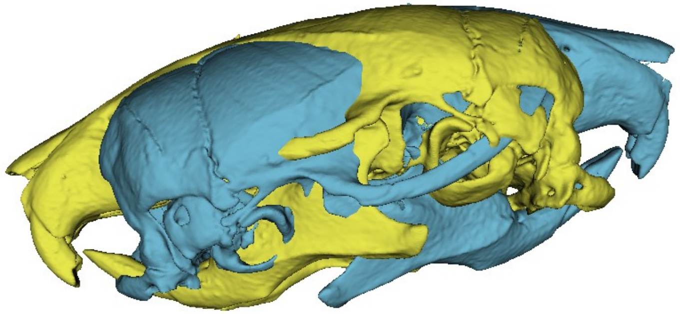
Rigid alignment



Objective: Find the optimal rotation, translation and scaling of the source structure in order to match the target one, starting from arbitrary positions in 3D space

Rigid - Challenge

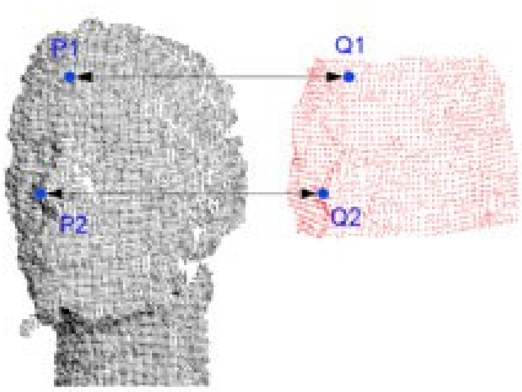


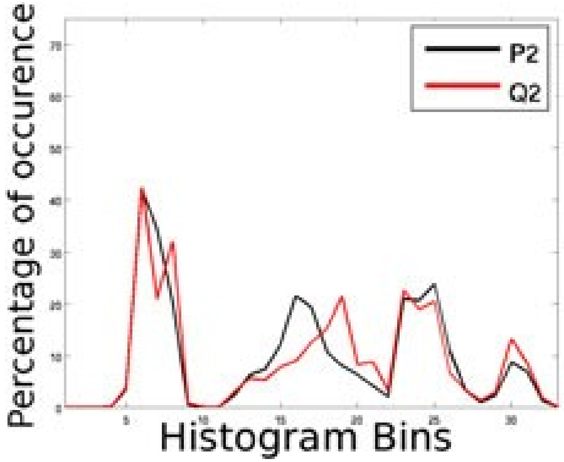


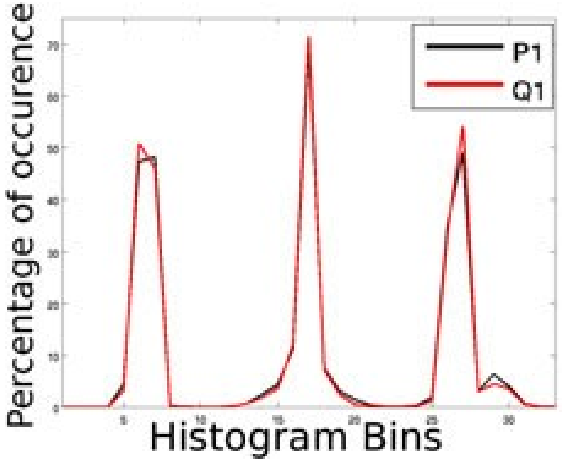
Main challenge : How to prevent local optima?

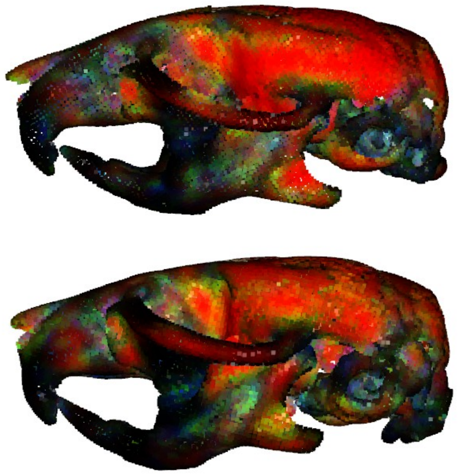
Rigid – Our approach

To find the initial rough alignment, ALPACA uses local geometric descriptors (=semantically rich)





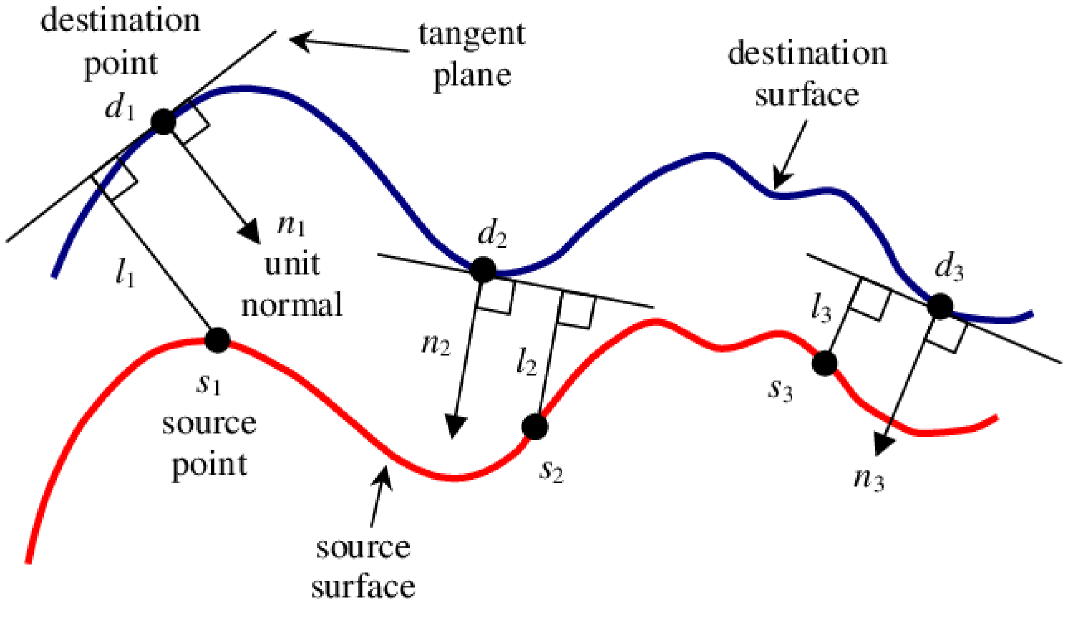


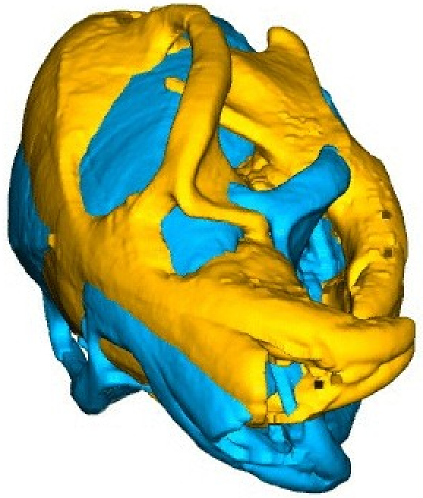


Fast Point Feature Histogram

Rigid – Local registration

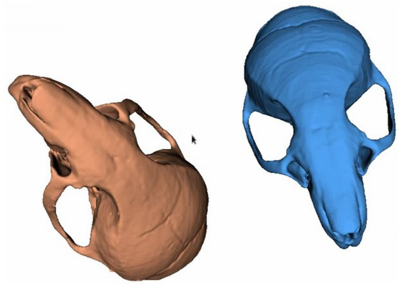
Refine initial alignment using iterative closest point

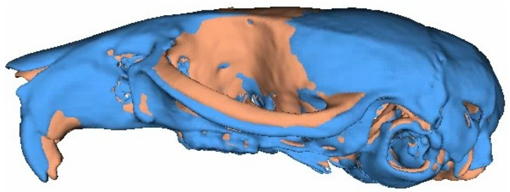


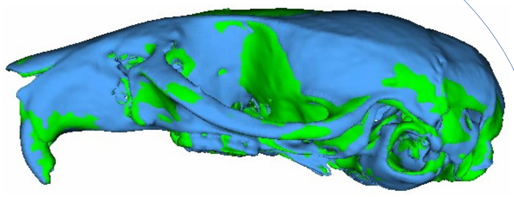


Point-to-plane ICP

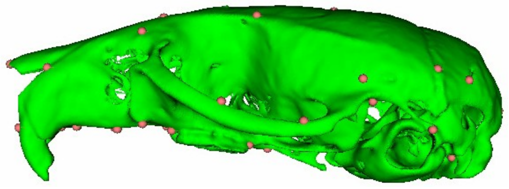
Deformation





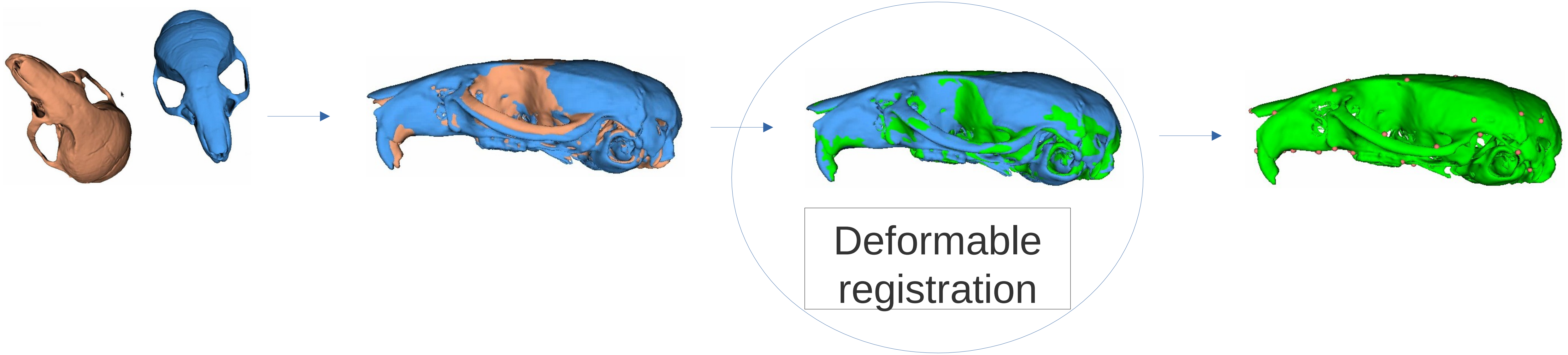


Deformable registration



Objective : Find the non-linear geometric transformation necessary to map two images onto a common coordinate system.

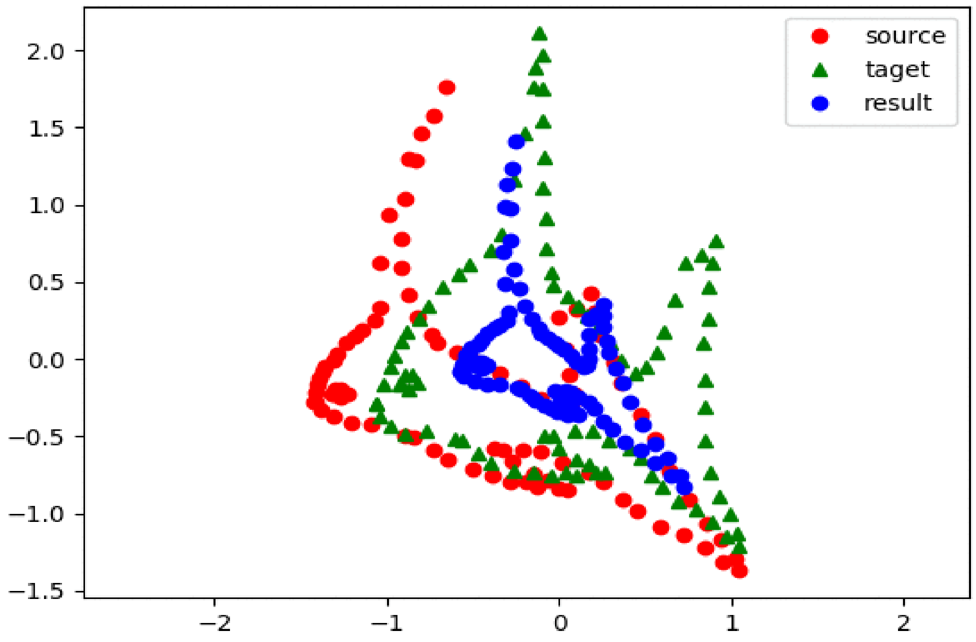
Deformation

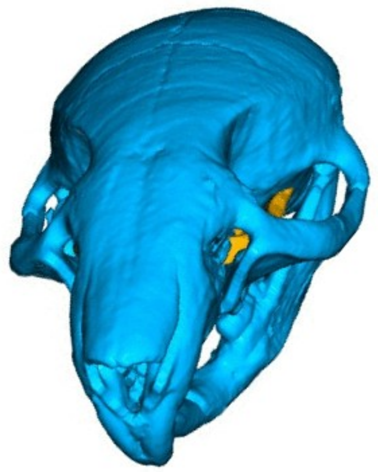


Challenge : Accurately representing biological deformations, and doing so in a reasonable amount of time

Deformable - CPD

Coherent Point Drift – imposes constraints on the deformation in the form of motion coherence among neighbors

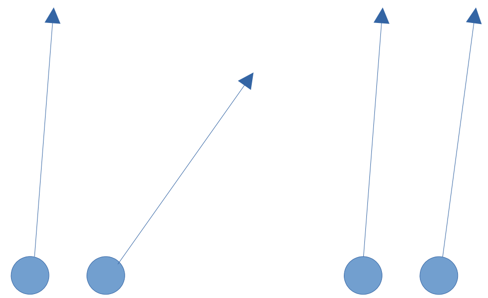




Deformable – Structure specific

The deformable step has two regularization parameters (α and β) . These parameters will typically have to be modified to better serve your own needs.

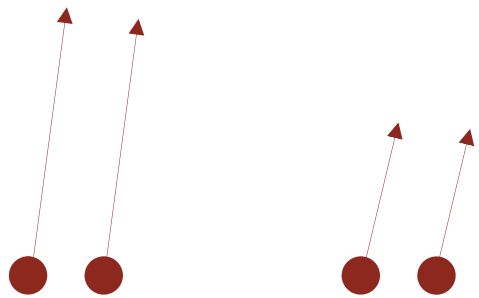
Motion coherence



Small β

Large β

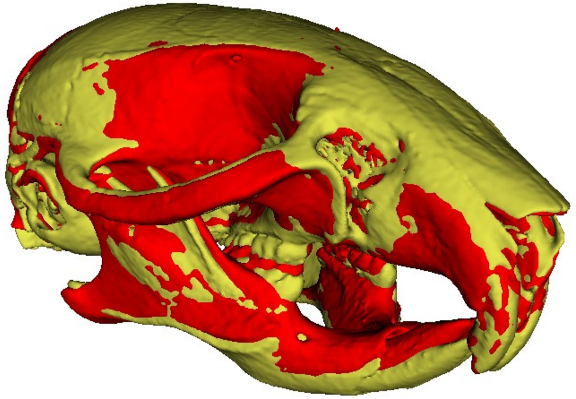
Displacement



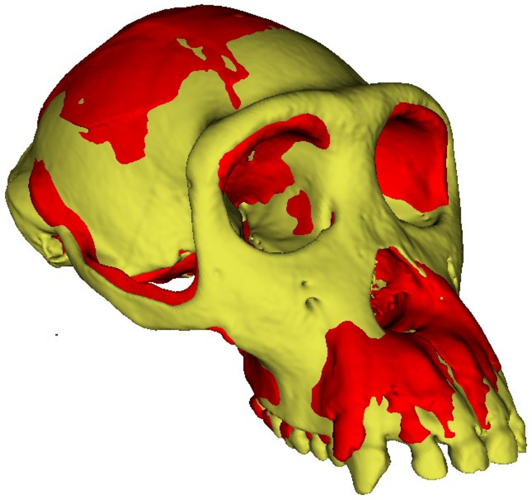
Small α

Large α

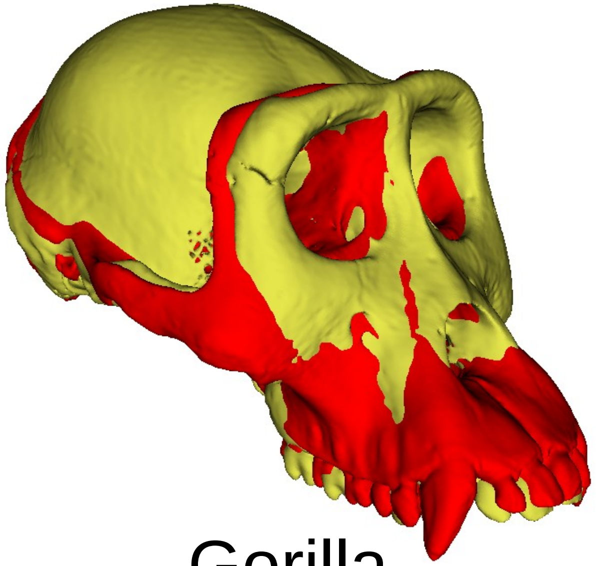
Initial development - Four datasets



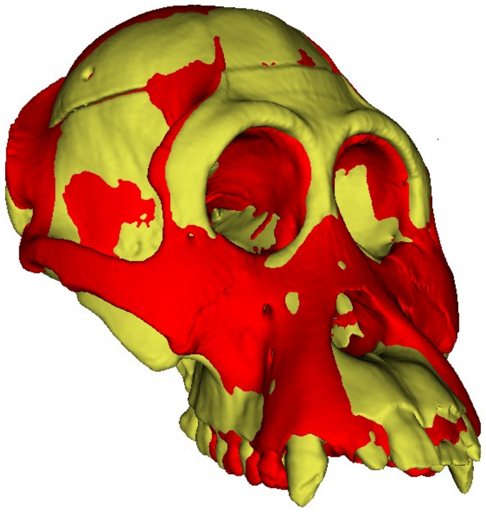
Mouse
(N=62)



Chimpanzee
(N=11)



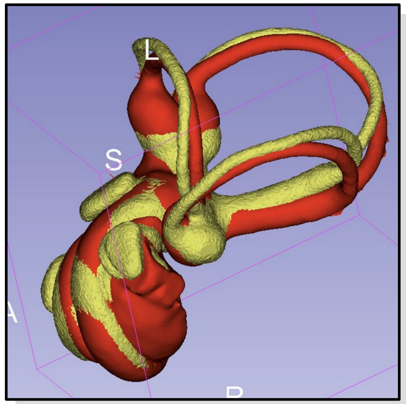
Gorilla
(N=23)



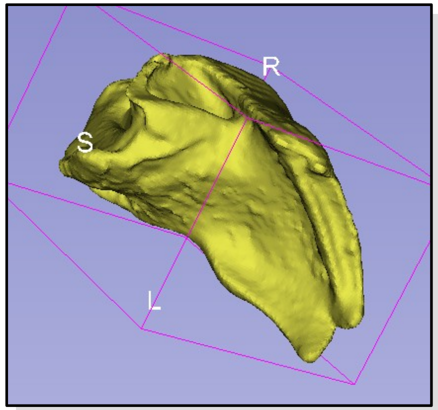
Orangutan
(N=18)

- Craniofacial bias

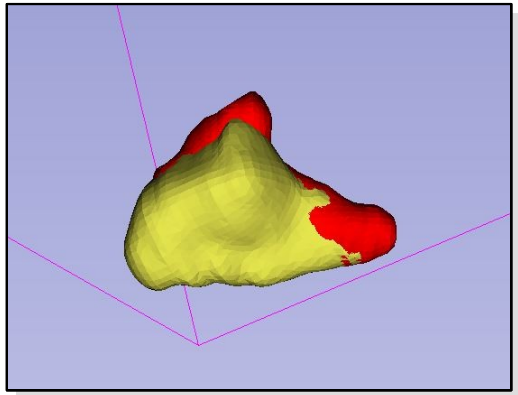
Since publishing - Other groups



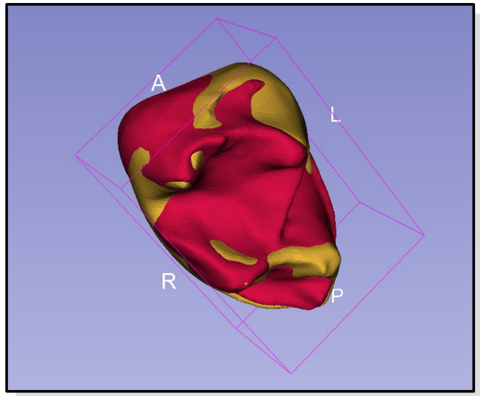
Cochlea



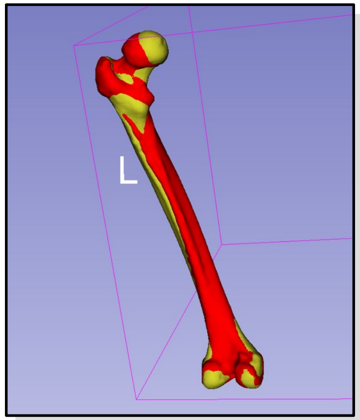
Ant Mandible



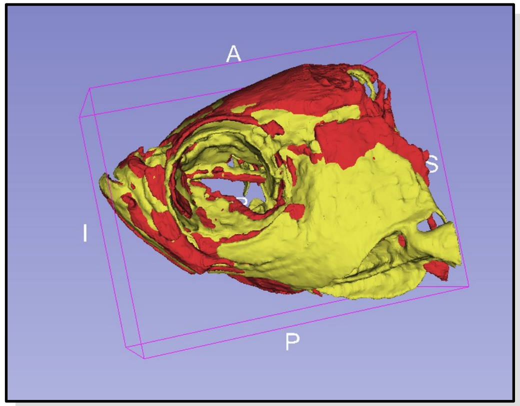
Sclerites



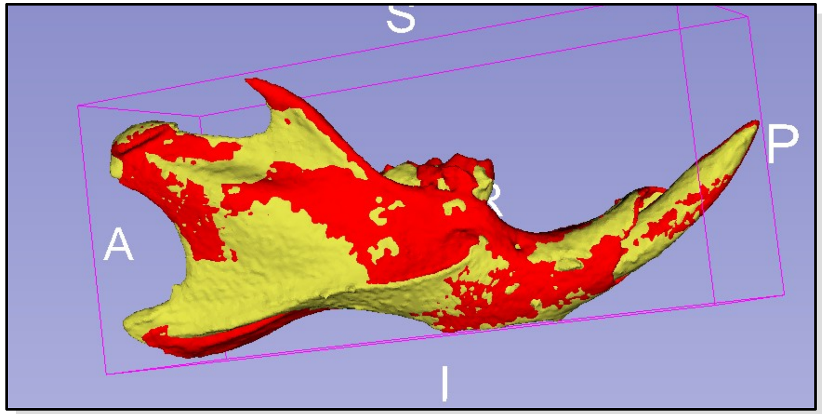
Dentition



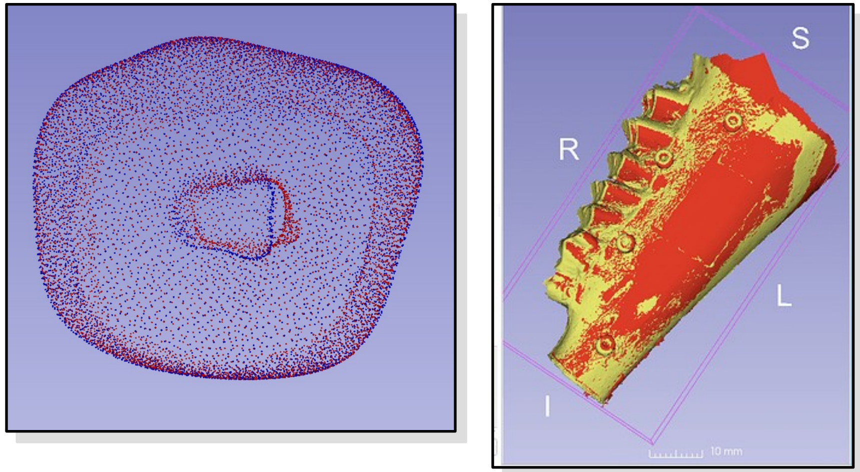
Femur



Fish skull



Mouse mandible



Dentists – Pre/Post Surgery

Check our paper for details of validation

Accepted: 11 July 2021

DOI: 10.1111/2041-210X.13689

RESEARCH ARTICLE

Methods in Ecology and Evolution BRITISH ECOLOGICAL SOCIETY

ALPACA: A fast and accurate computer vision approach for automated landmarking of three-dimensional biological structures

Arthur Porto[1,2] | Sara Rolfe[3,4] | A. Murat Maga[4,5]

[1]Department of Biological Sciences, Louisiana State University, Baton Rouge, LA, USA

[2]Center for Computation and Technology, Louisiana State University, Baton Rouge, LA, USA

[3]Friday Harbor Laboratories, University of Washington, San Juan Island, WA, USA

[4]Center for Development Biology and Regenerative Medicine, Seattle Children's Research Institute, Seattle, WA, USA

[5]Division of Craniofacial Medicine, Department of Pediatrics, University of Washington, Seattle, WA, USA

Abstract

1. Landmark-based geometric morphometrics has emerged as an essential discipline for the quantitative analysis of size and shape in ecology and evolution. With the ever-increasing density of digitized landmarks, the possible development of a fully automated method of landmark placement has attracted considerable attention. Despite the recent progress in image registration techniques, which could provide a pathway to automation, three-dimensional (3D) morphometric data are still mainly gathered by trained experts. For the most part, the large infrastructure requirements necessary to perform image-based registration, together with its system specificity and its overall speed, have prevented its wide dissemination.

Advantages - ALPACA

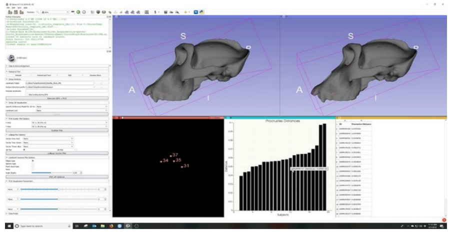
Fast – No acceleration (2 min), Acceleration – Slicer (20s), Python (6s)

High-throughput – Can be run on batch to process thousands of specimens on a personal computer in a matter of hours/day

High dimensional - Allows high-dimensional characterization of 3D structures with no significant impact on inference speed

Easily generalizable – Can be used to landmark any 3D structure

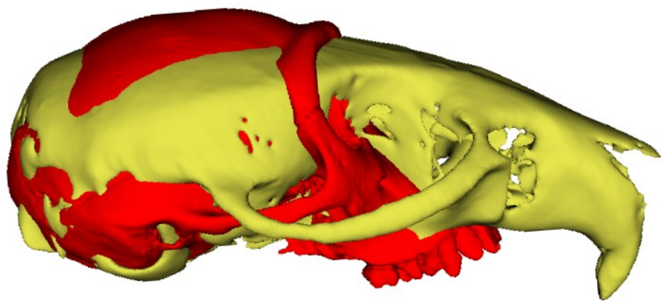
User interface – Has a simple 3D Slicer (point-and-click) user interface



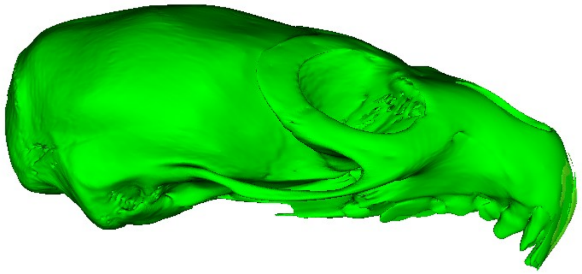
Shortcomings - ALPACA

Mostly intraspecific/closely related species – Although it can work in certain interspecific contexts (e.g. apes), it is a pipeline that is most useful when shape deviations are not extreme.

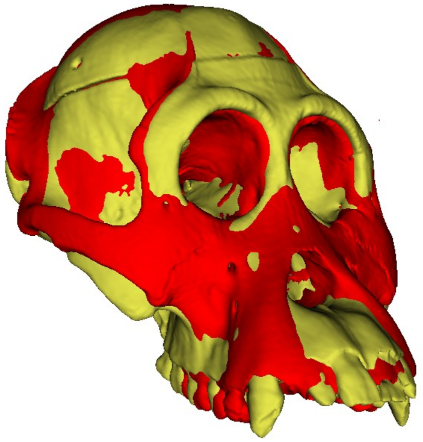
Complete objects – Although robust to localized damage, ALPACA can breakdown when significant portions of the object are missing.



Gorilla/Mouse



Gorilla mouse?



Missing incisors

Conclusion

* Geometric morphometrics provides tools that are useful for shape analysis and that are system-agnostic

* Automation of landmark data collection is now possible given the explosion in computer vision approaches

*Automation can increase the scale and reproducibility of biological research

Thanks!

Sara Rolfe

Murat Maga

Kelly Diamond

Chi Zhang

Emma Sherratt

Matt Tocheri

SlicerMorph Workshop participants

3D Slicer & Open3D Developers

… and many others

NSF

NIH
National Institutes of Health

Seattle Children's®
HOSPITAL · RESEARCH · FOUNDATION