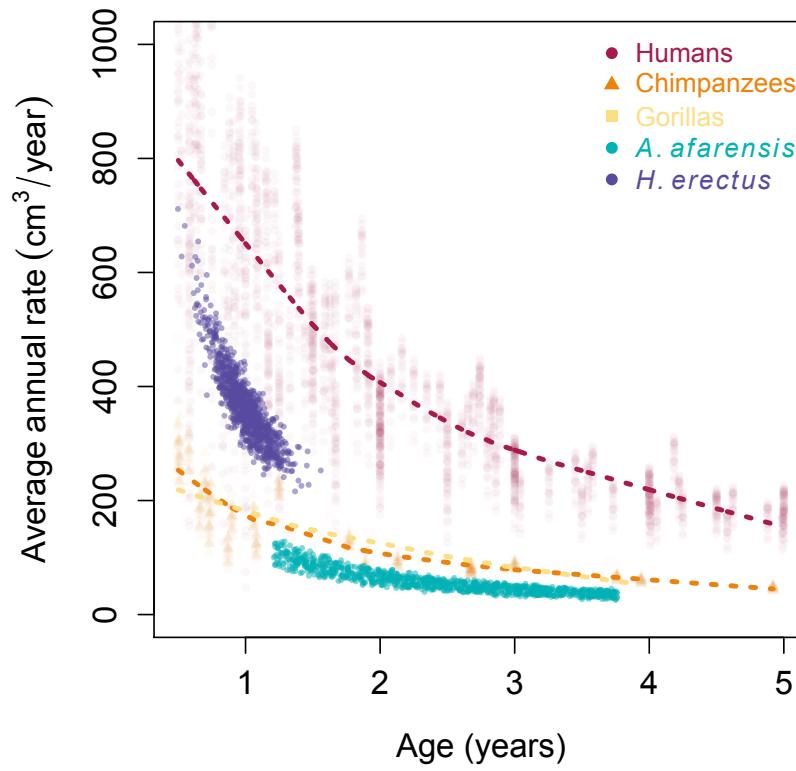
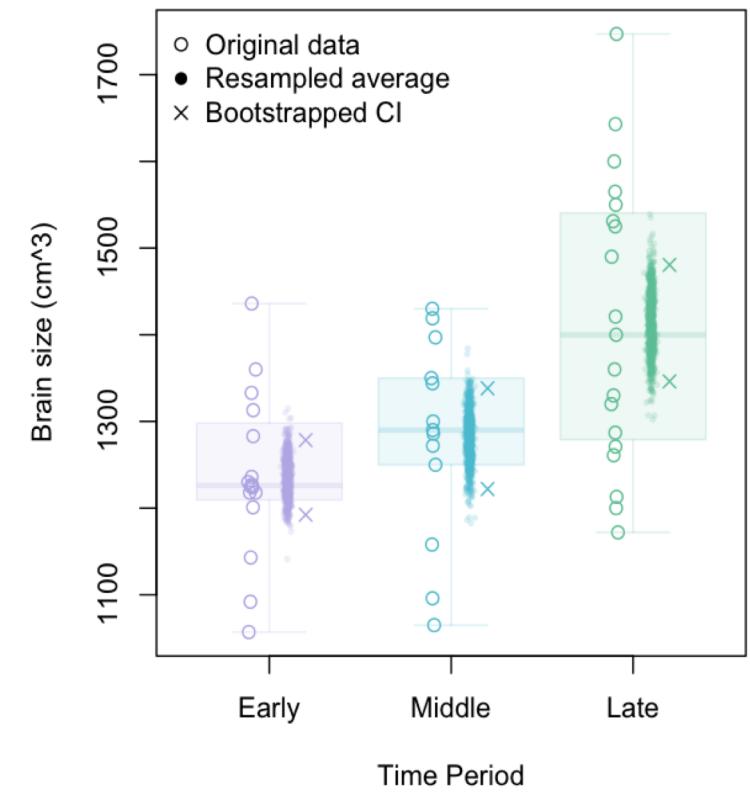


# Making the most with what you've got

## Resampling methods for statistical inference



Zachary Cofran  
Anthropology Department  
June 12, 2020



# Overview

- Basic ideas
- Permutation, Bootstrap, Monte Carlo
  - Examples of each
- Resampling in R

# #ShutDownAcademia

# #ShutDownSTEM

10 June 2020

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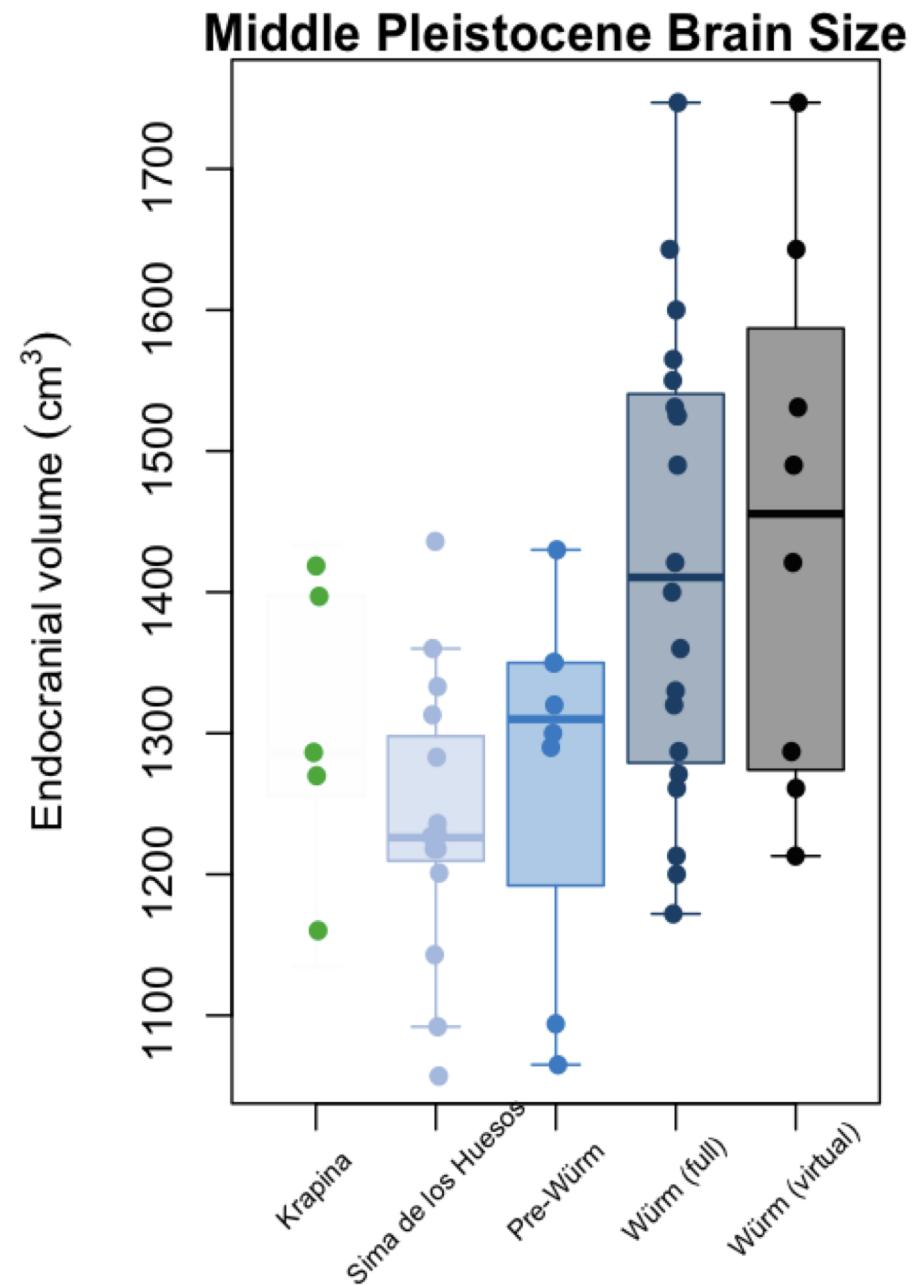
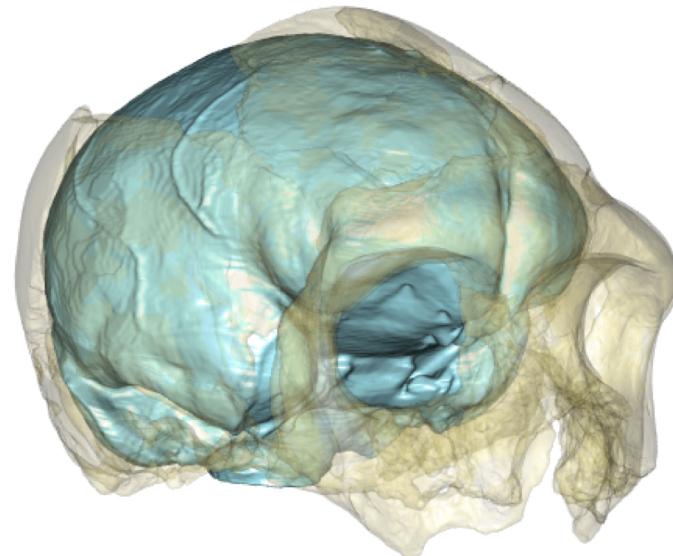
## Additional links

<https://physanth.org/about/position-statements/open-letter-our-community-response-police-brutality-against-african-americans-and-call-antiracist-action/>

<http://aba.americananthro.org/>

# Statistical inference

- Making sense of variation
- Types of questions / tests
- Examples in human evolution



# Resampling — Further reading

vassar college  
libraries

Introduction to Statistics Through Resampling Methods and R   New Search Advanced ▾

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CONTENT TYPE ▾

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1  **Introduction to statistics through resampling methods and R**  
by [Good, Phillip I.](#)  
2013  
"Intended for class use or self-study, the second addition of this text aspires like the first to introduce statistical methodology to a wide audience, simply..."  
eBook [Full Text Online](#)

<https://ebookcentral-proquest-com.libproxy.vassar.edu/lib/vcl/detail.action?docID=1104736>

# Statistical inference

**Table 5** Key features of three categories of statistical methods

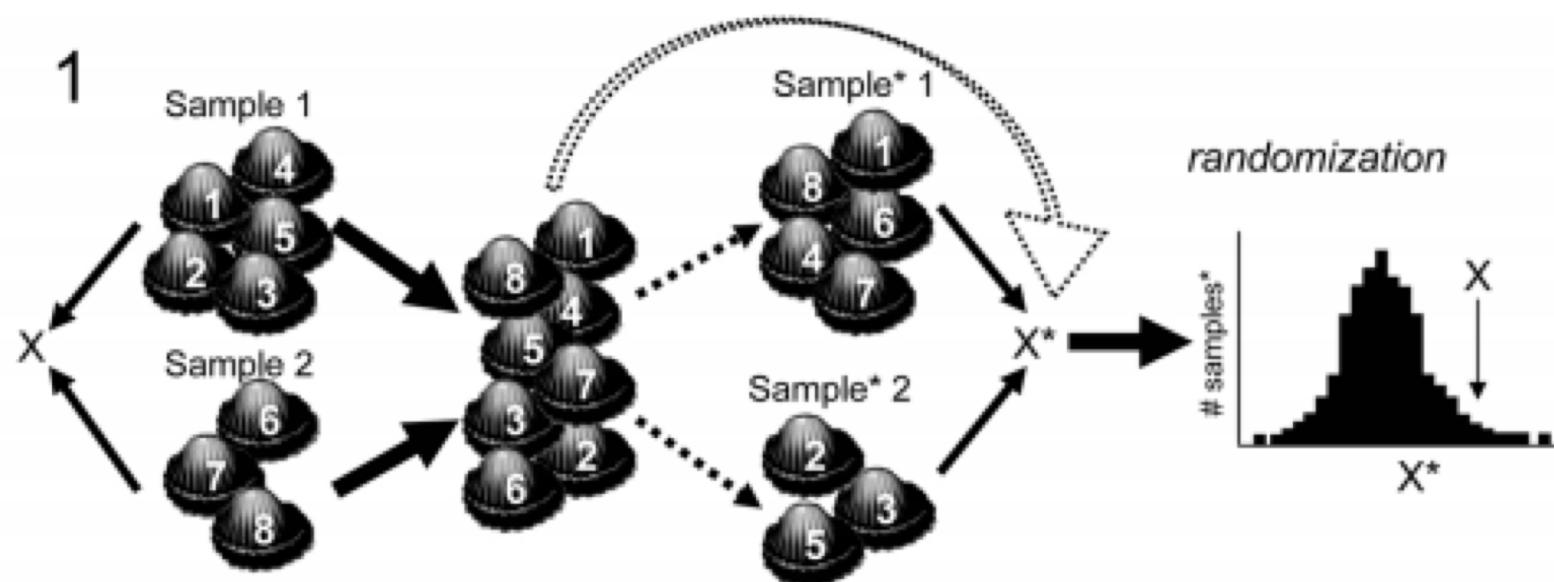
Feature	Standard Parametric Methods	Standard Nonparametric Methods	Resampling Methods
→ Statistical power	High (when assumptions met)	Moderate	High
Known by researchers	Very widely	Widely	Sometimes & increasing
Acceptance	Widespread	Widespread	Common & increasing
Standardization	Very high	High	Moderate
→ Flexibility	Low	Moderate	High
→ Assumptions (see Table 1)	Moderate-strong (robust to some departures)	Moderate	Weak-moderate
Population or sample	Population	Sample	Population (except randomization)
Time & effort cost	Moderate	Somewhat lower	Higher & decreasing
→ Conceptual complexity	High	Moderate	Low-moderate

# Resampling methods

- Permutation/randomization
- Bootstrap
- Monte Carlo

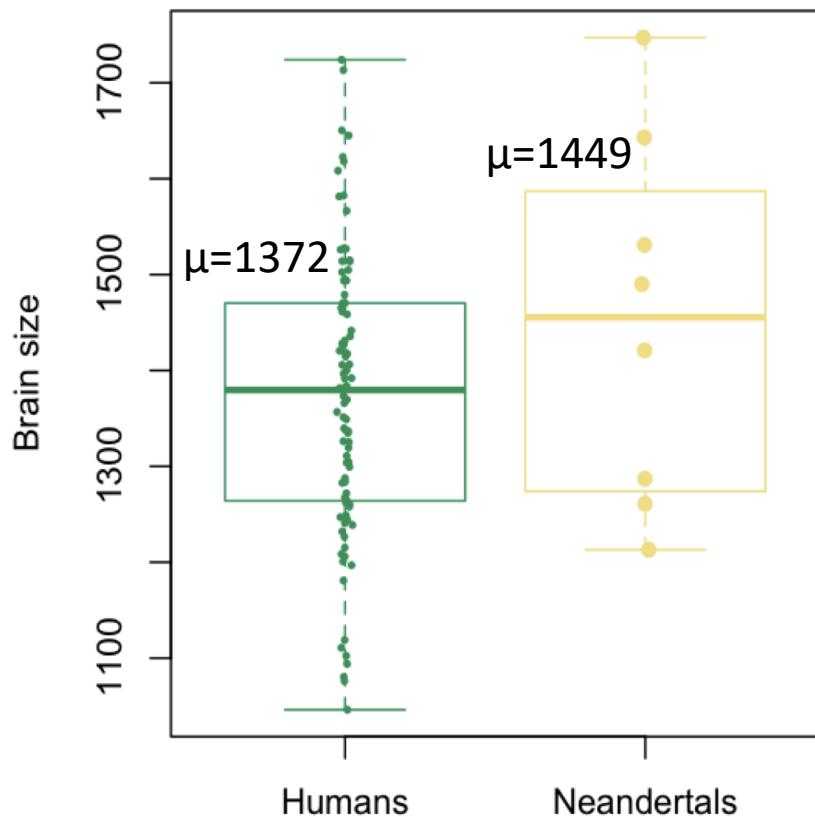
# Resampling methods: Permutation

- Hypothesis or assumption: association is random
- If the hypothesis is true, then random groupings should yield similar effect



# Resampling methods: Permutation

- Example: Did Neandertals have bigger brains than modern humans?

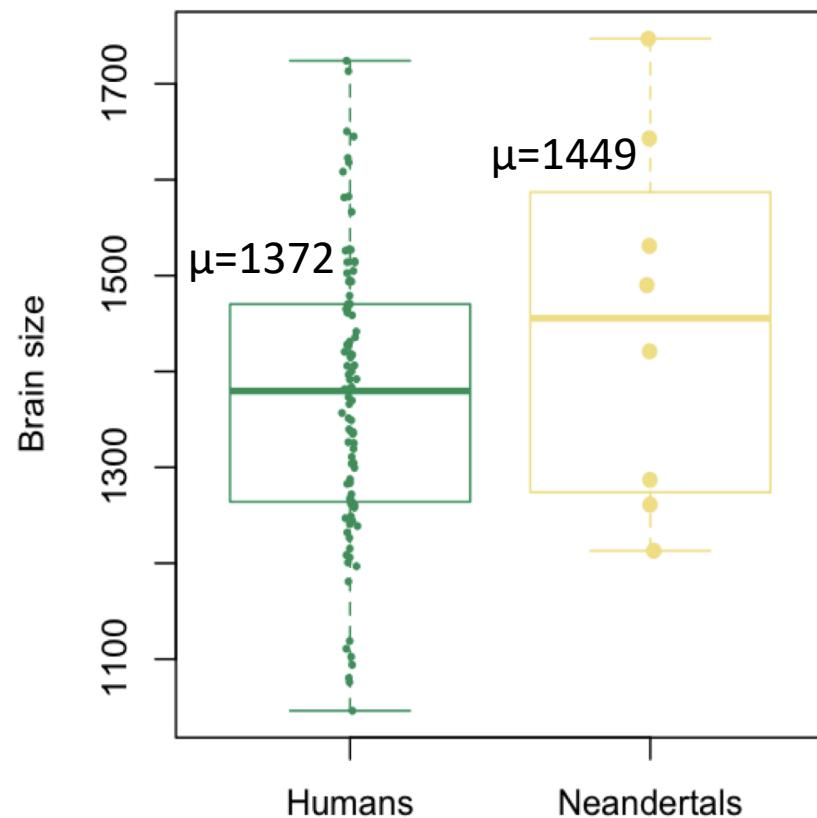


$$\mu(\text{Neandertal}) - \mu(\text{Human}) = 77$$

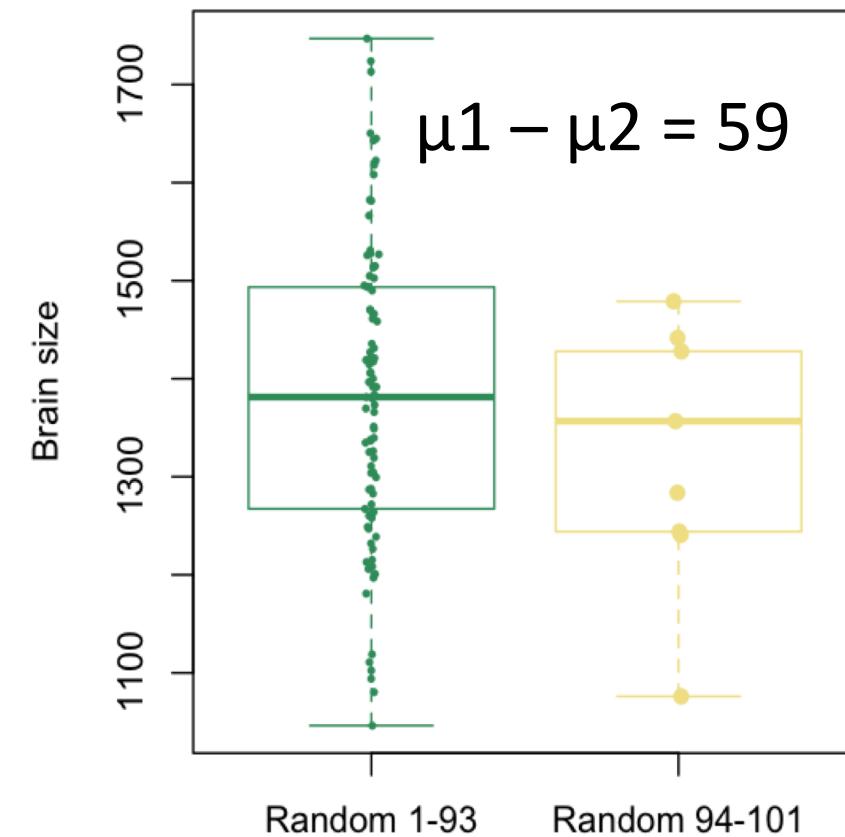
$H_0$ : Any random combination could  
be as disparate observed

# Resampling methods: Permutation

$$\mu(\text{Neandertal}) - \mu(\text{Human}) = 77$$

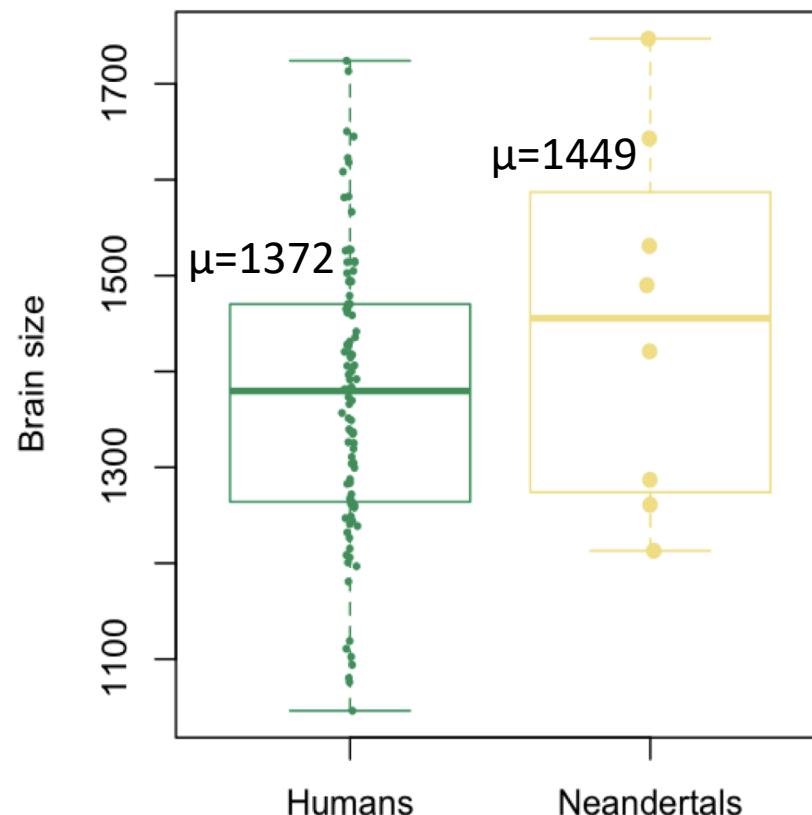


$H_0$ : Any random combination could be as disparate observed

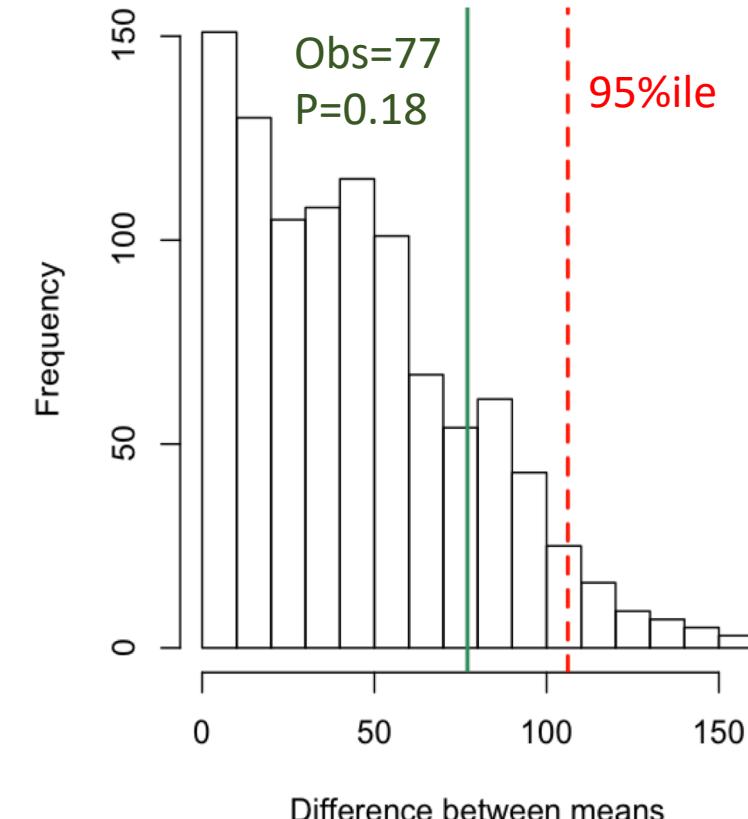


# Resampling methods: Permutation

$$\mu(\text{Neandertal}) - \mu(\text{Human}) = 77$$

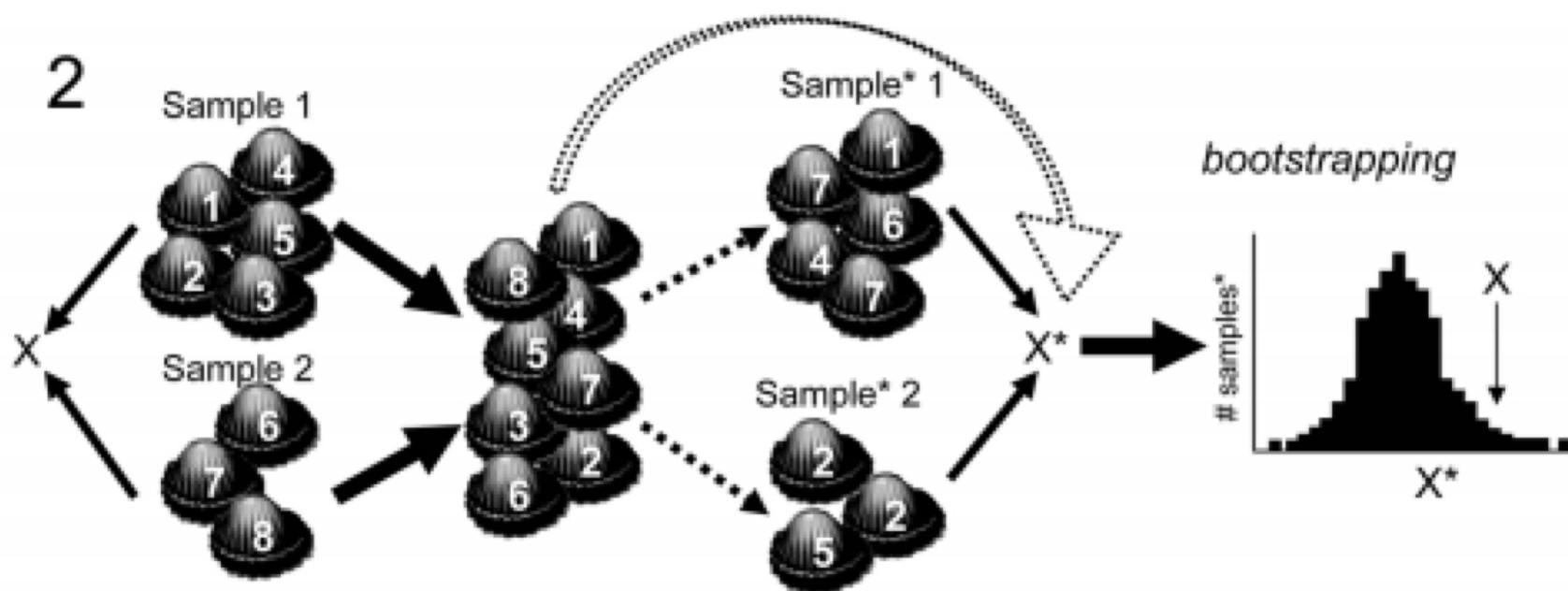


$H_0$ : Any random combination could be as disparate observed



# Resampling methods: Bootstrap

- Random sampling with replacement
- Estimate standard error, confidence intervals



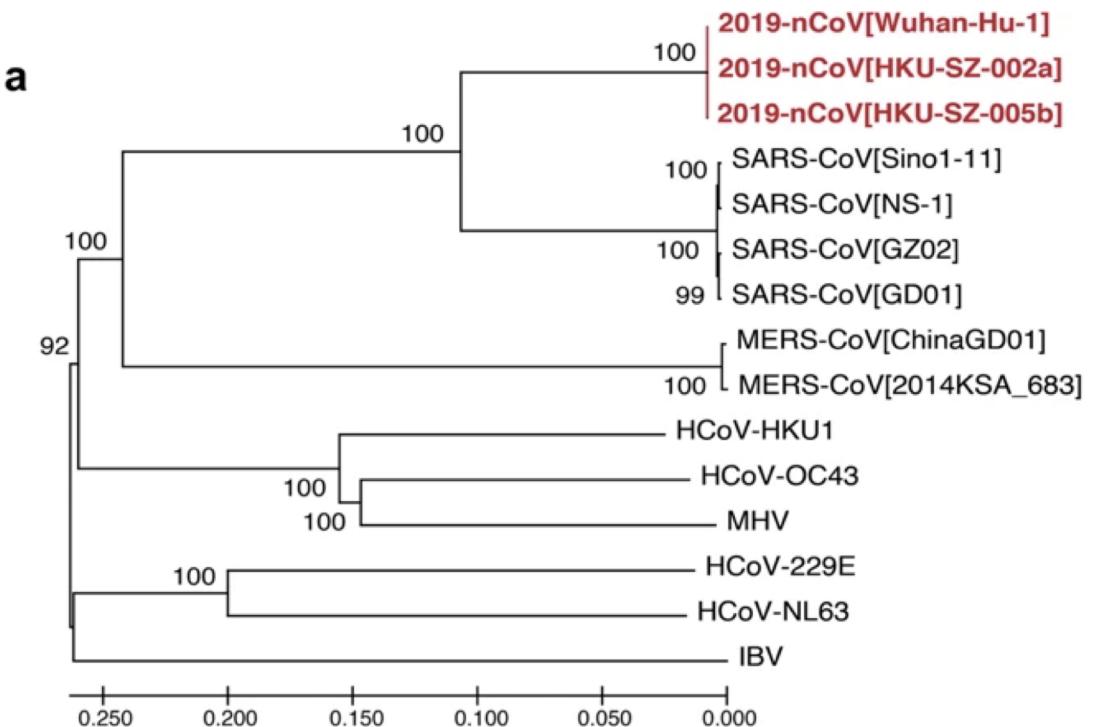
# Resampling methods: Bootstrap

- Regression slope and intercept confidence intervals
- Phylogenetic trees

**Network-based drug repurposing for novel coronavirus 2019-nCoV/SARS-CoV-2**

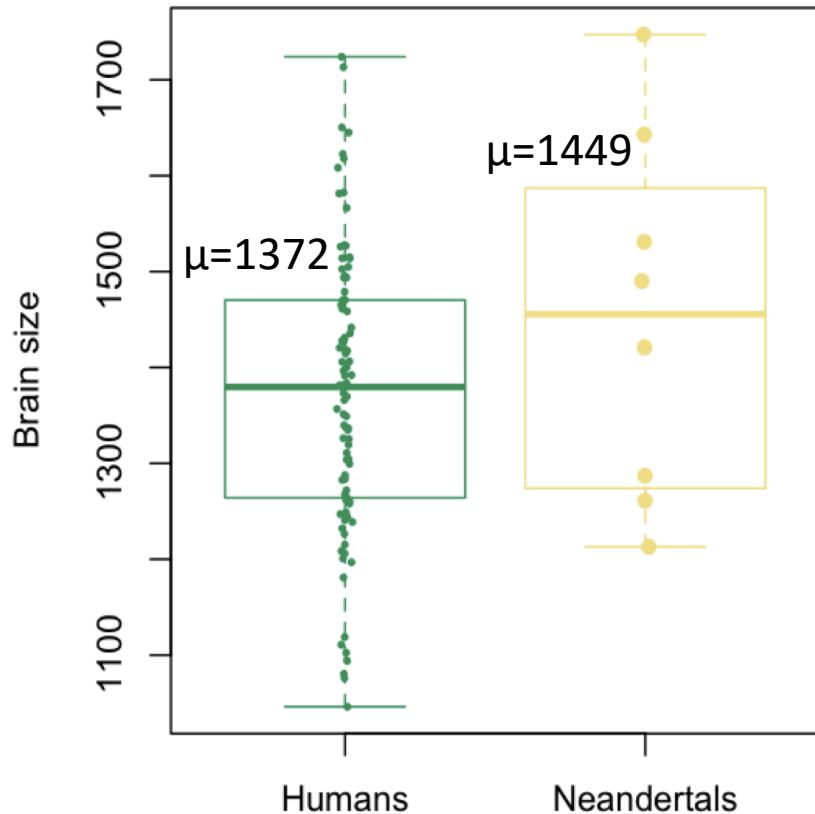
Yadi Zhou, Yuan Hou, Jiayu Shen, Yin Huang, William Martin & Feixiong Cheng 

*Cell Discovery* 6, Article number: 14 (2020) | Cite this article



# Resampling methods: Bootstrap

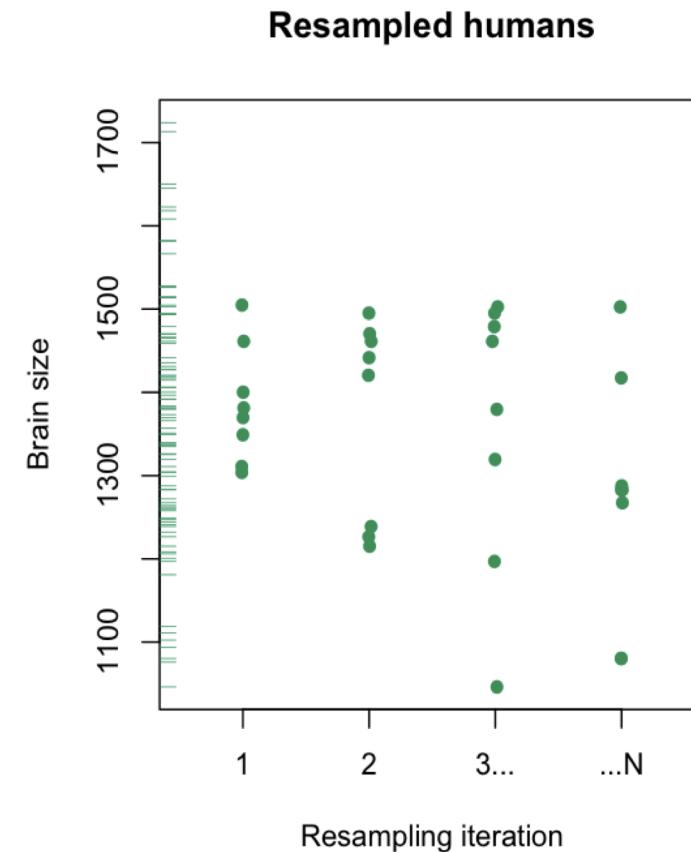
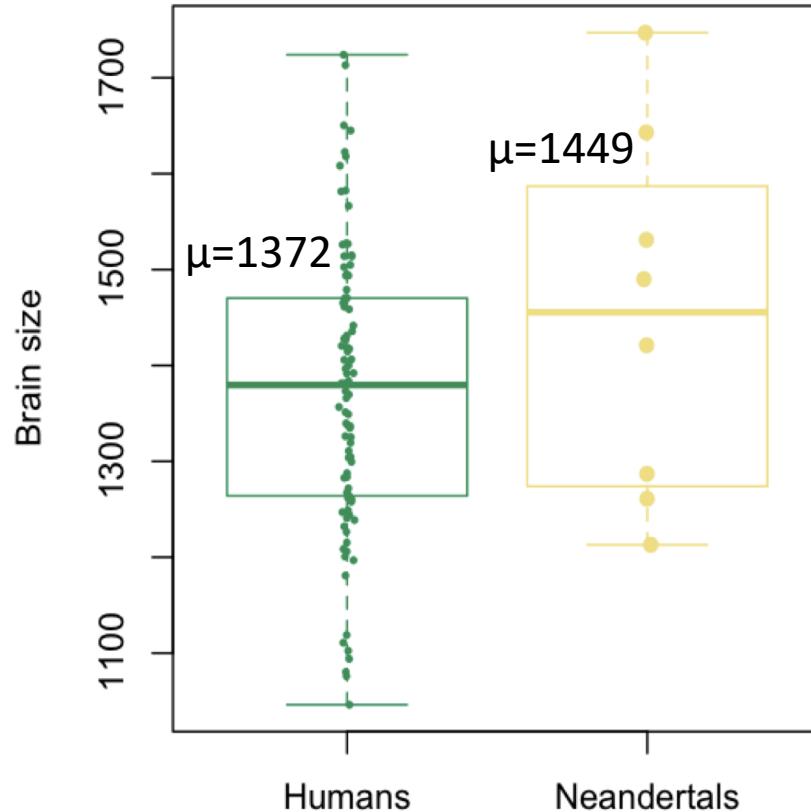
- Example: Did Neandertals have bigger brains than modern humans?



$H_0$ : Any random combination of 8 humans could be as large as the Neandertal average

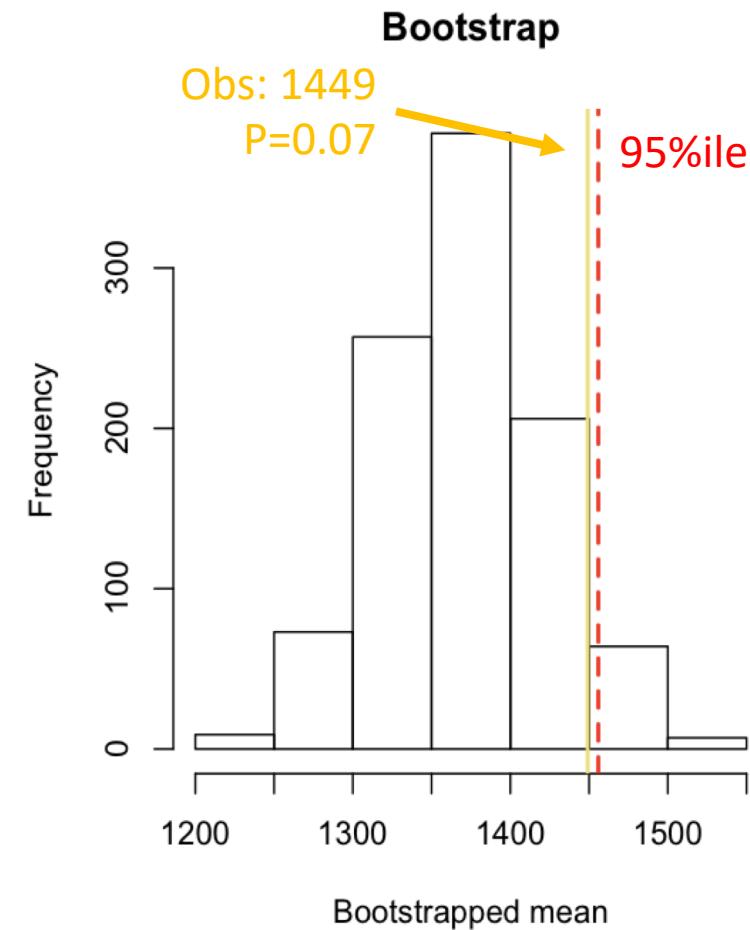
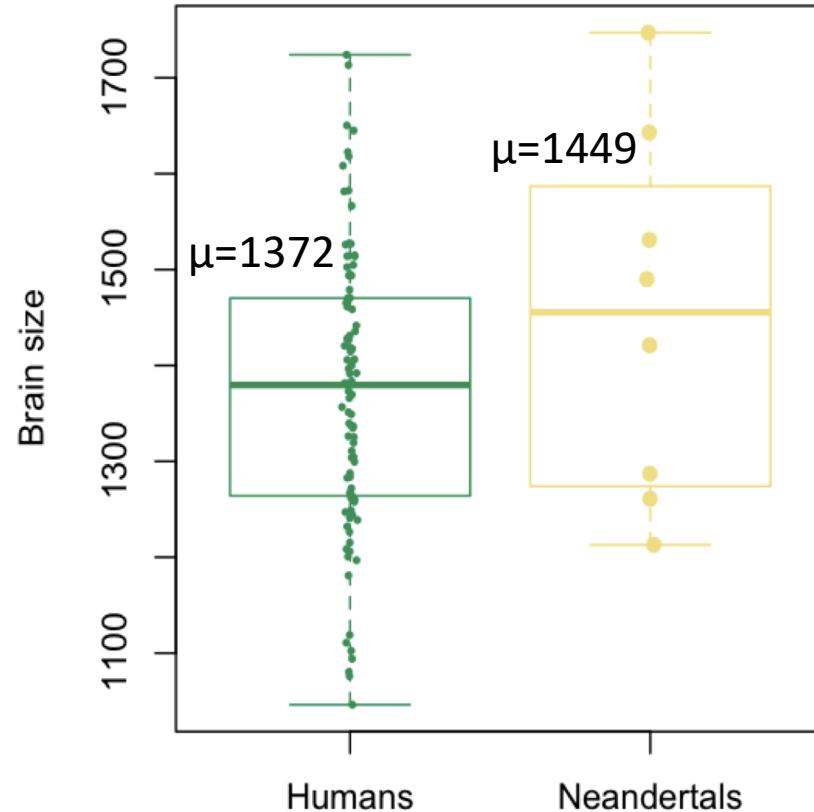
# Resampling methods: Bootstrap

- Example: Did Neandertals have bigger brains than modern humans?



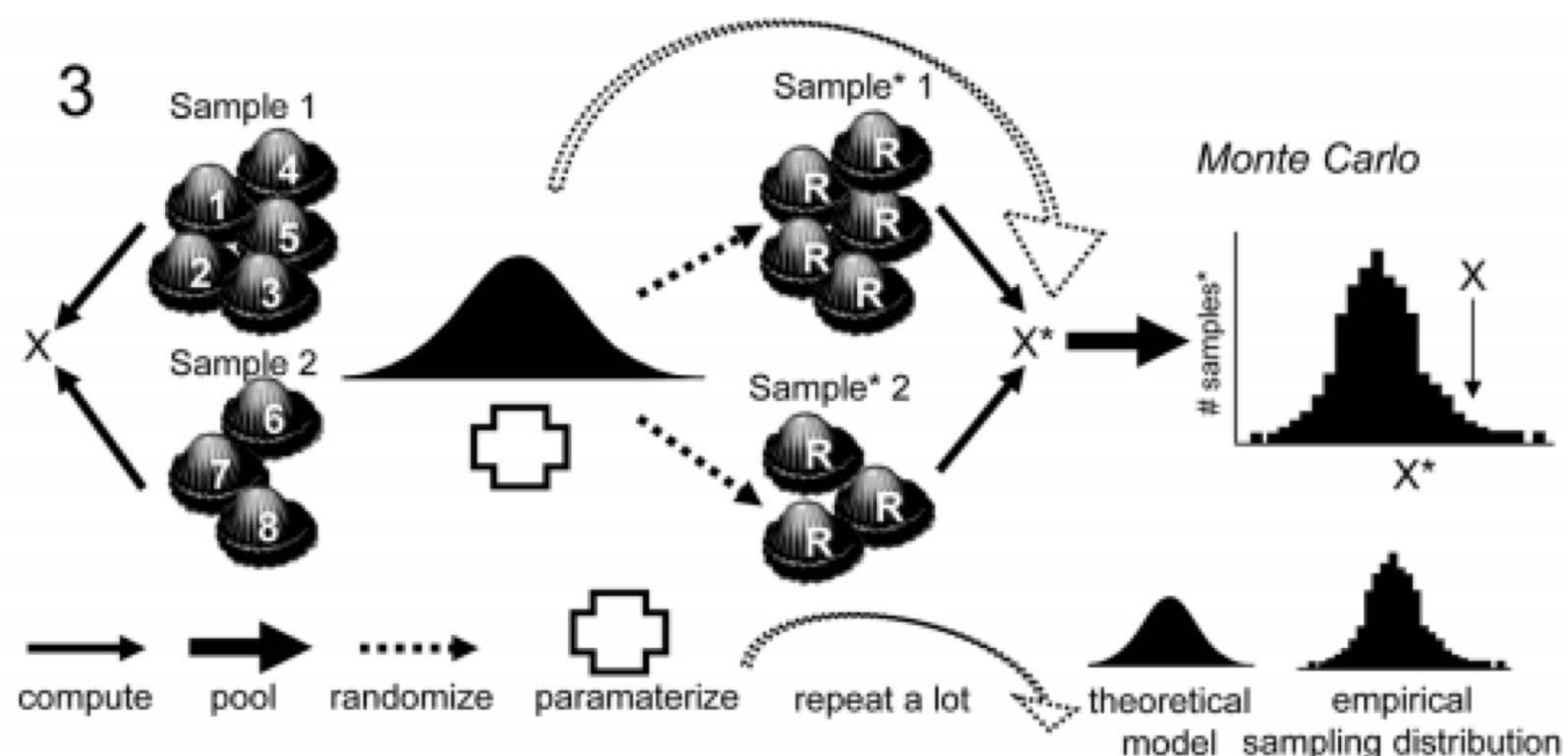
# Resampling methods: Bootstrap

- Example: Did Neandertals have bigger brains than modern humans?

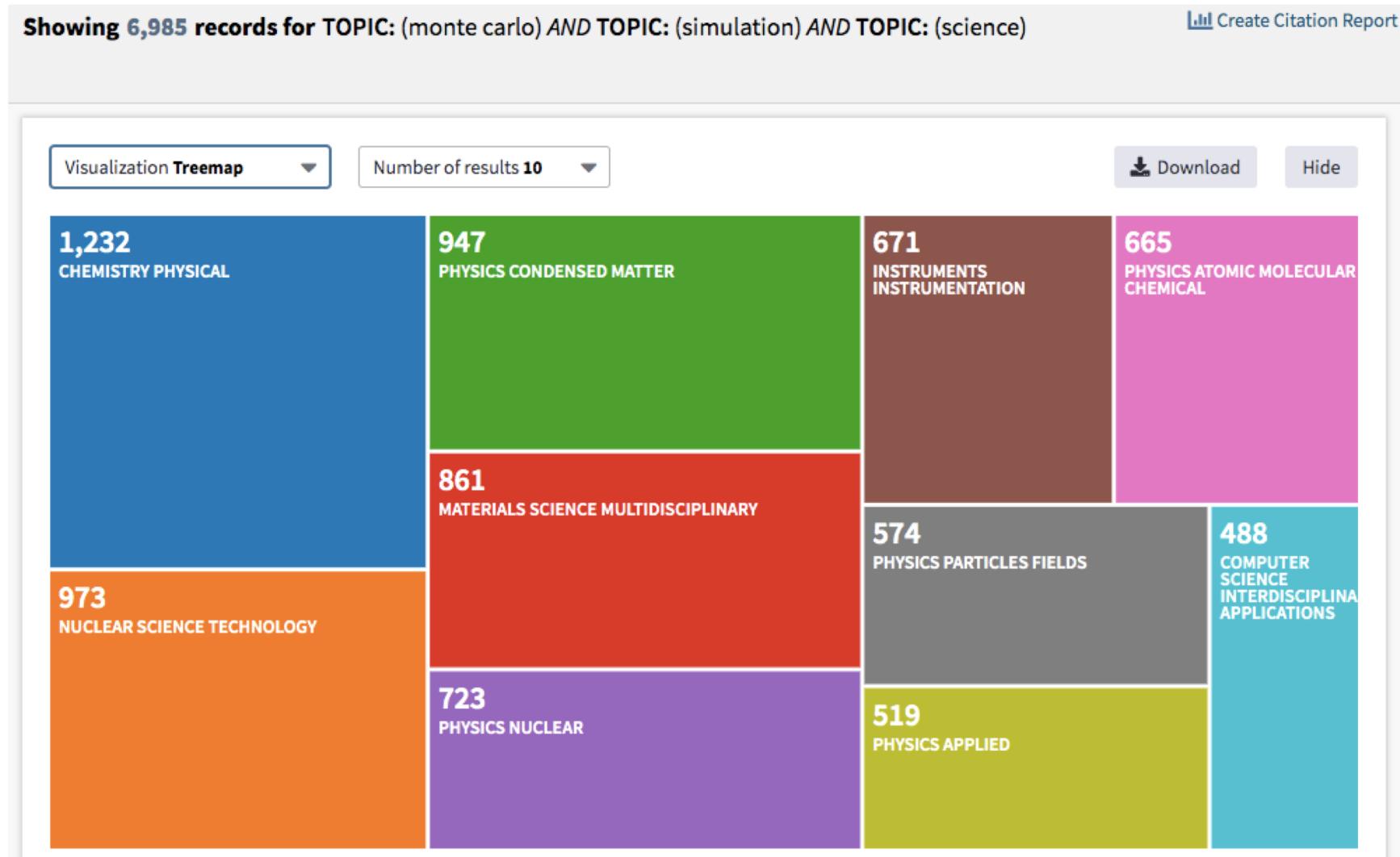


# Resampling methods: Monte Carlo

- Simulation, drawing from theoretical distribution



# Resampling methods: Monte Carlo



# Resampling methods: Monte Carlo

Contents lists available at [ScienceDirect](#)

**Journal of Human Evolution**

journal homepage: [www.elsevier.com/locate/jhevol](http://www.elsevier.com/locate/jhevol)



**ELSEVIER**

A neonatal perspective on *Homo erectus* brain growth

Zachary Cofran <sup>a,\*</sup>, Jeremy M. DeSilva <sup>b</sup>



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**Journal of Human Evolution**

journal homepage: [www.elsevier.com/locate/jhevol](http://www.elsevier.com/locate/jhevol)



**ELSEVIER**

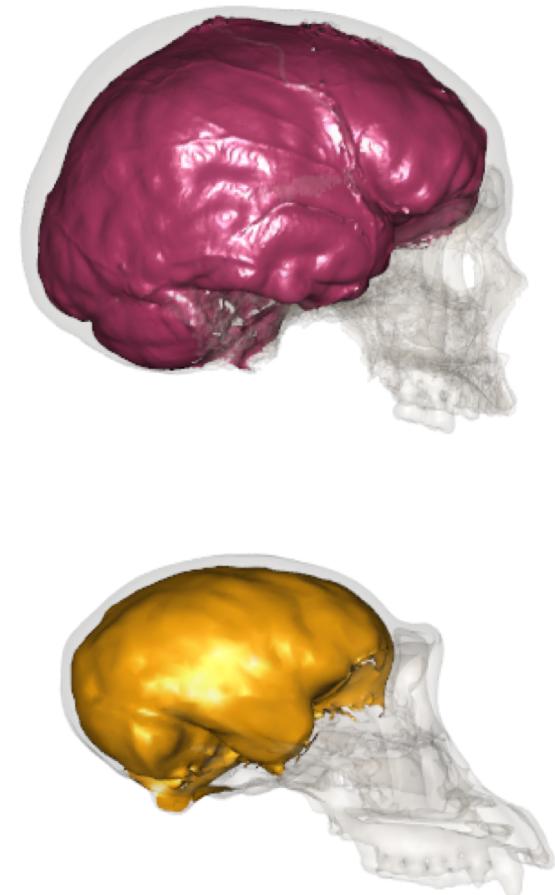
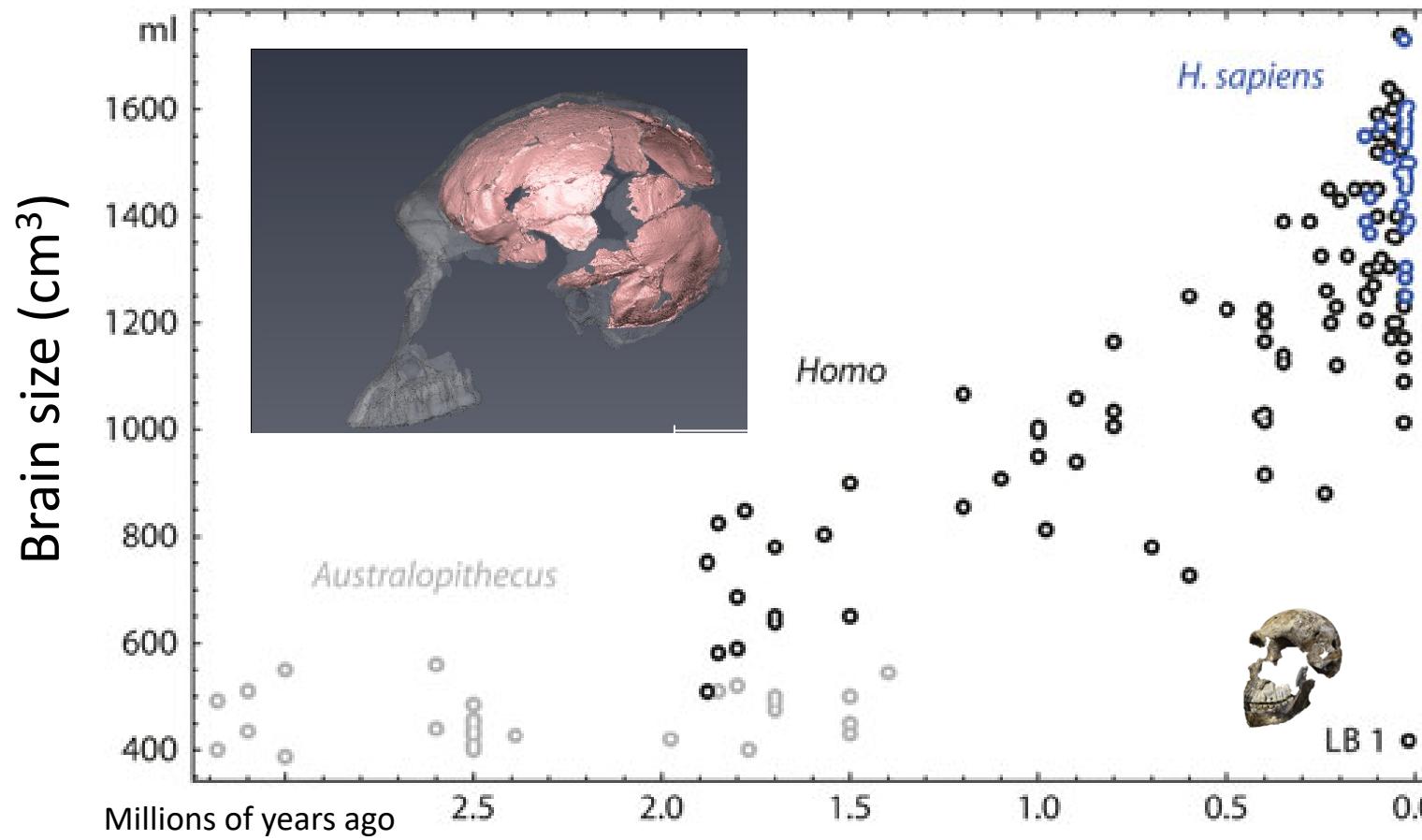
Brain size growth in *Australopithecus*

Zachary Cofran <sup>\*</sup>



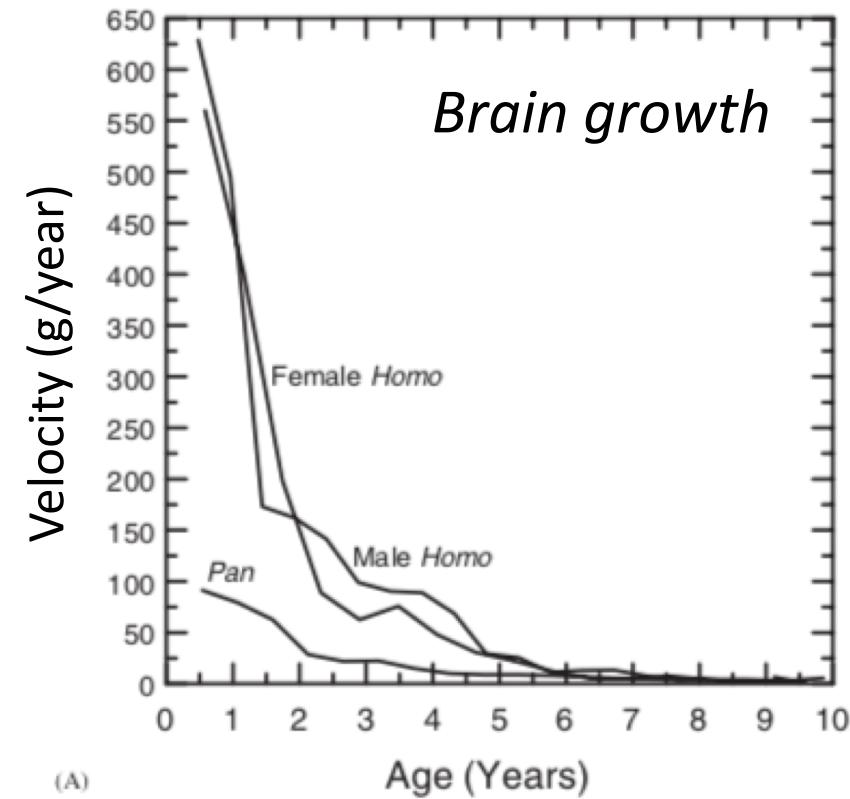
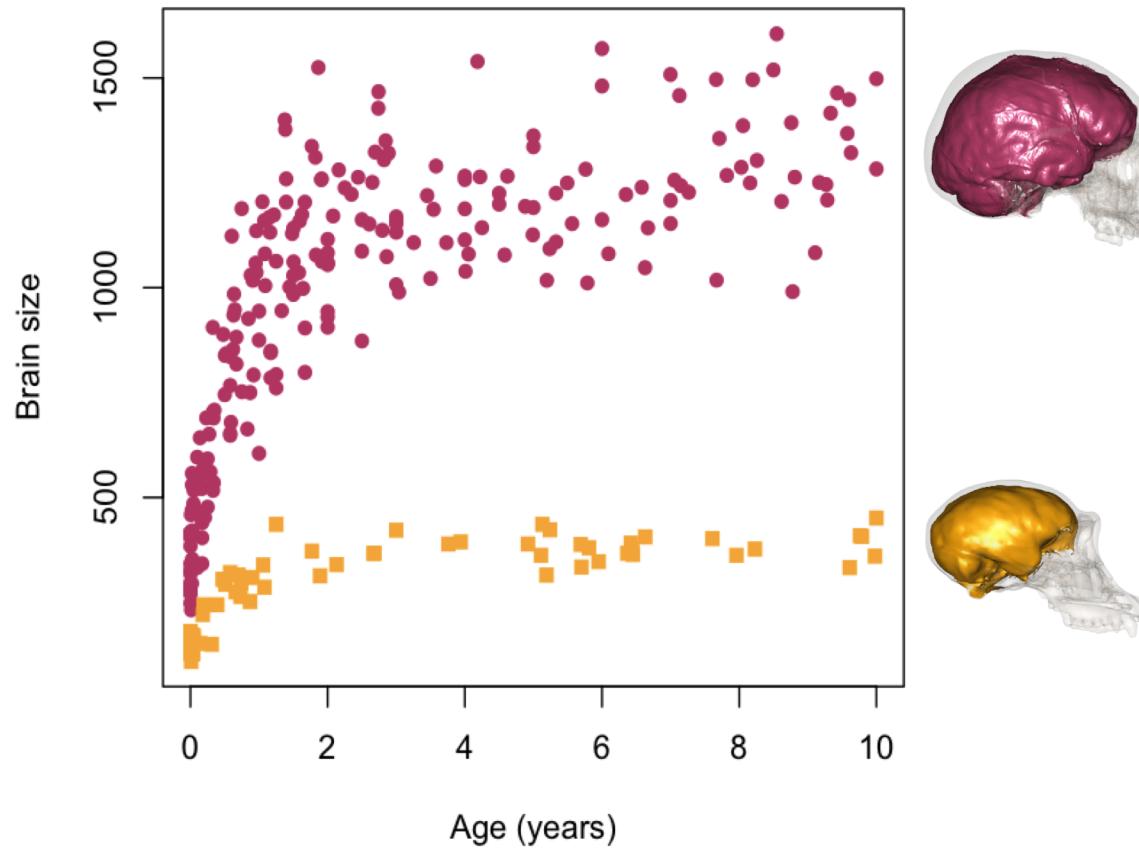
# Resampling methods: Monte Carlo

- Example: Evolution of brain growth



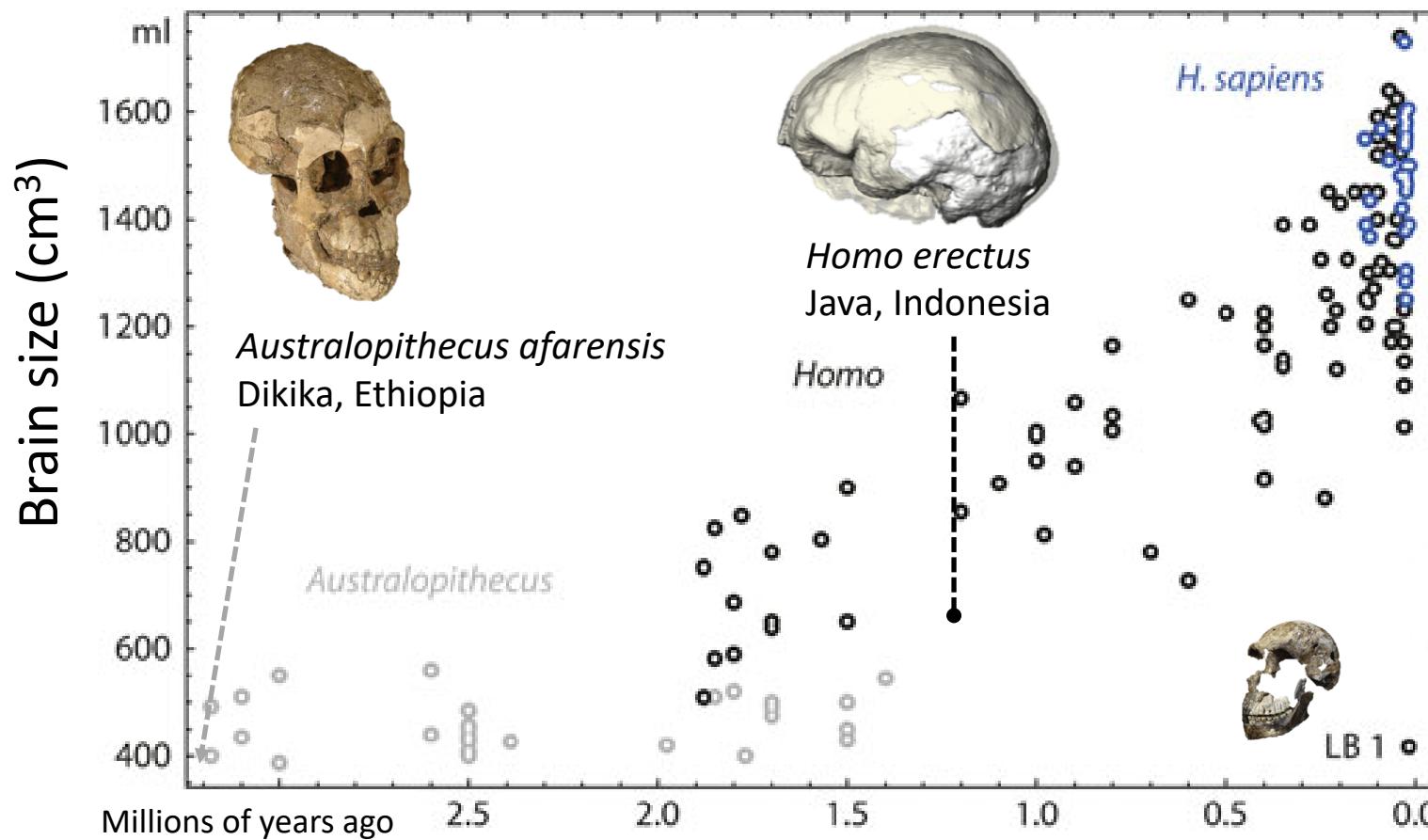
# Resampling methods: Monte Carlo

Human brain = larger newborn size + higher rates + longer duration



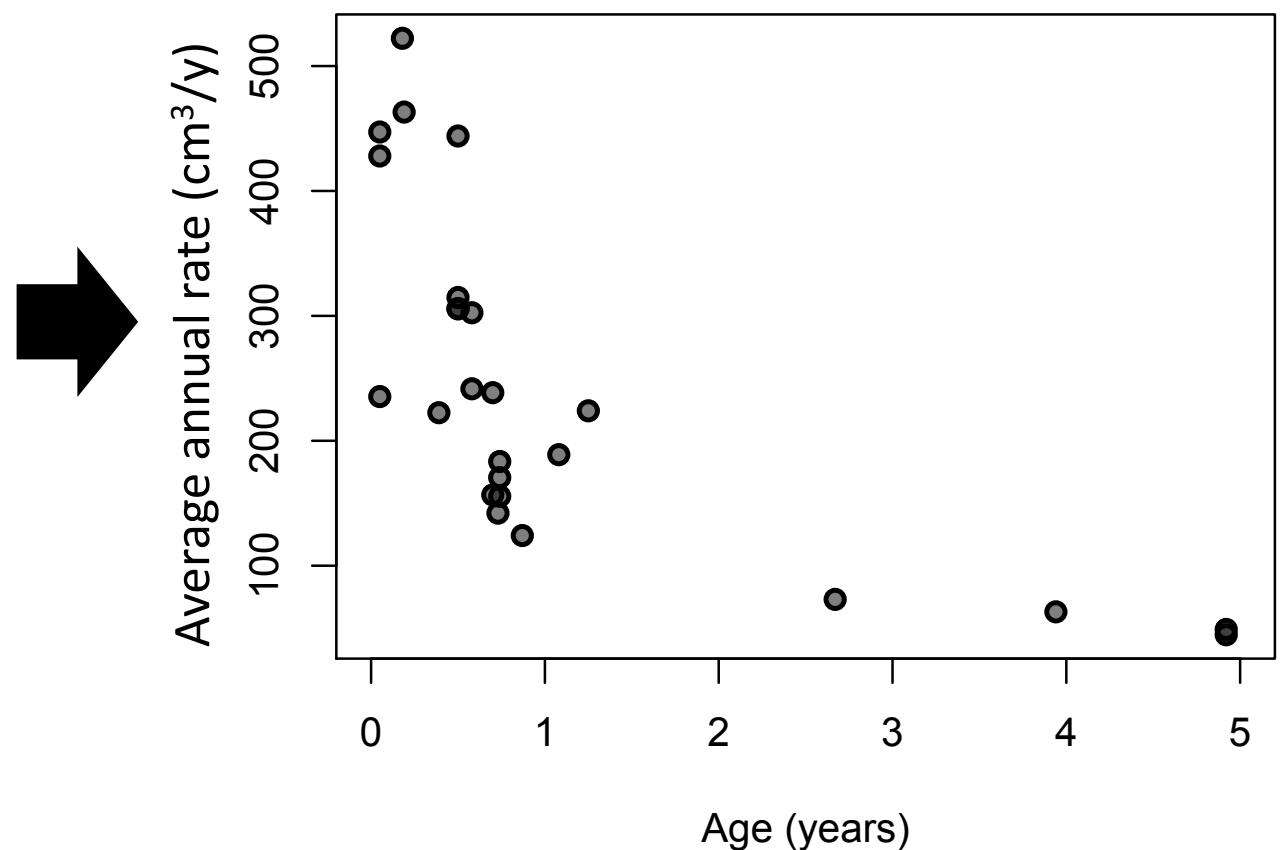
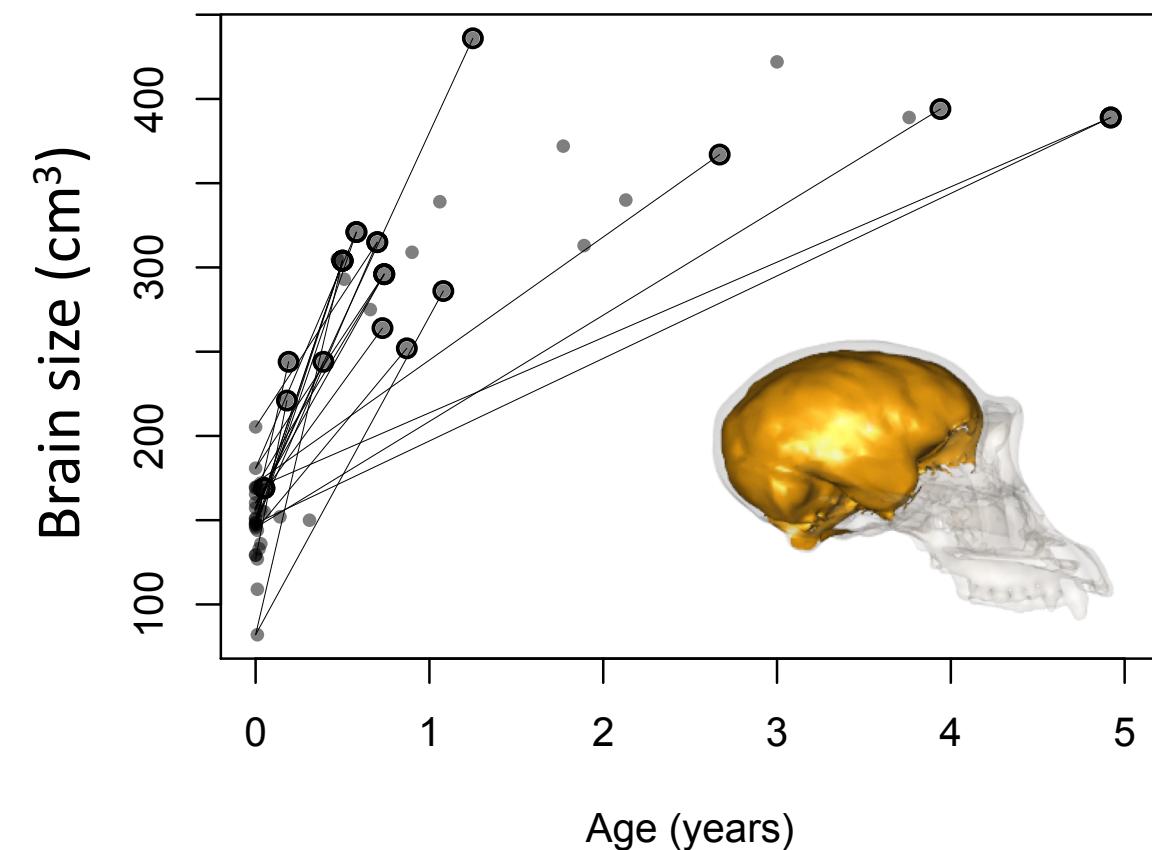
# Resampling methods: Monte Carlo

How to analyze brain growth in fossil species?



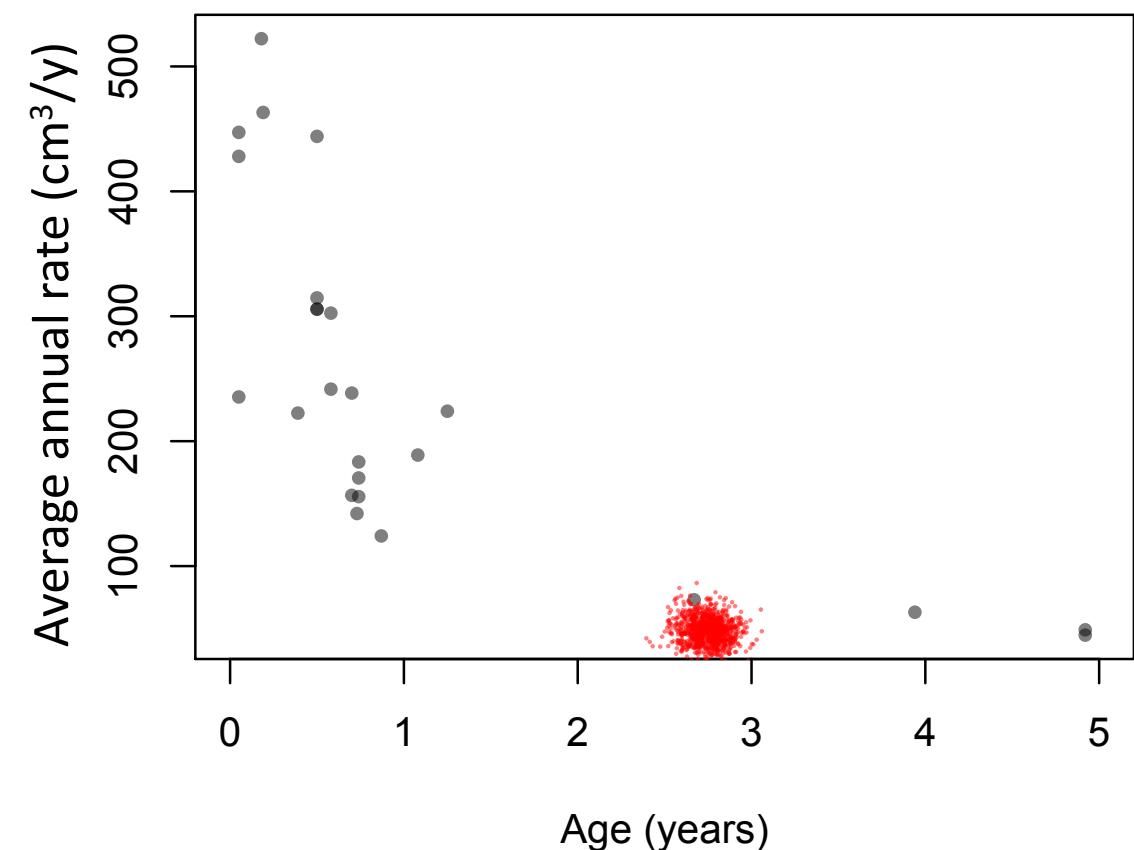
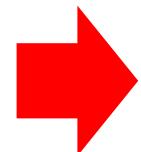
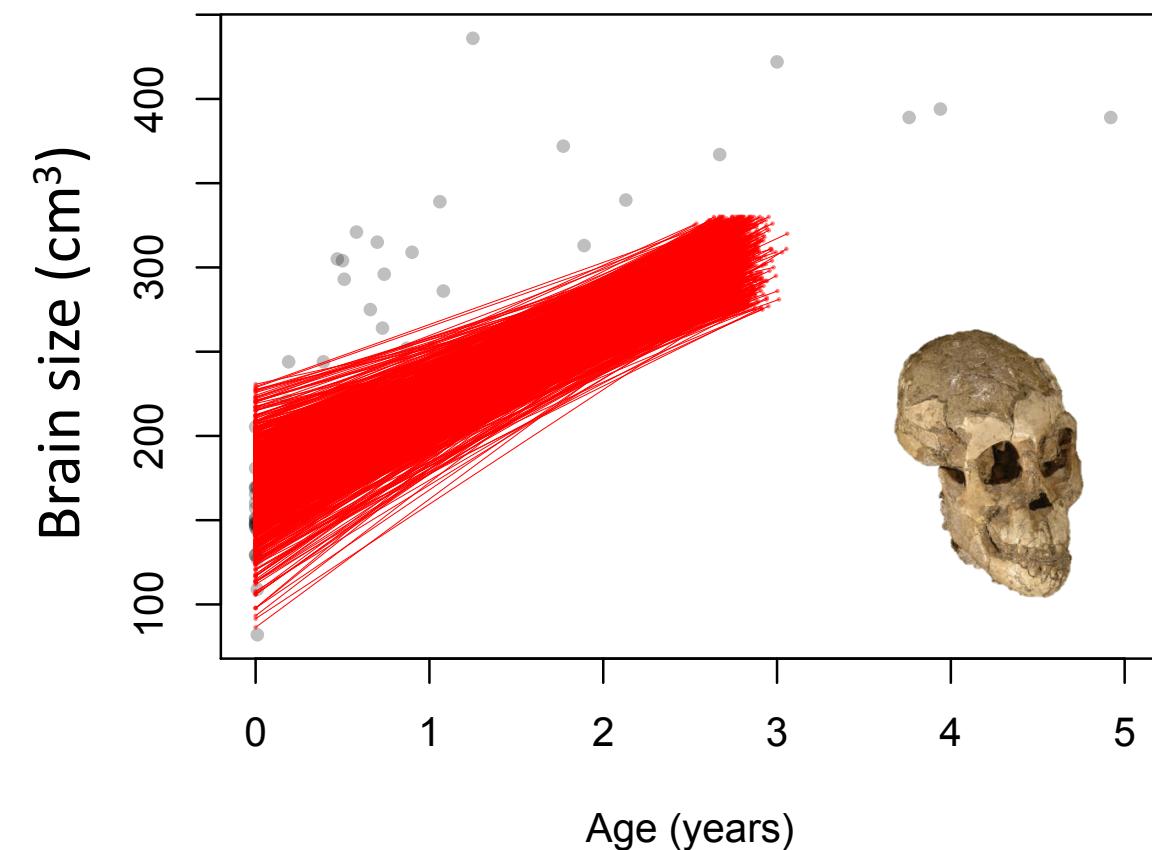
# Resampling methods: Monte Carlo

Reframe the question to accommodate fossil limitations (resampling)



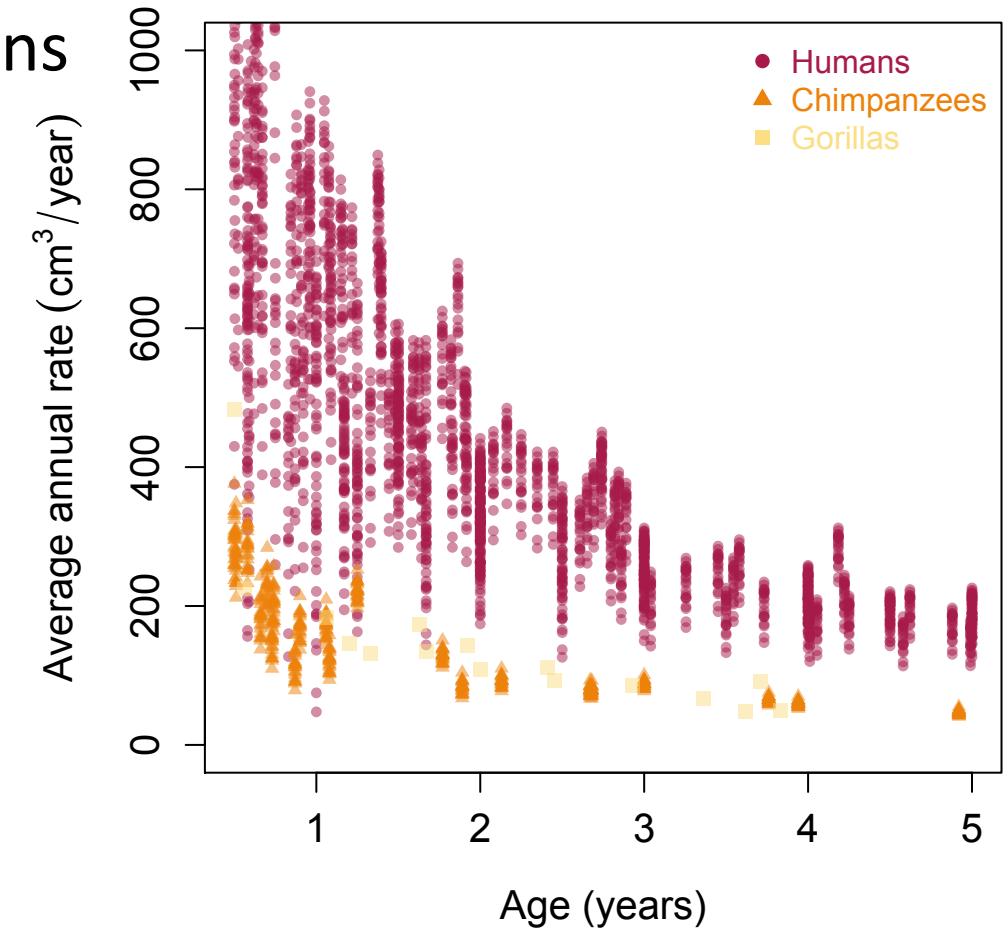
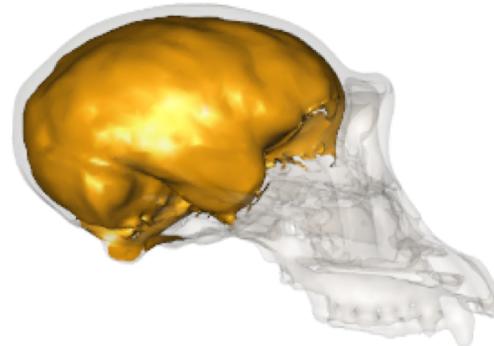
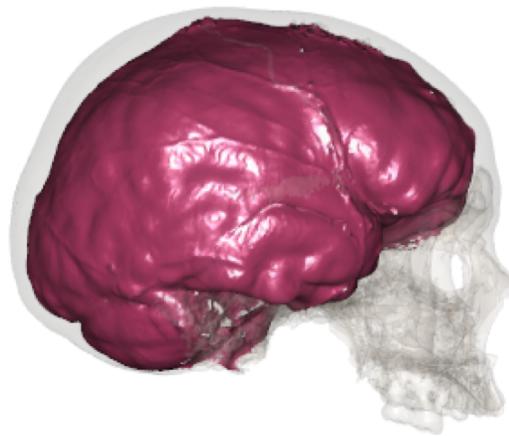
# Resampling methods: Monte Carlo

Reframe the question to accommodate fossil limitations (Monte Carlo)



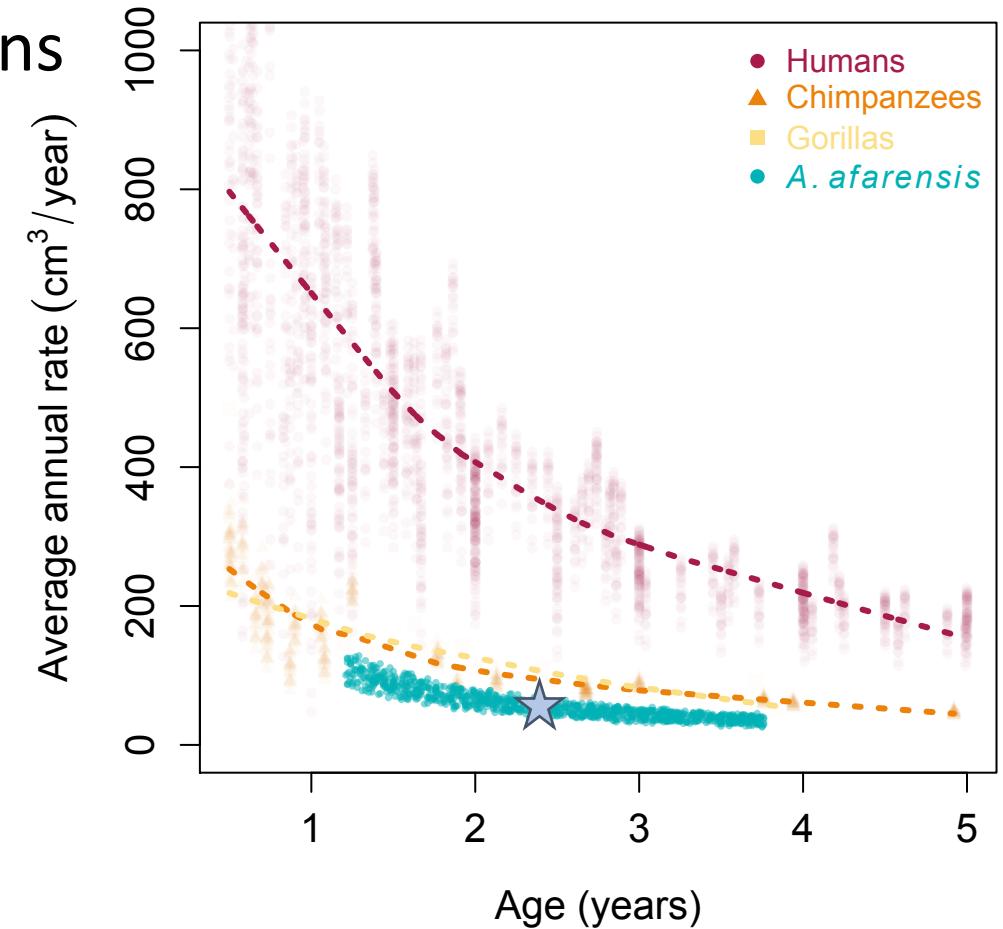
# Resampling methods: Monte Carlo

- Resampled rates reflect empirical patterns



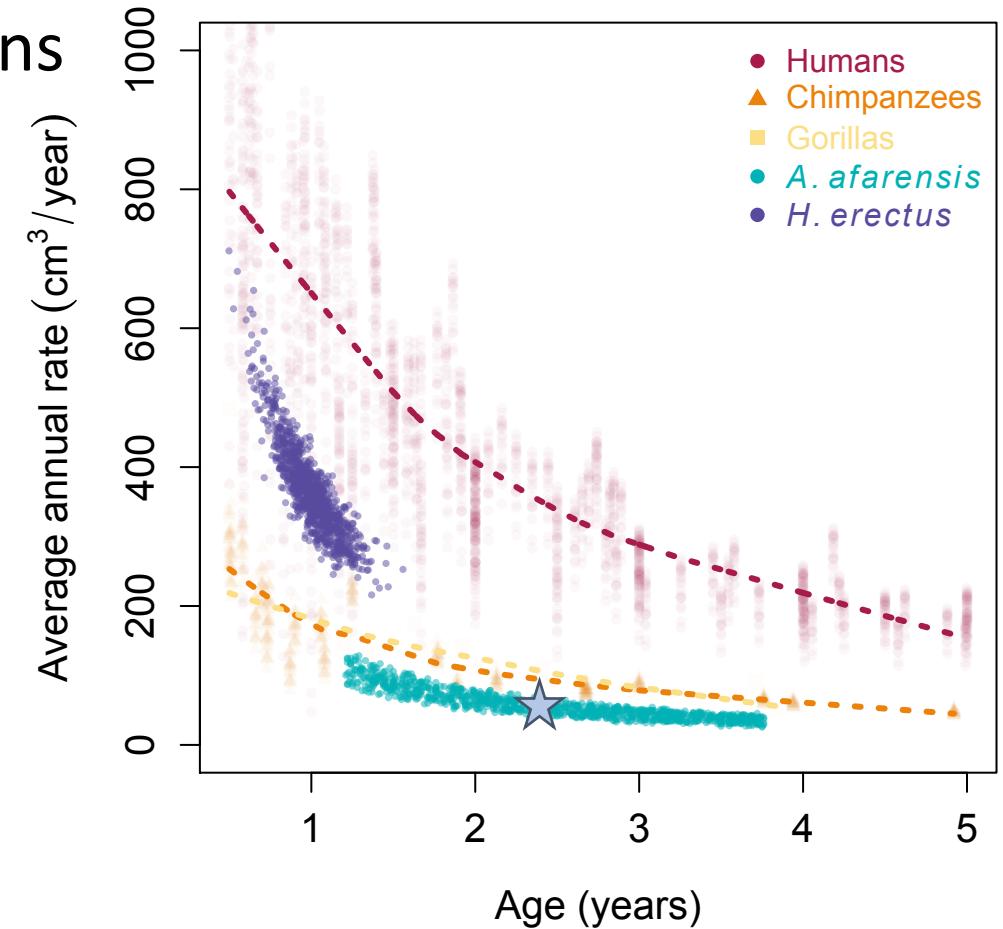
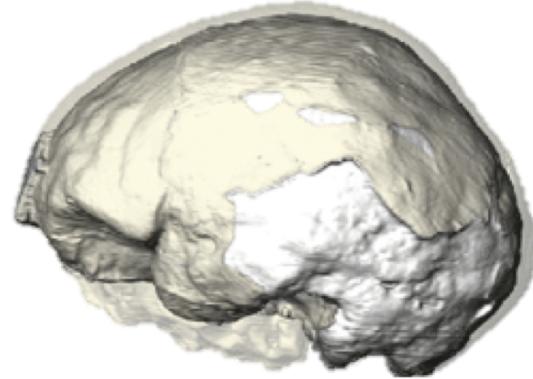
# Resampling methods: Monte Carlo

- Resampled rates reflect empirical patterns
- *A. afarensis* slower than apes



# Resampling methods: Monte Carlo

- Resampled rates reflect empirical patterns
- *A. afarensis* slower than apes
- *H. erectus* at low end of human range



# Resampling methods: Summary

## Benefits

- Statistically robust
- Non-ideal samples
- Flexibility

## Drawbacks

- ~~Computationally expensive~~
- Programming