NACS 645 – Evolution of cognition

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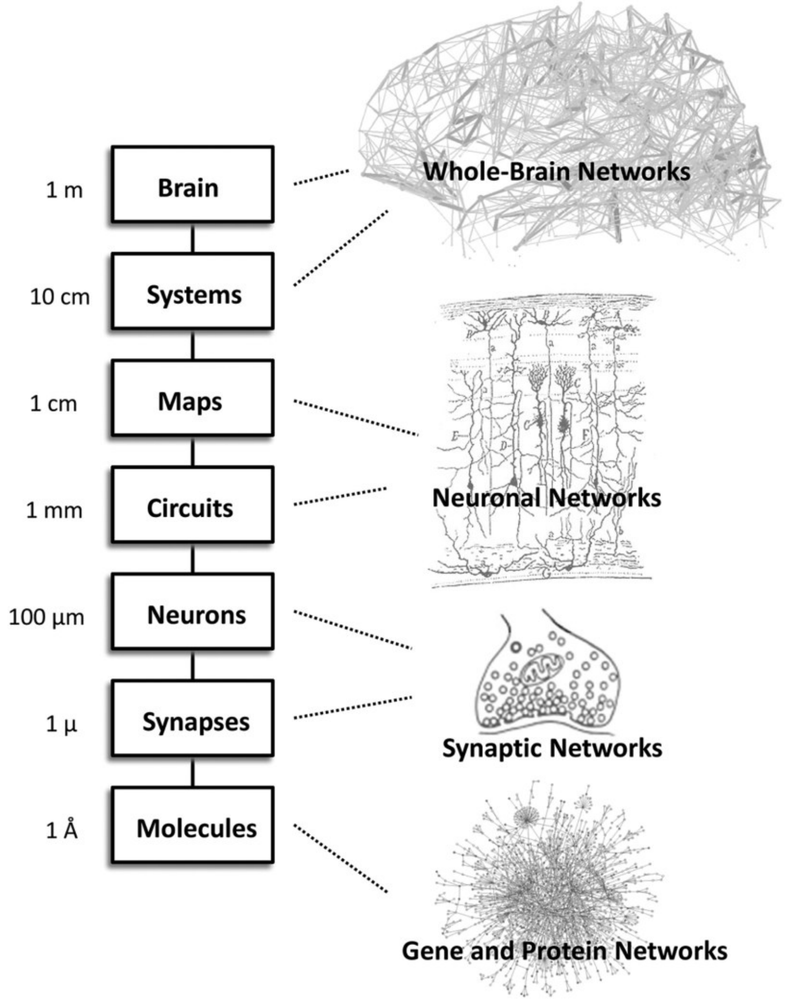
Circuity & functions



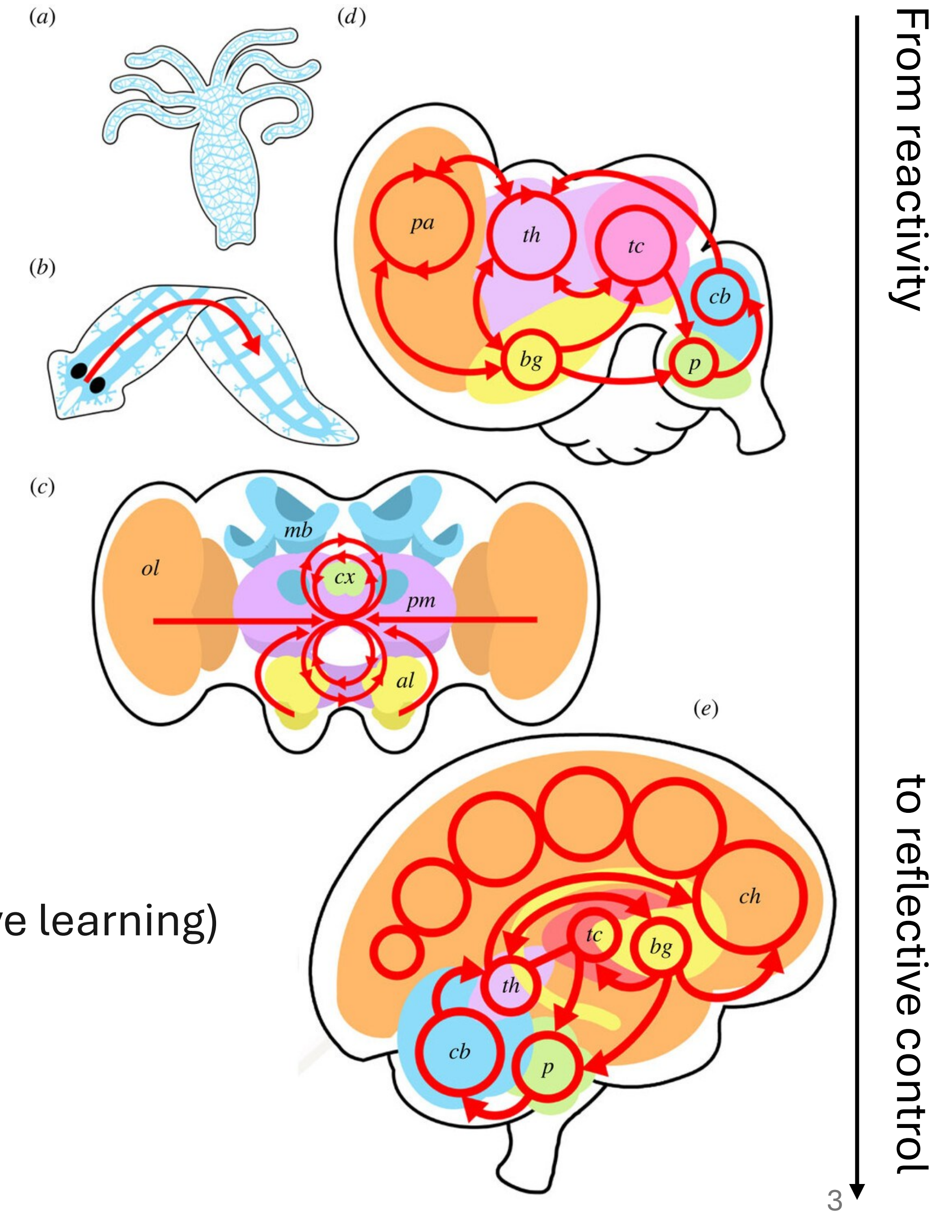
Schematic Representation of Levels of Structure within the Nervous System

- Nested neural structure give rise to cognition
- Spatial expansions and new folds since common ancestors
- Differences localized at each level since common ancestors
- New cognitive functions and behaviors since common ancestors

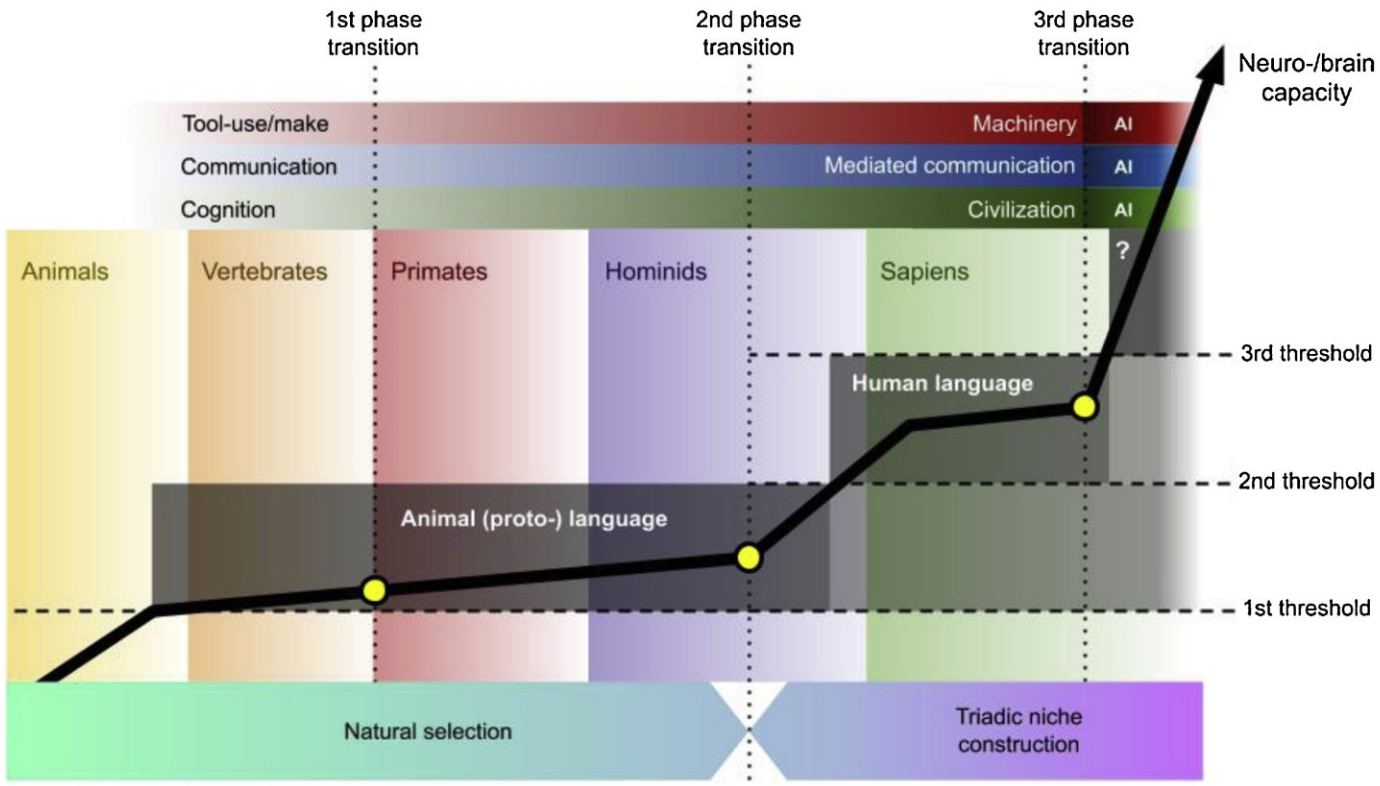
Barron, Halina & Klein, 2023. *Proceedings of the Royal Society B.*

Computational architectures

- (a) **Decentralized** – *Hydra vulgaris*
  - Diffuse nerve net without central brain
  - Control is local and distributed
- (b) **Centralized** – *Dugesia japonica* (flatworm)
  - Bilateral ganglia integrate input and coordinate global output
  - First appearance of a centralized feed-forward hierarchy
- (c) **Recurrent** – Insect brain
  - Bidirectional loops between sensory, integrative, and premotor
  - Feedback enables functions: short-term memory, cross-modal learning, and adaptive goal control
- (d) **Laminated** – Avian brain
  - Layered recurrent circuits linking brain localizations
  - Allows optimization of control flow through experience (predictive learning)
- (e) **Reflective** – Human brain
  - Prefrontal regions generate can reshape control flow itself
  - Enables planning, simulation, and symbolic reasoning (cognition capable of self-modification)



Phase transitions in brain-architecture evolutions



1st transition: natural selection → cortical expansion and modular differentiation in early primates.
Proto-language present

2nd transition: *triadic* coupling among tool use, social communication, and cognition → recursive feedback between brain, behavior, and niche
Human language emerges

3rd (ongoing): human–AI → distributed cognitive systems beyond the biological brain

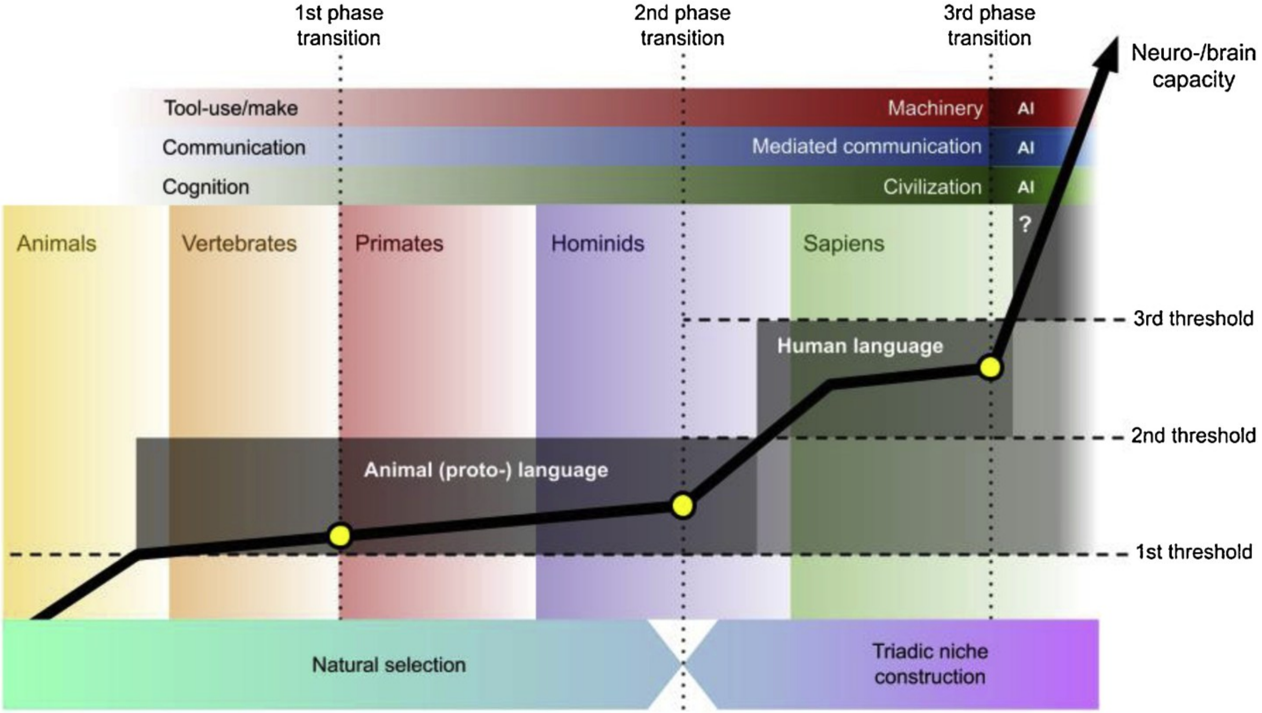
Language and tool use emerge as phase transitions, not incremental adaptations

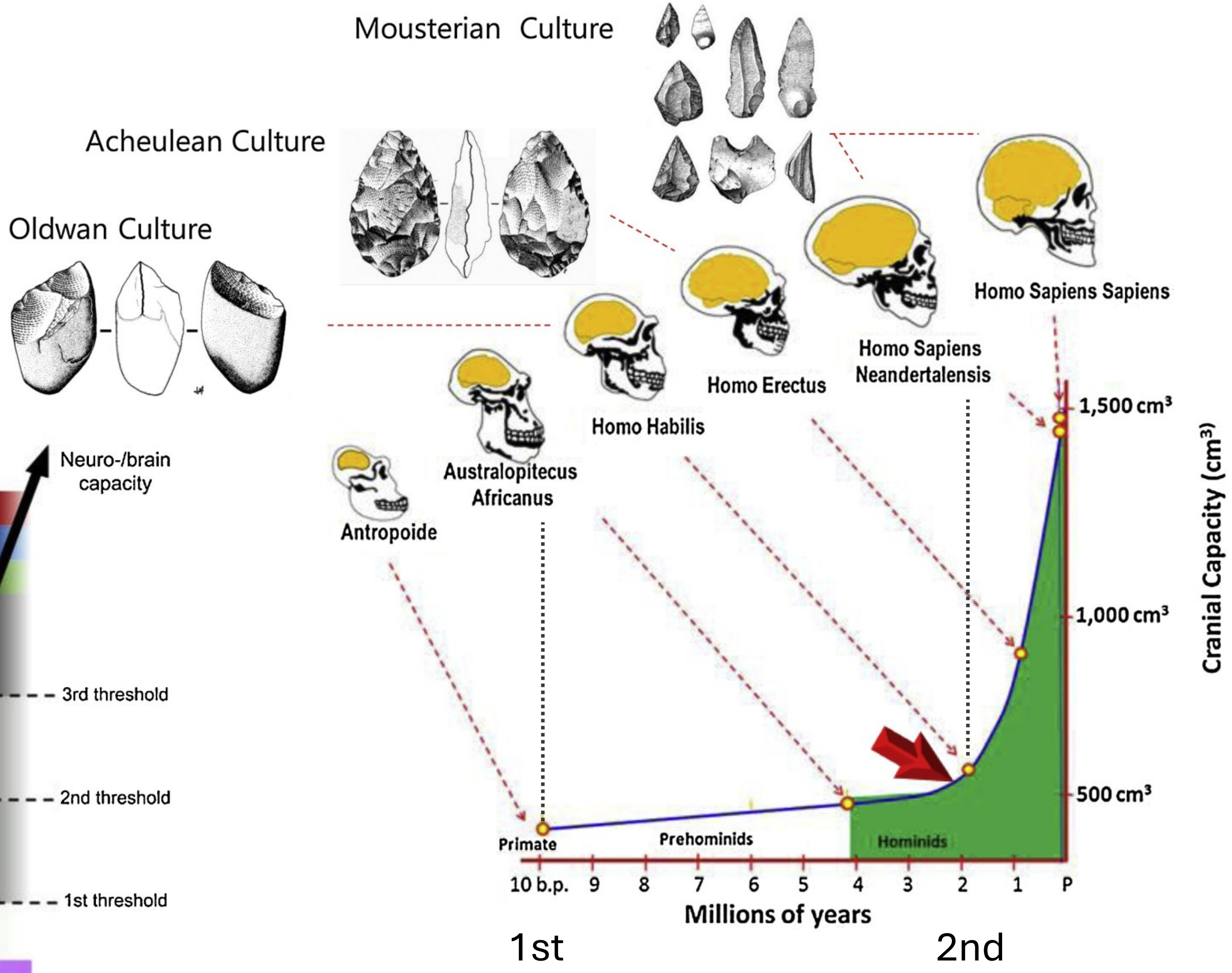
Evolution of brain, language, and tool use

Bretas, Yamazaki & Iriki, 2020. *Neuroscience Research.*

Each transition marks a qualitative reorganization of neural architecture and cognition: cortical expansion, tool–language–cognition coupling

Recursive behavior, communication, and representation evolved in parallel

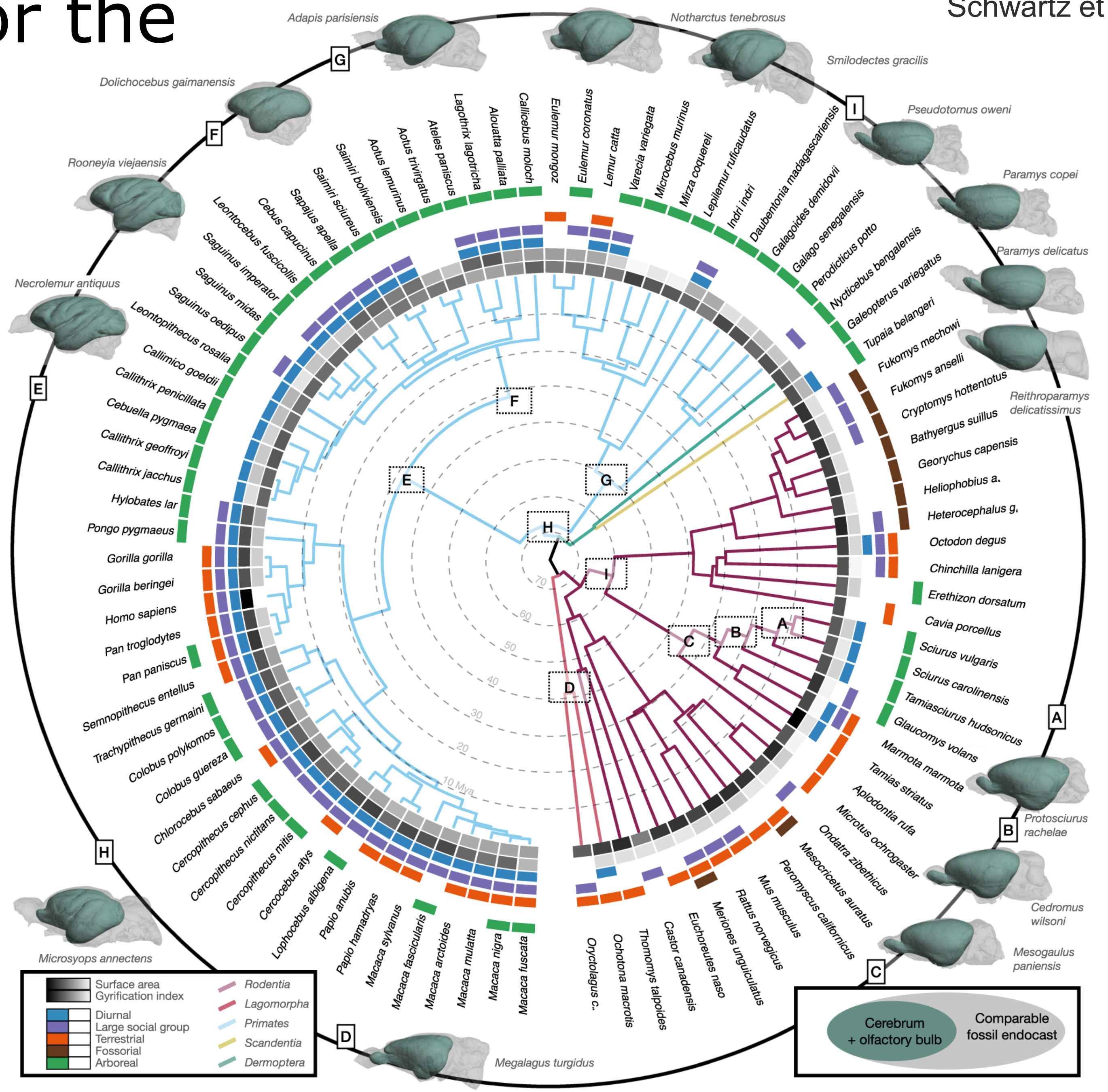




Schwartz et al., 2023. *Nature Communications.*

Looking for the common ancestor

Authors established a **joint geometric representation of the cerebral cortices of ninety species of extant *Euarchontoglires*** (superorder mammals)

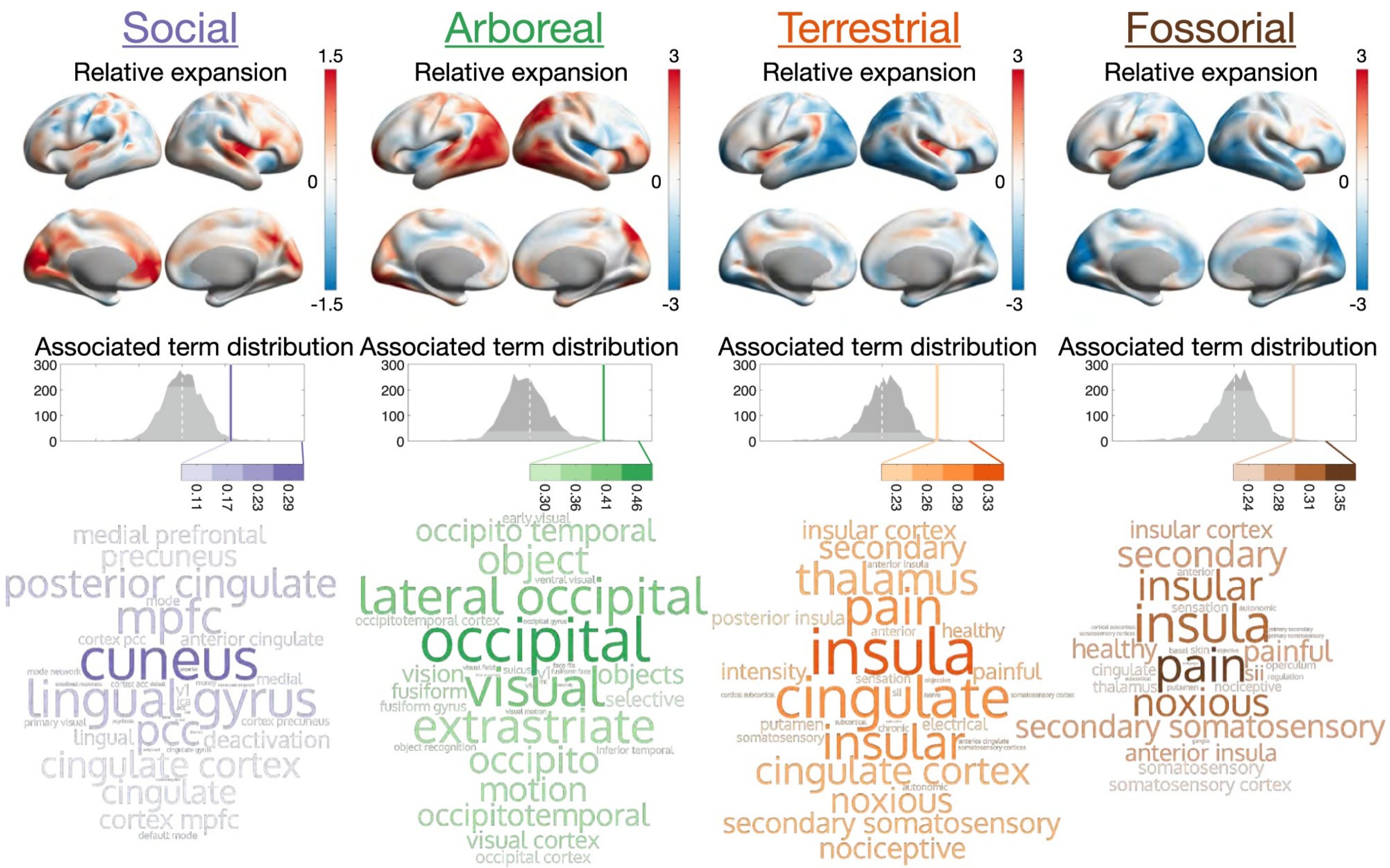


Variability in surface geometry relates to species' ecology and behaviour, independent of overall brain size

Individual cortical regions follow different sequences of area increase during evolutionary adaptations to dynamic socio-ecological niches

Schwartz et al., 2023. *Nature Communications.*

Ecological dimensions and Functional expansions



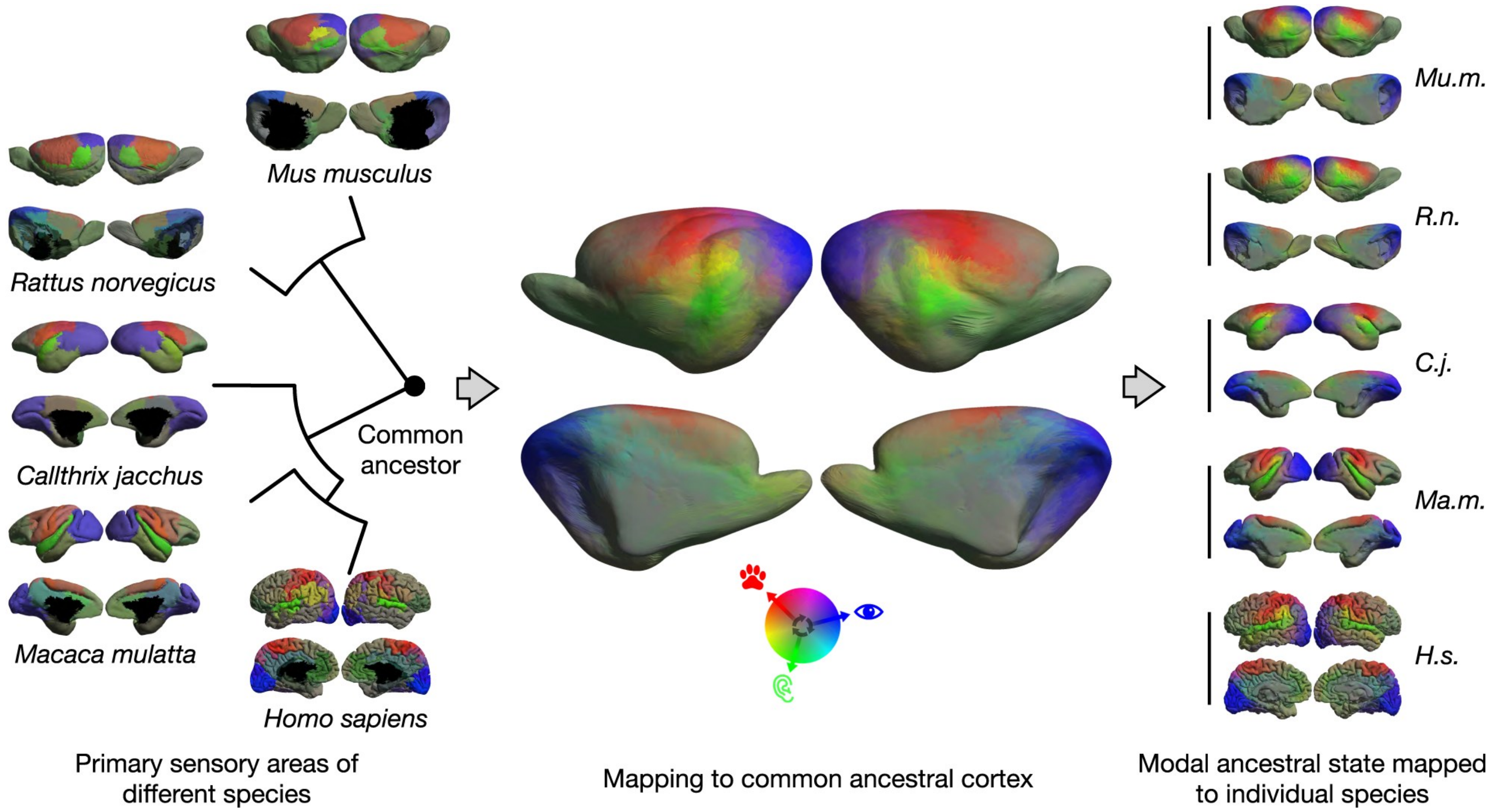
- Social and arboreal species: enlarged temporal, parietal, and prefrontal association areas (visuospatial coordination, manipulation, and social inference)
- Terrestrial: larger sensorimotor integration for navigation and foraging
- Fossorial : contraction and stronger modality segregation, for simplified sensory demands

Authors reconstructed cortical surface geometry for the 90 species and aligned each cortex to a common ancestral map

They then regressed local surface-area expansion against four ecological predictors to see how environment shapes cortices

Ancestral cortical functional specialization

Schwartz et al., 2023. *Nature Communications.*



Using cross-species surface-shape alignment, the authors reconstructed the ancestral cortical map for primates and rodents

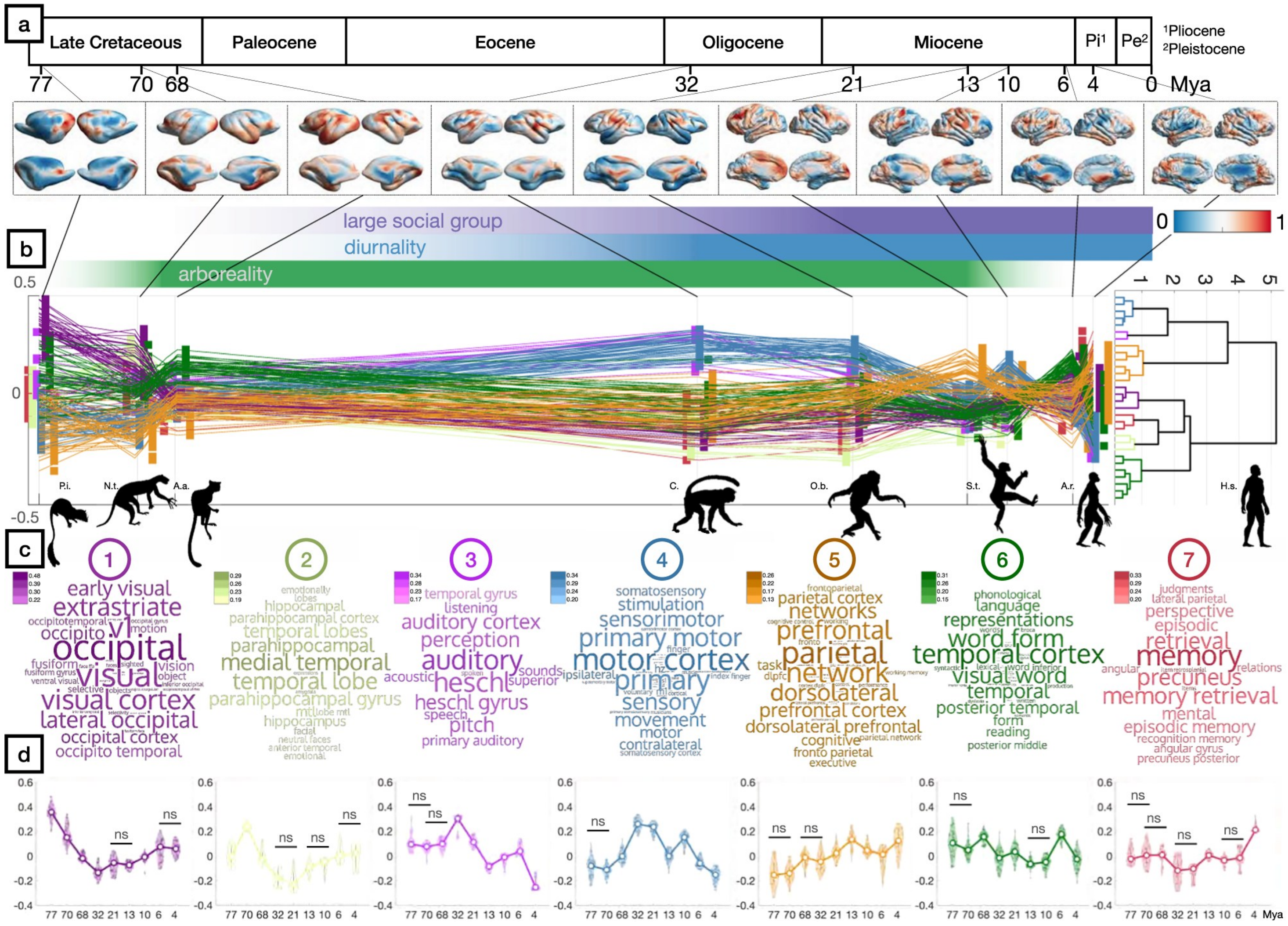
By anchoring shared geometric landmarks, they estimated the spatial distribution of primary sensory areas:
Visual (blue), Auditory (green), Somatosensory (red)

The ancestral template was then projected onto all species' cortical surfaces to trace how **modal specificity** evolved relative to local shape expansion.

- Primary sensory and motor regions: conserved topology
- Association areas: flexible, expanding at evolutionary "hinges"
- Predicts the later **shift toward transmodal integration** in humans

Sequence of cortical expansion in the human lineage

Schwartz et al., 2023. *Nature Communications.*



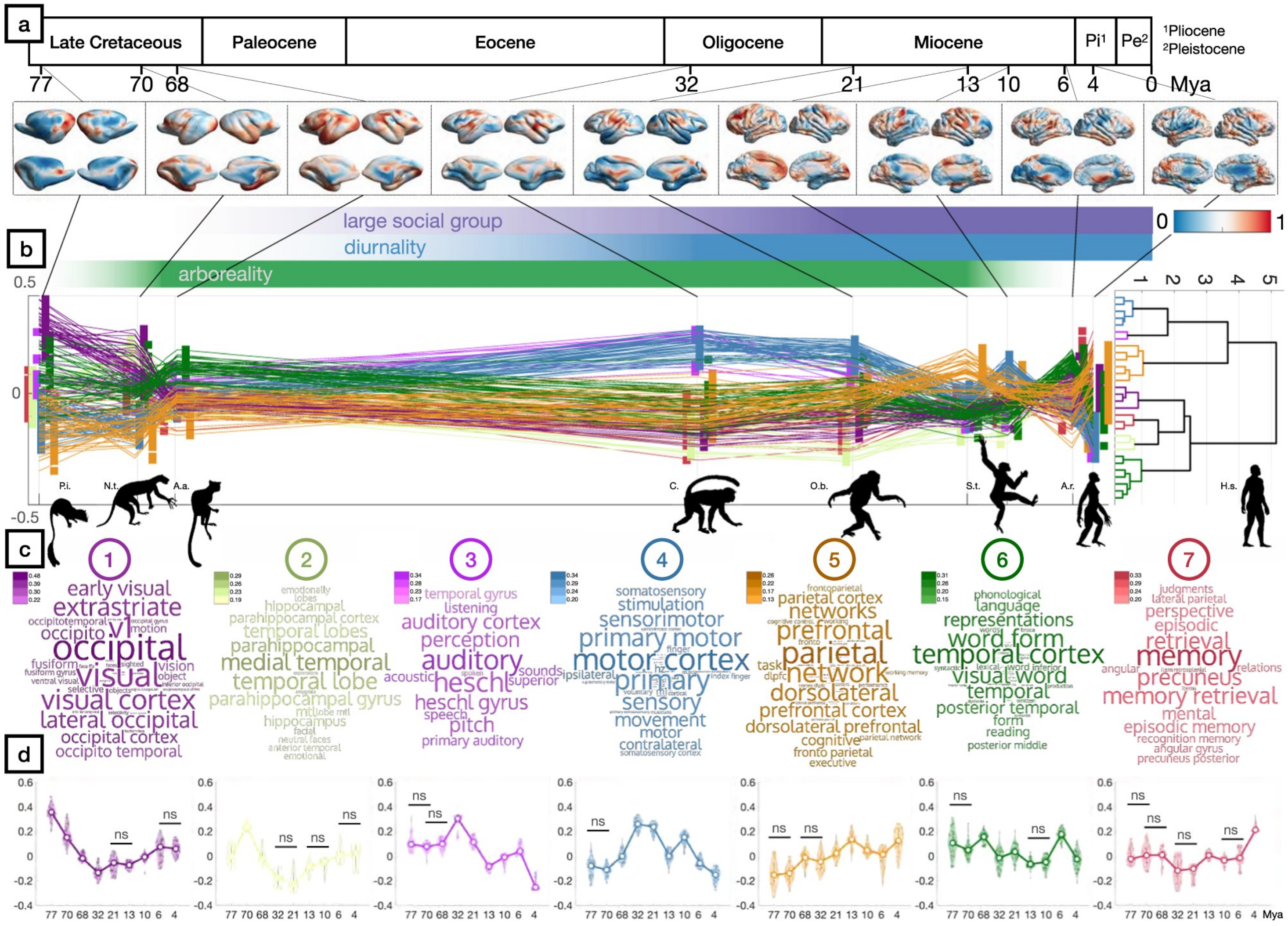
Authors reconstructed cortical surfaces for ancestral nodes along the primate lineage (from early *Glires* to Homo sapiens) to trace where and when different cortical regions expanded.

For each ancestral surface, they computed relative areal expansion between successive ancestors, then decoded each expansion map by correlating it with human functional activation maps (NeuroSynth database).

The 1% strongest correlations at each evolutionary step were hierarchically clustered to identify functionally coherent waves of cortical expansion.

Sequence of cortical expansion in the human lineage

Schwartz et al., 2023. *Nature Communications.*



Results show a temporal sequence of cortical reorganization:

- **Cretaceous–Oligocene**: primary visual, auditory, and motor regions expand first (sensorimotor adaptation to ecological complexity)
- **Miocene–Pliocene–Pleistocene**: subsequent, accelerated expansion of parietal, temporal, and prefrontal association areas (underpinning abstract cognition and flexible control)

Hierarchical emergence of cortical network: human association cortices arose through successive, domain-specific expansions building on earlier sensory–motor scaffolds