

KISS Workshop: Biological Insights into Robotic Design

Shane Campbell-Staton, Princeton University

Bio-Inspired Engineering in the Real World



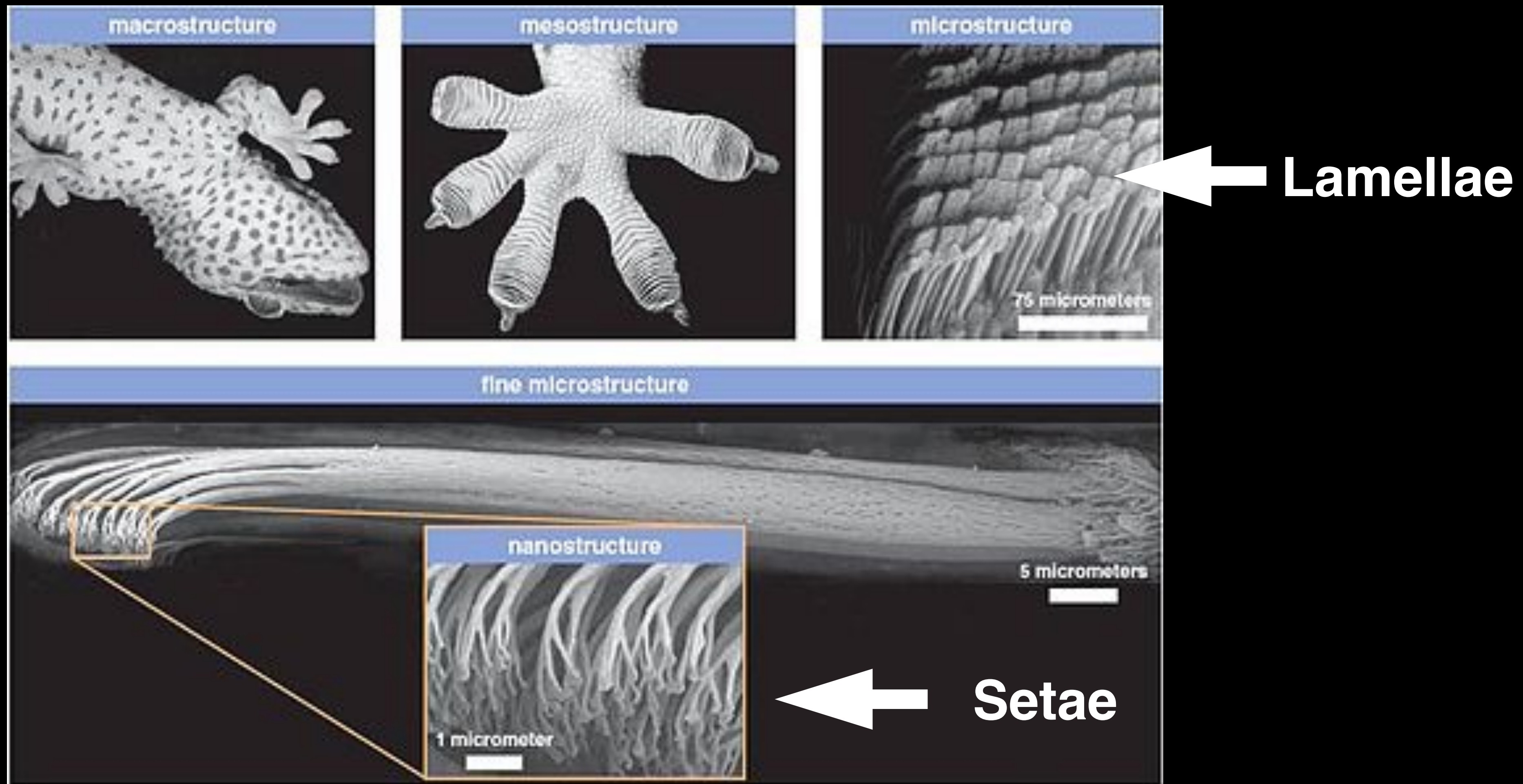
August Krogh
Danish Zoophysiologicalist
(1874-1949)

"for such a large number of problems there will be some animal of choice, or a few such animals, on which it can be most conveniently studied."

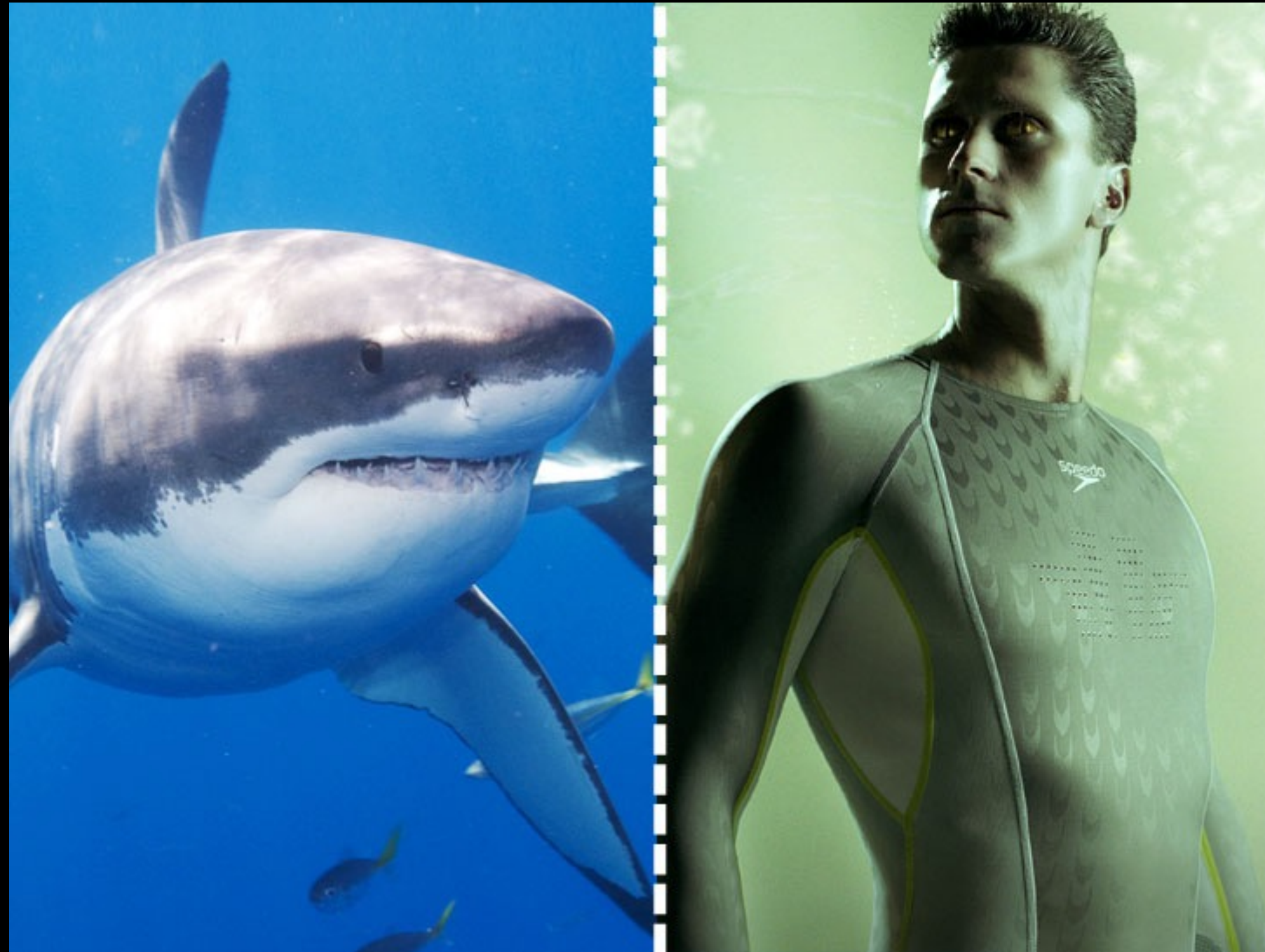
Bio-Inspired Engineering in the Real World



Bio-Inspired Engineering in the Real World



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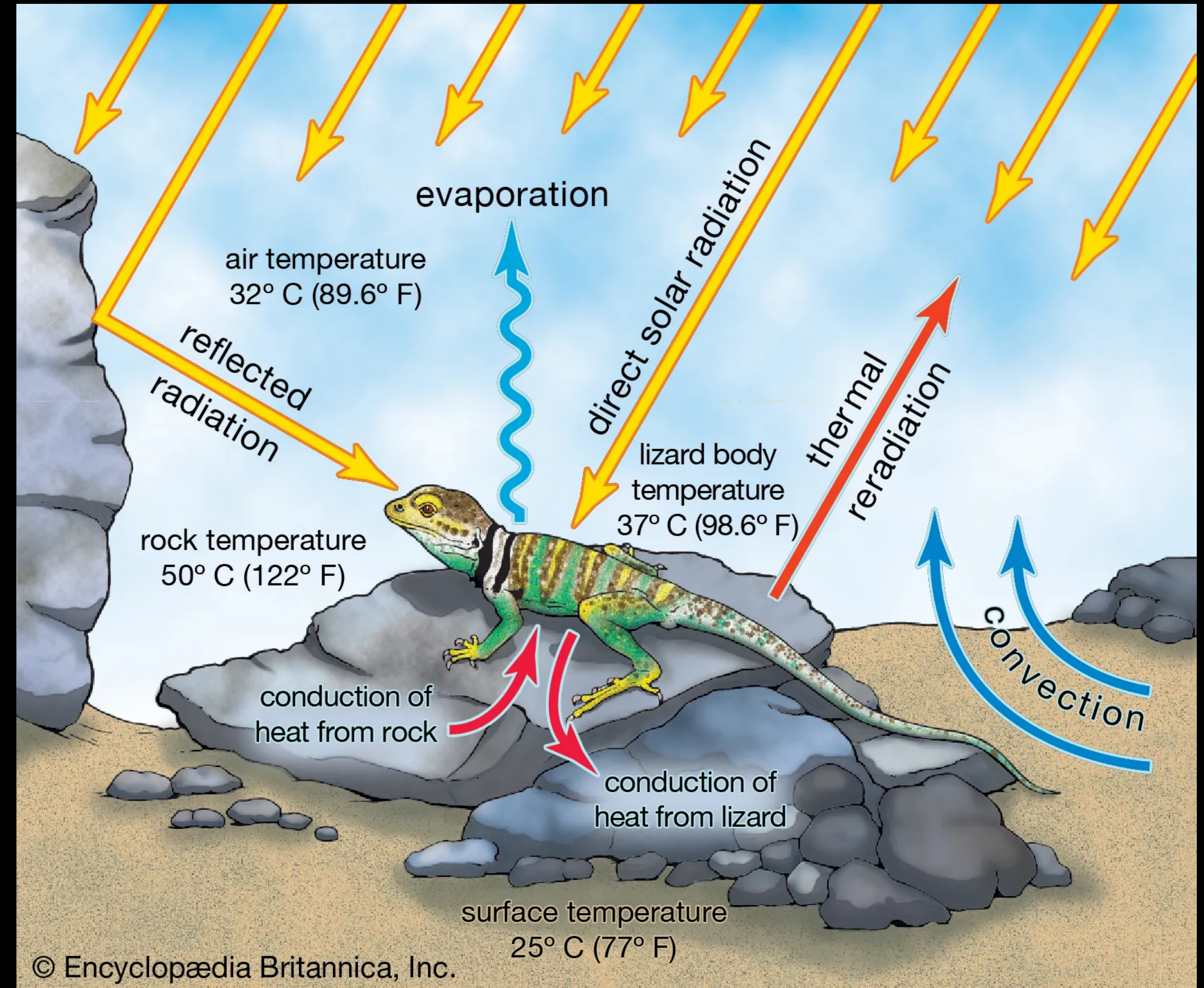
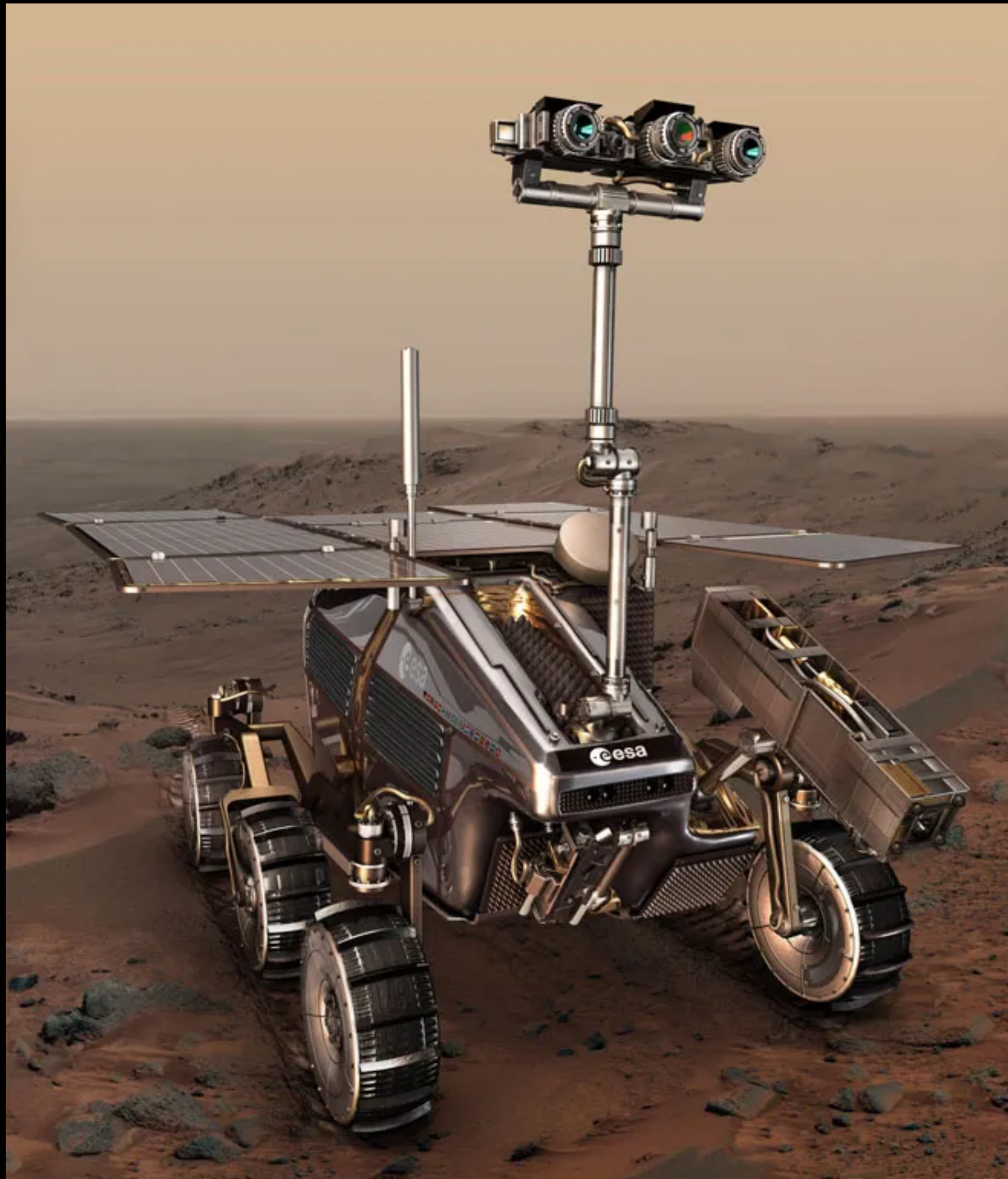
**Darkling beetle
(family Tenebrionidae)**



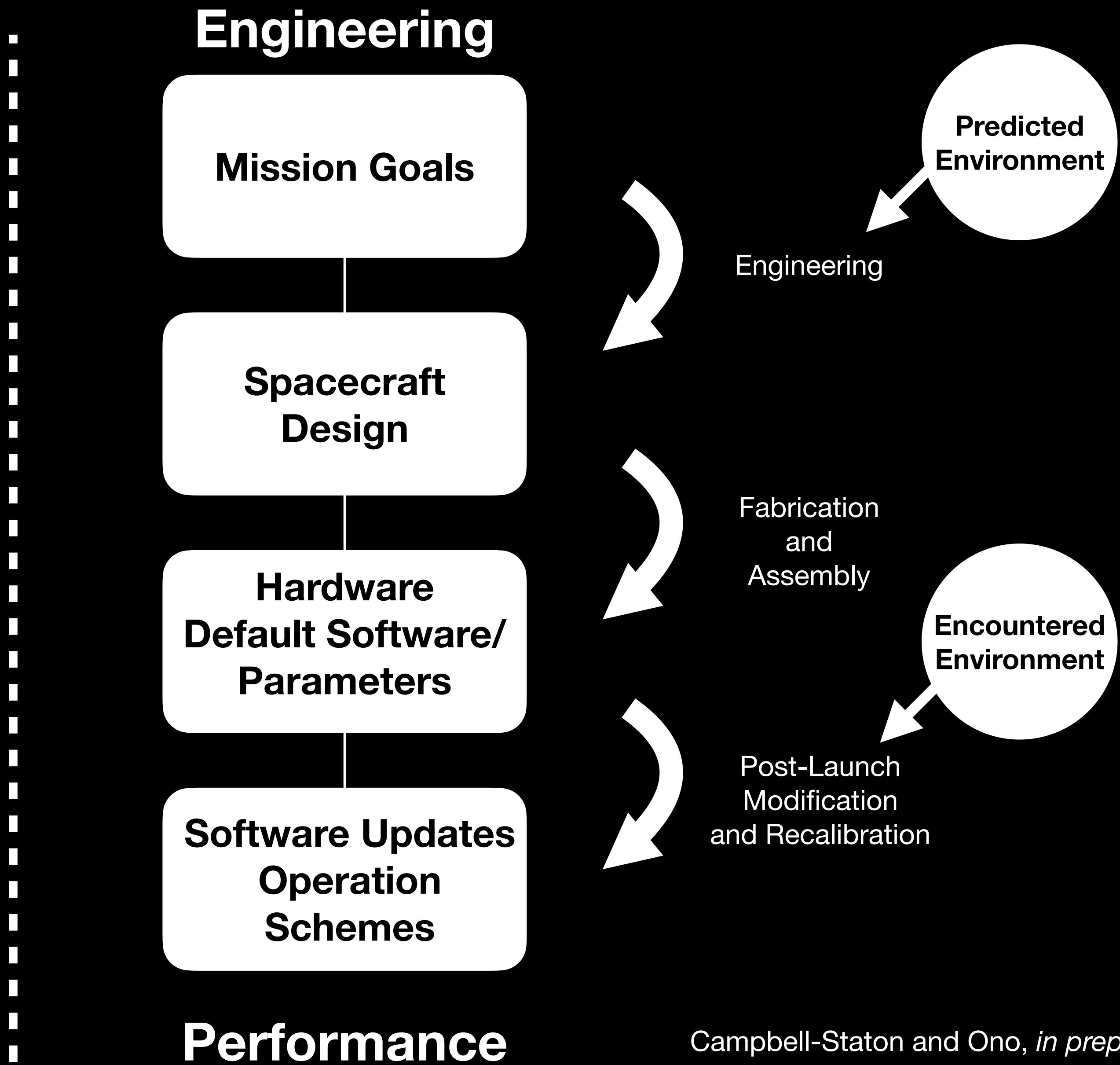
Autonomous Exploratory Units



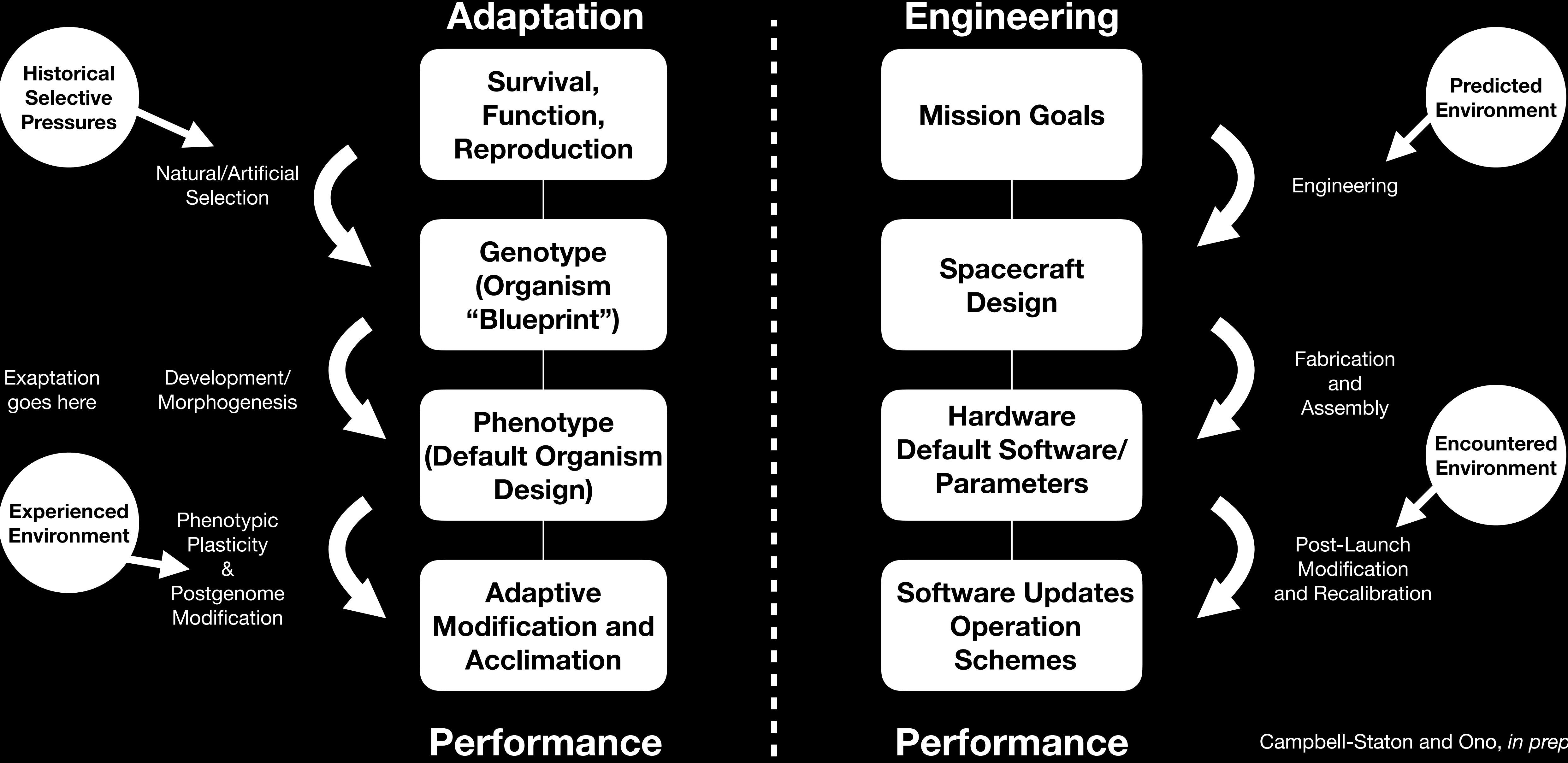
Autonomous Exploratory Units



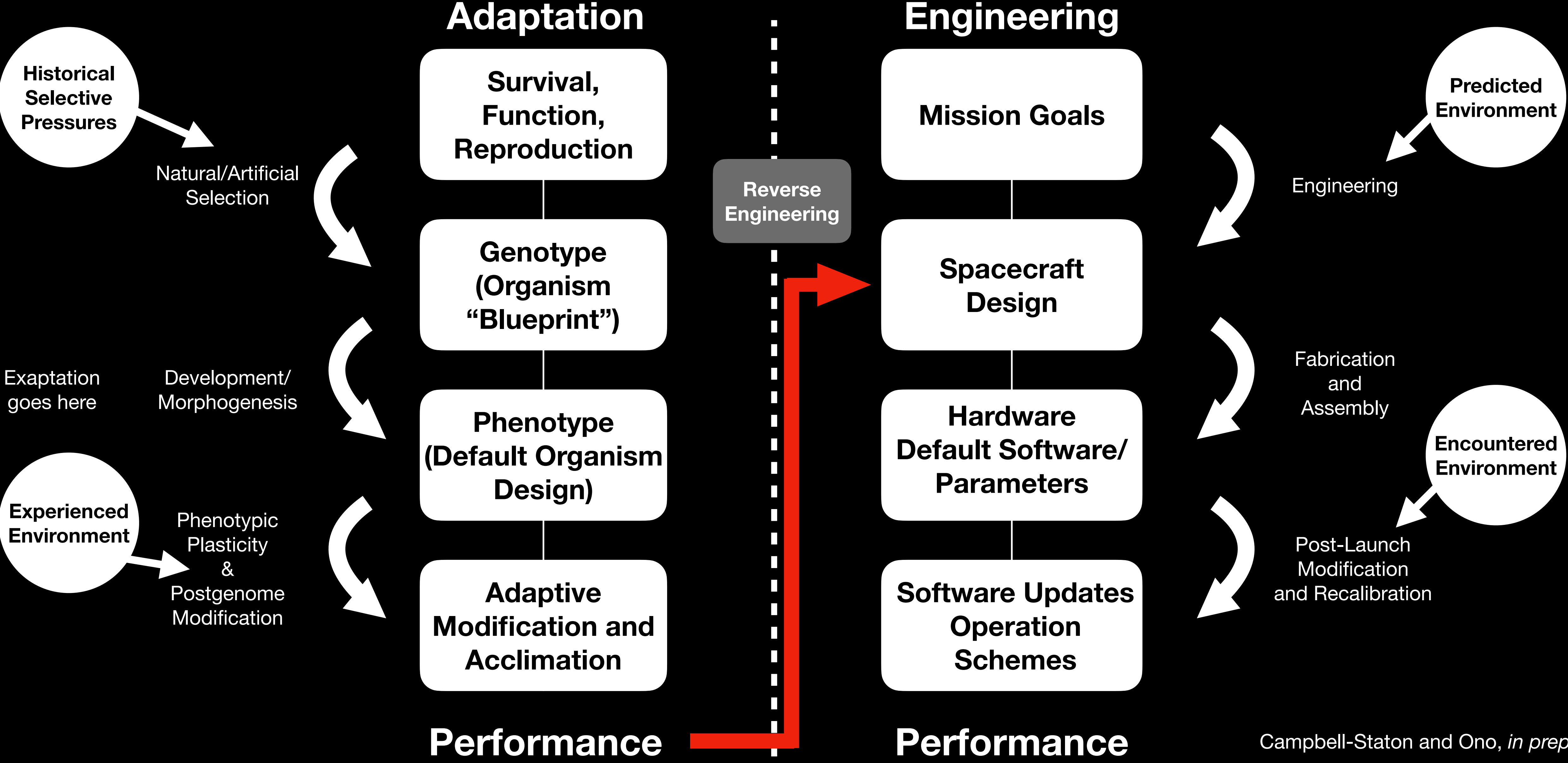
Beyond Biologically-Inspired Engineering



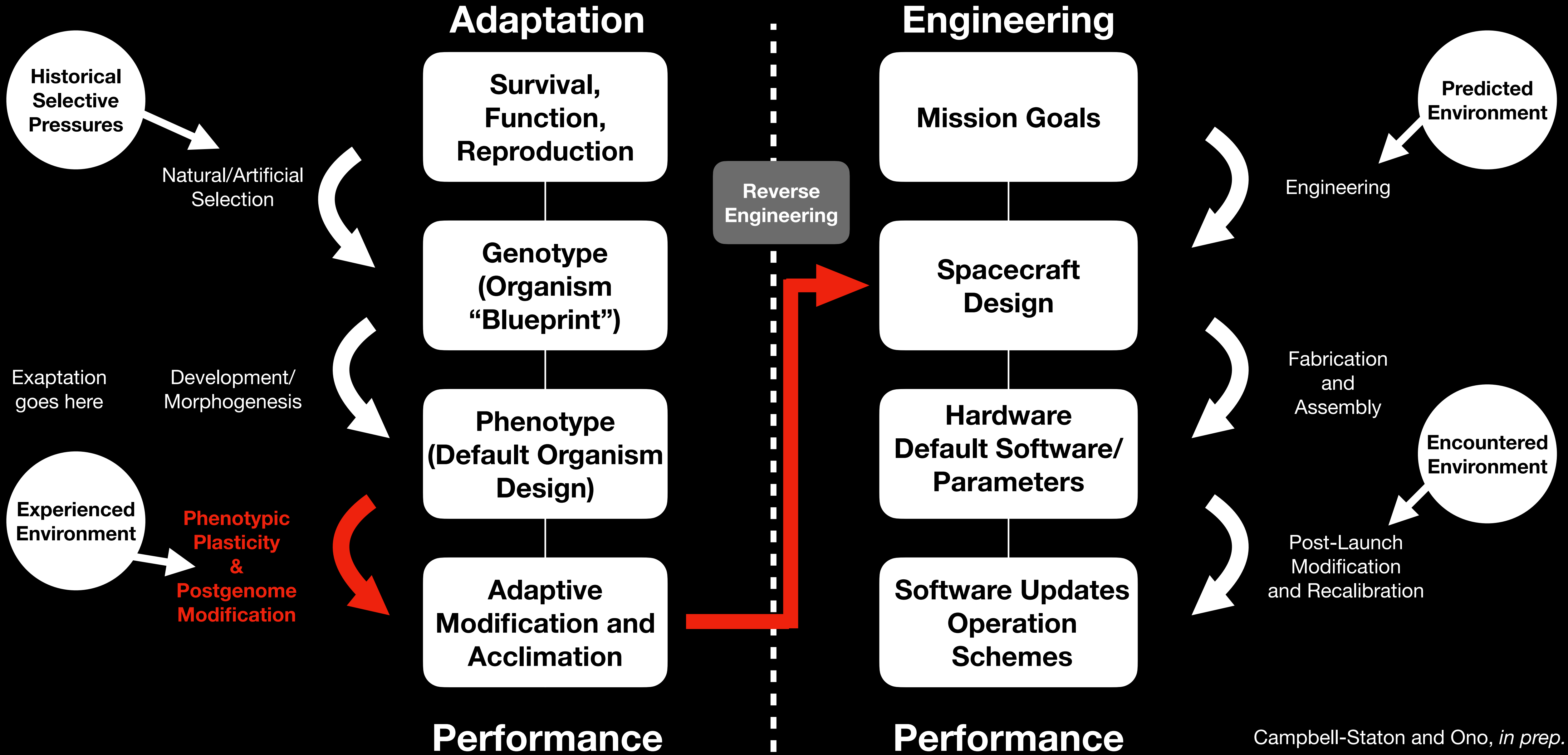
Beyond Biologically-Inspired Engineering



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Beyond Biologically-Inspired Engineering



Phenotypic Plasticity

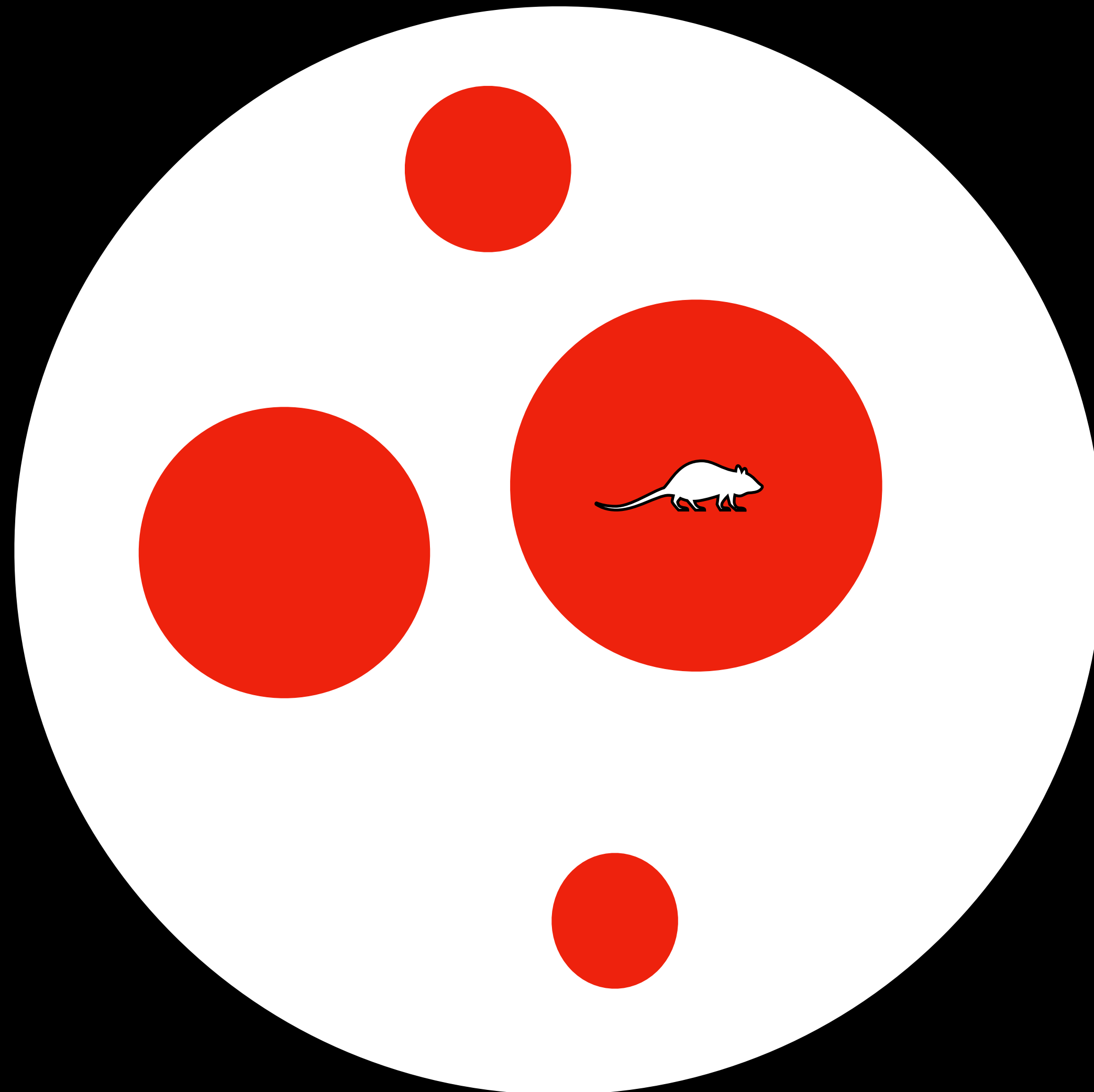
The ability of a single genotype to produce multiple possible phenotypes

- organismal response that allows for rapid adaptive adjustments to base traits
 - Can increase performance within the lifetime of an individual.
 - Informed by real-time environmental signals, without the need for a change in allele frequencies across generations.
-
- Behavioral (Decision Making)
 - Developmental (Functional Design)
 - Locomotor (Movement)

Behavioral Plasticity (Decision Making)

PREDICTED ENVIRONMENT

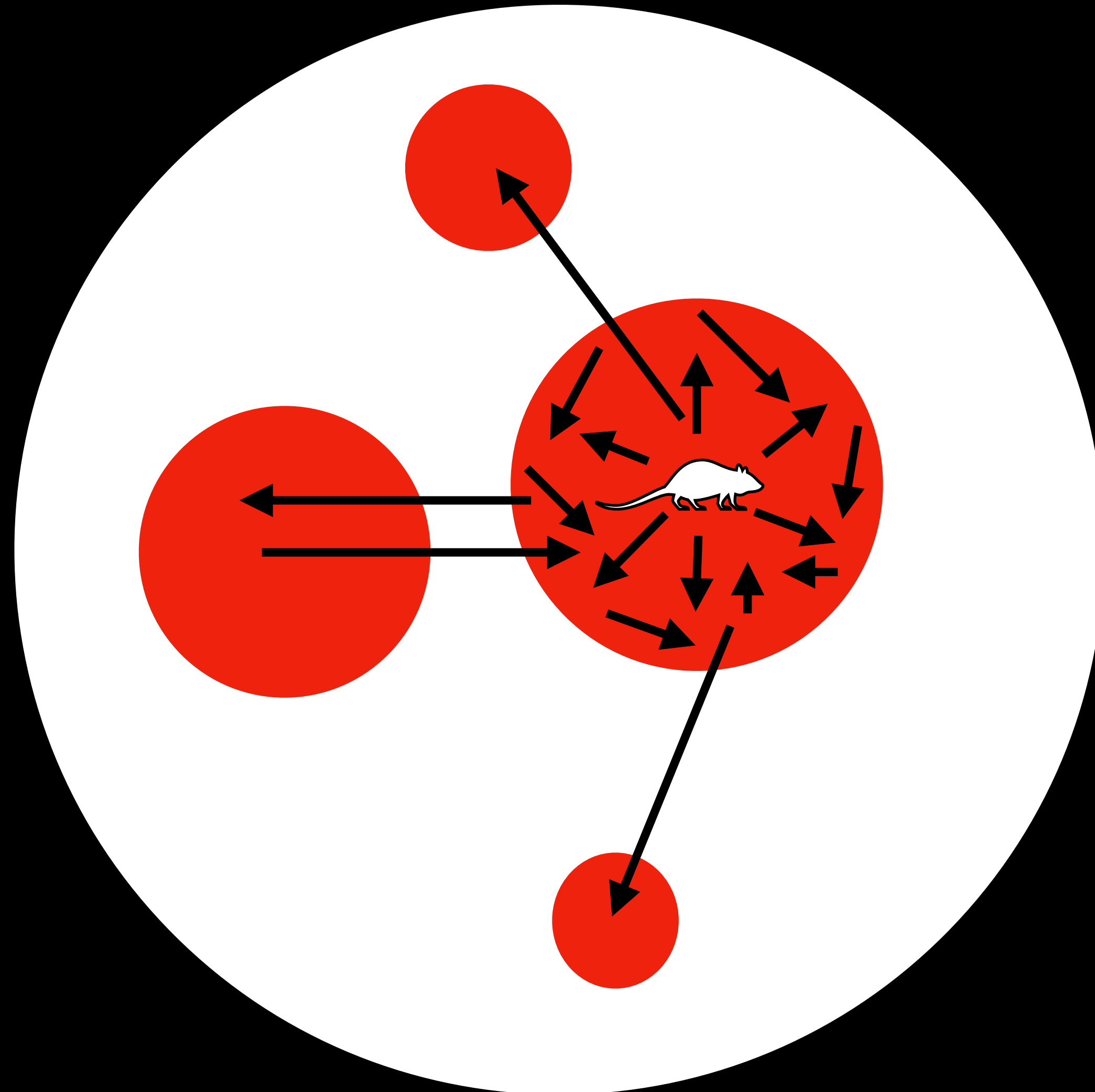
**NOVEL UNFORESEEN
ENVIRONMENT**



Behavioral Plasticity (Decision Making)

BOGERT EFFECT

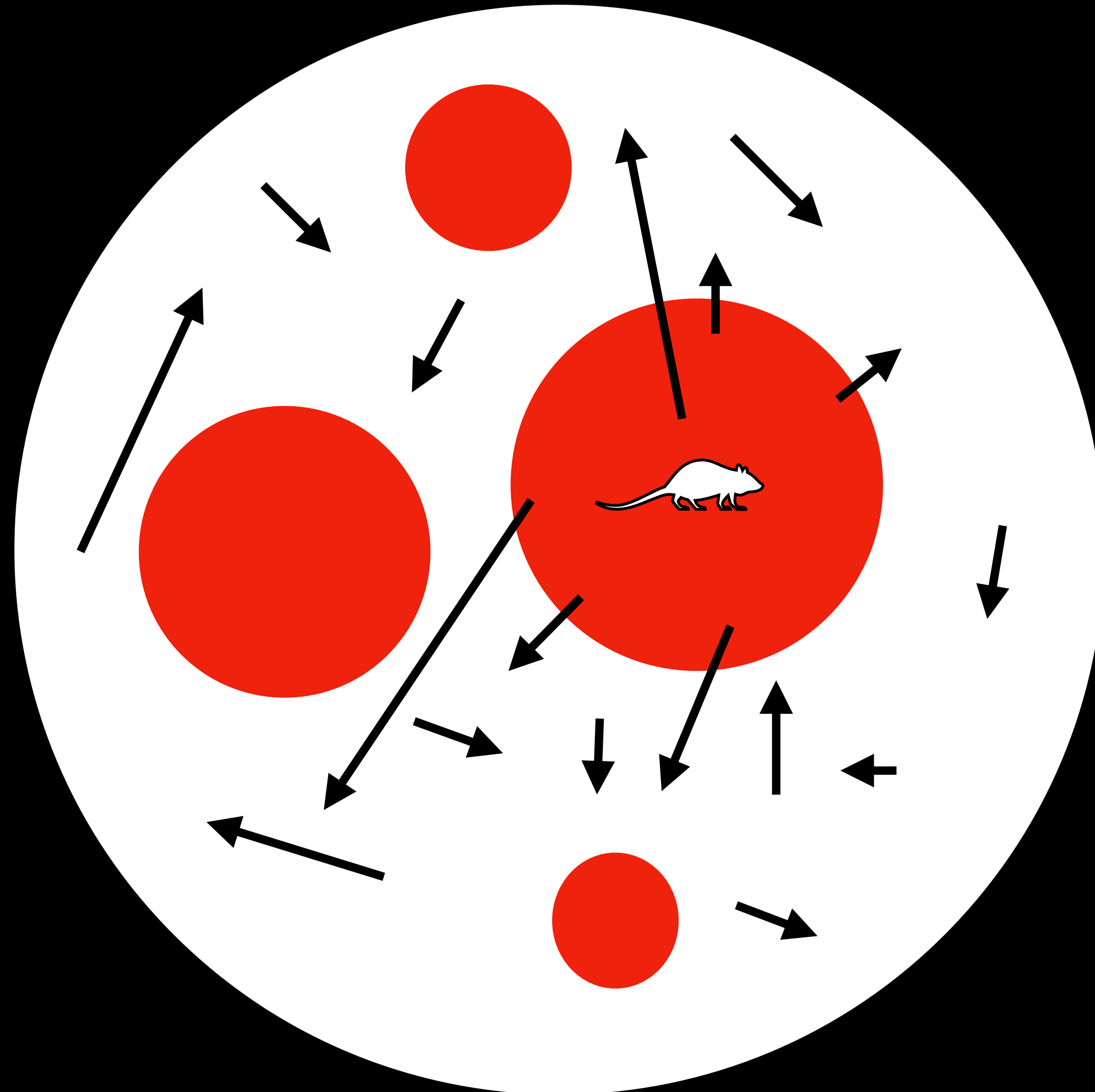
- Behavior can act as a “buffer” against novel selective pressures
- Minimizes the strength of selection (exposure to novel stresses)
- Maintains homeostasis



Behavioral Plasticity (Decision Making)

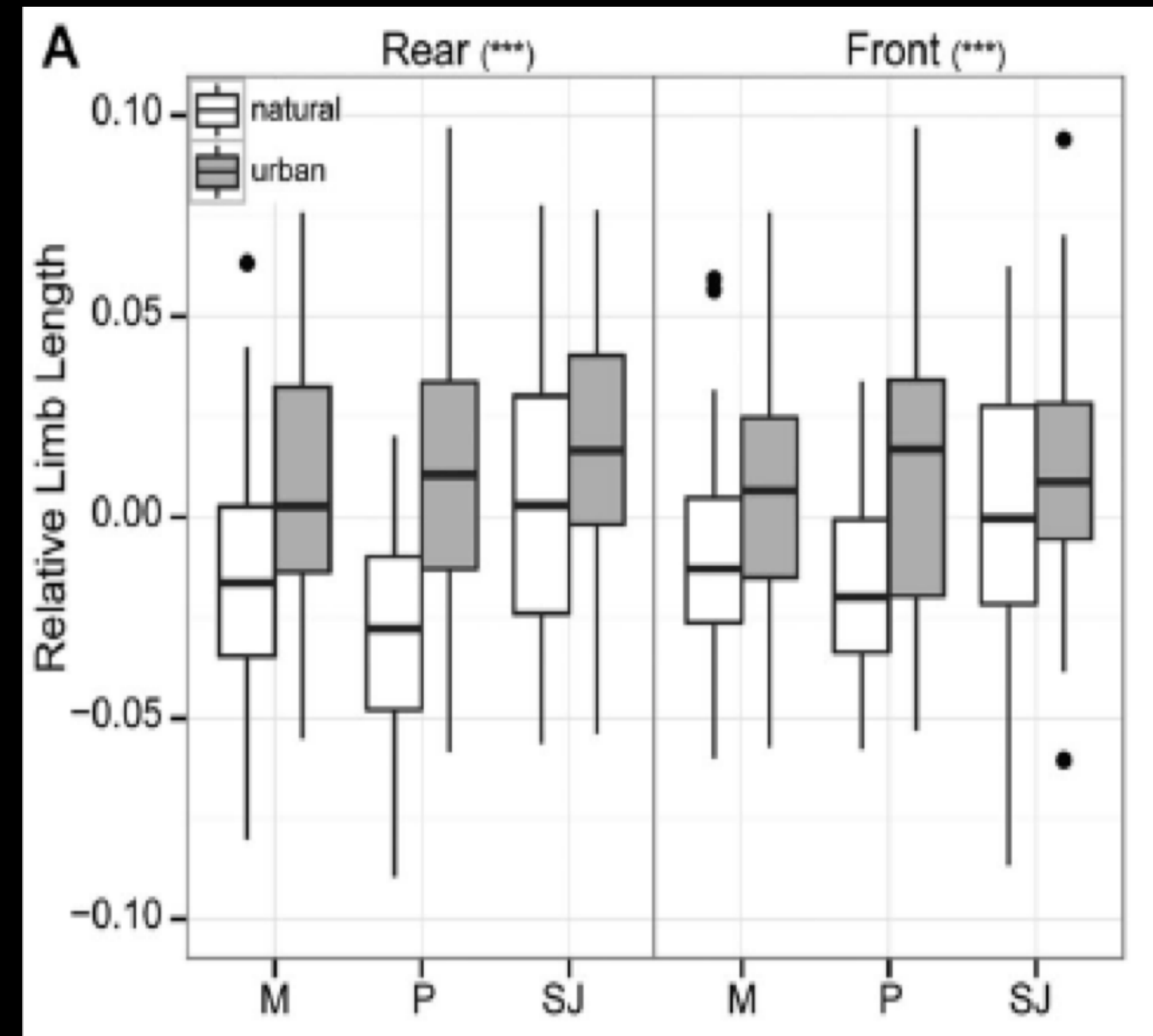
BALDWIN EFFECT

- Behavior can act as an “engine” of evolutionary change
- Increasing the probability of exposure to novel environments/stresses
- Resulting in selection on physiological, morphological, or other aspects of performance



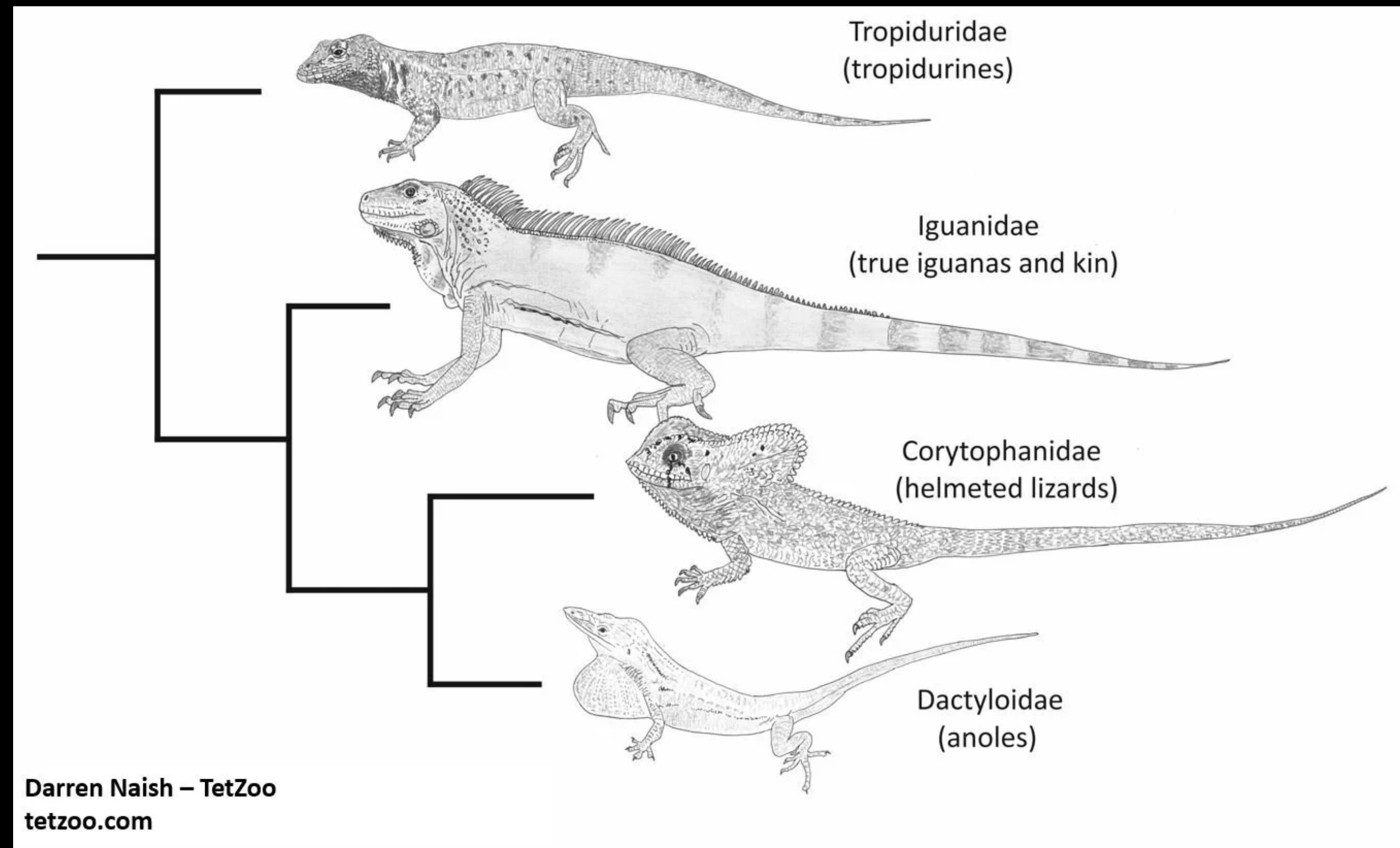
Developmental Plasticity

Changes in Growth or Proportion in Response to Structural Environment



Locomotor Plasticity

Context-Dependent Changes in Movement Patterning and Performance



Locomotor Plasticity

Context-Dependent Changes in Movement Patterning and Performance



Phenotypic Plasticity

The ability of a single genotype to produce multiple possible phenotypes

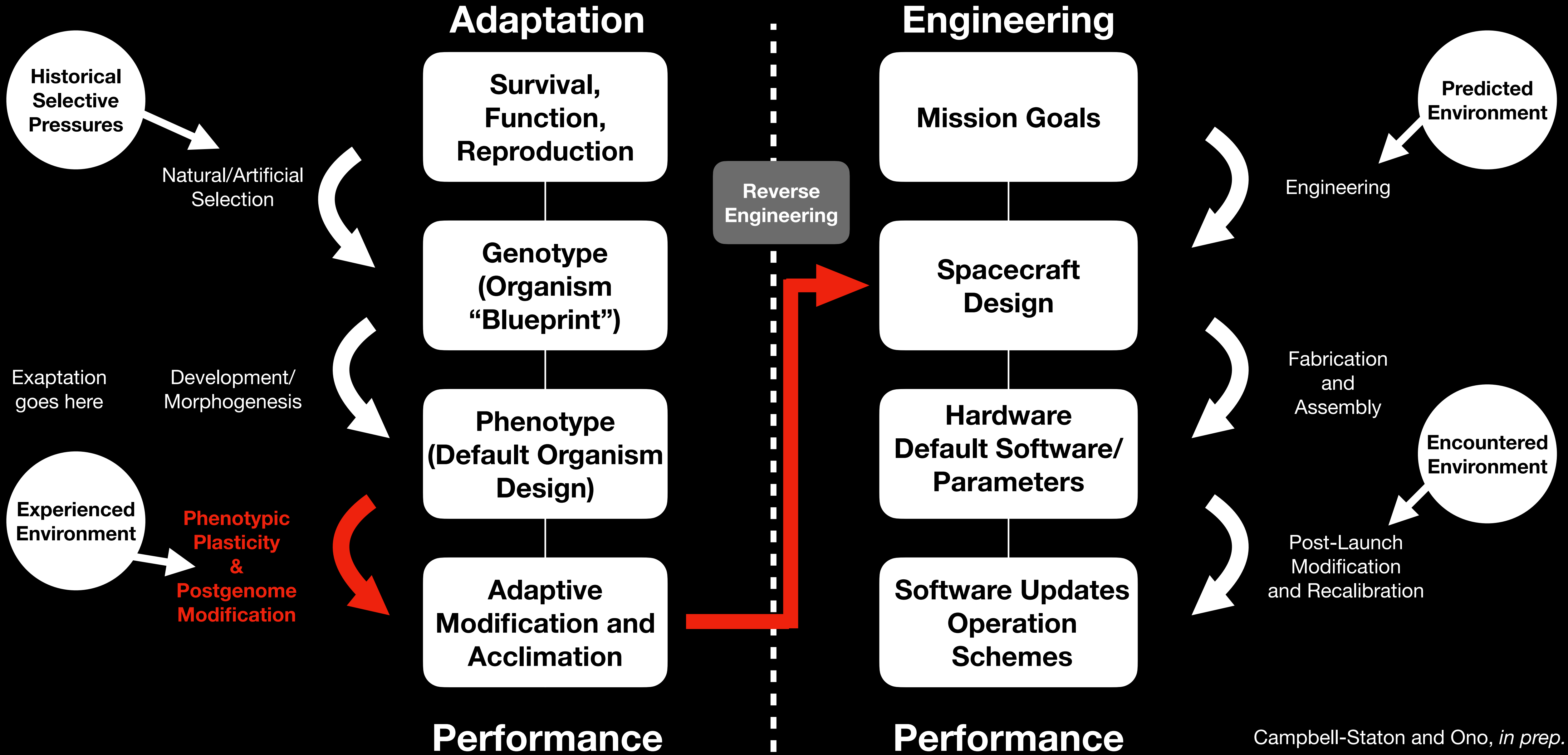
- organismal response that allows for rapid adaptive adjustments to base traits
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- Behavioral (Decision Making)
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TAKE HOME POINT

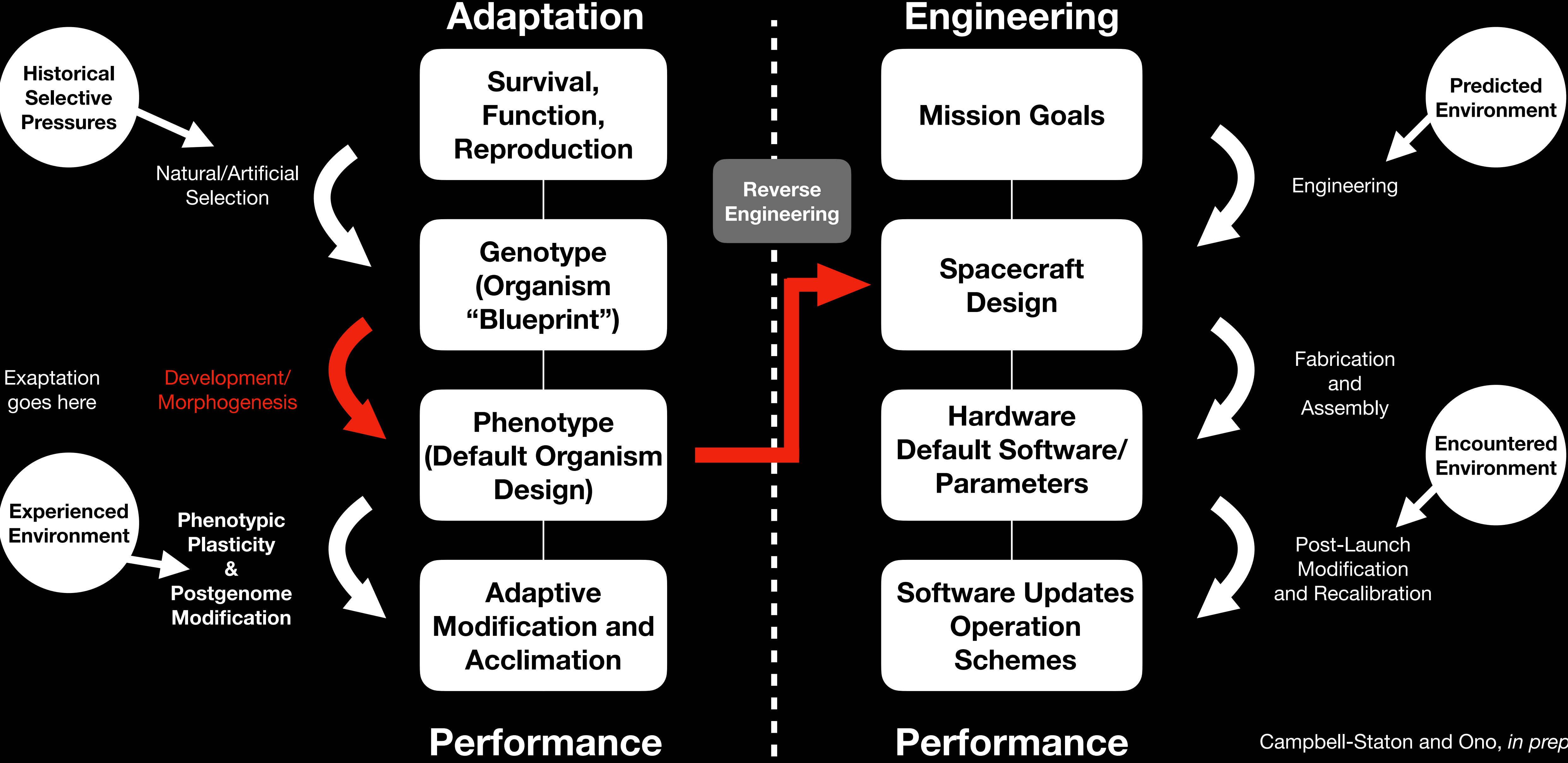
The purposeful engineering of plasticity into autonomous robotic units offers expanded problem-dependent alteration of functionality to complete tasks in the face of unforeseen variables post deployment.

May be particularly useful in hardware design

Beyond Biologically-Inspired Engineering



Beyond Biologically-Inspired Engineering

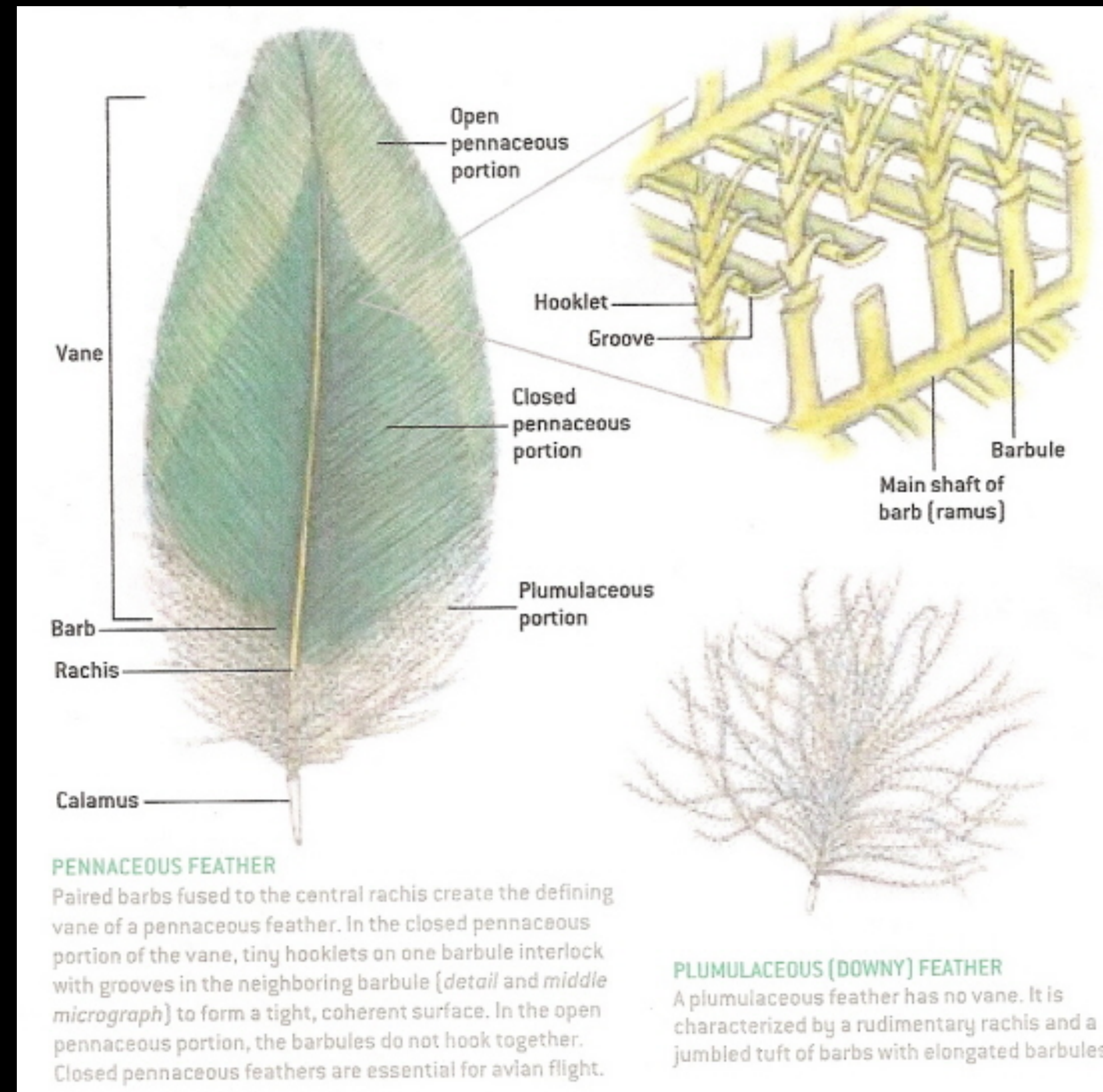


Exaptation

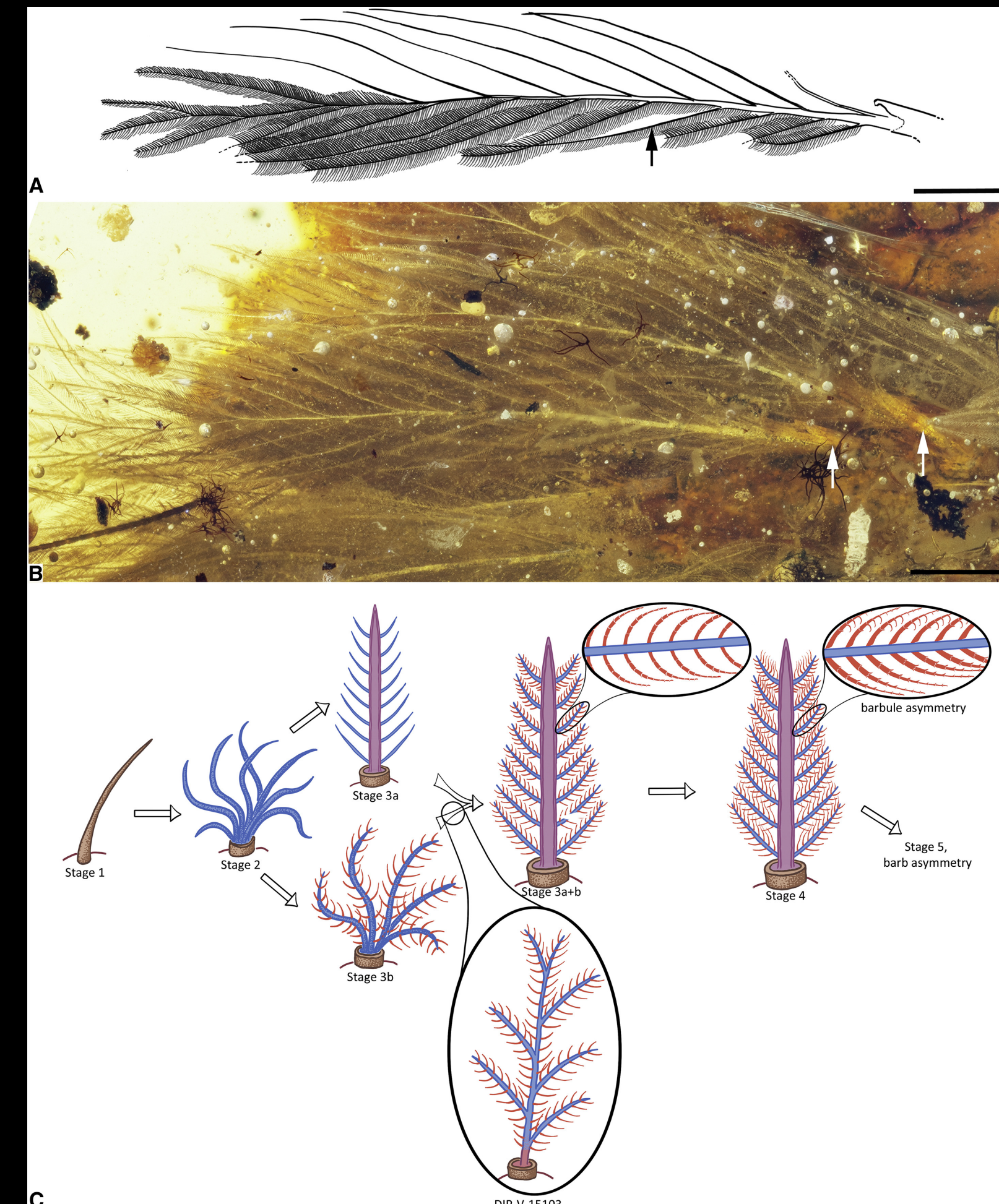
The adaptive repurposing of biological subsystems to perform alternative functions

- Across the tree of life structures and physiological systems are repurposed in the face of novel environmental challenges to perform unintended functions.
- This repurposed system is commonly referred to as an exaptation.

Modern Feather



Ancient Feather (Cretaceous)



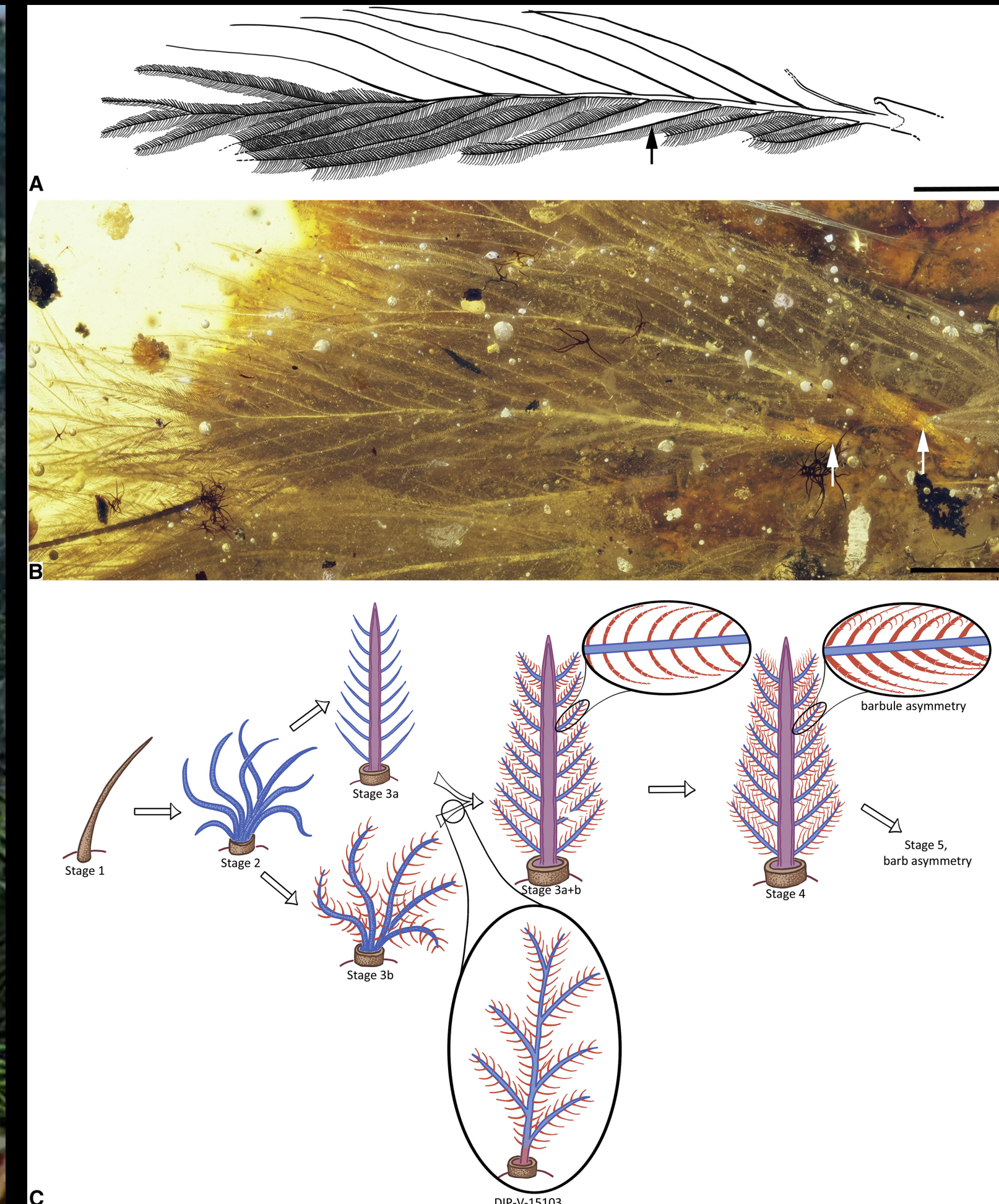
Exaptation

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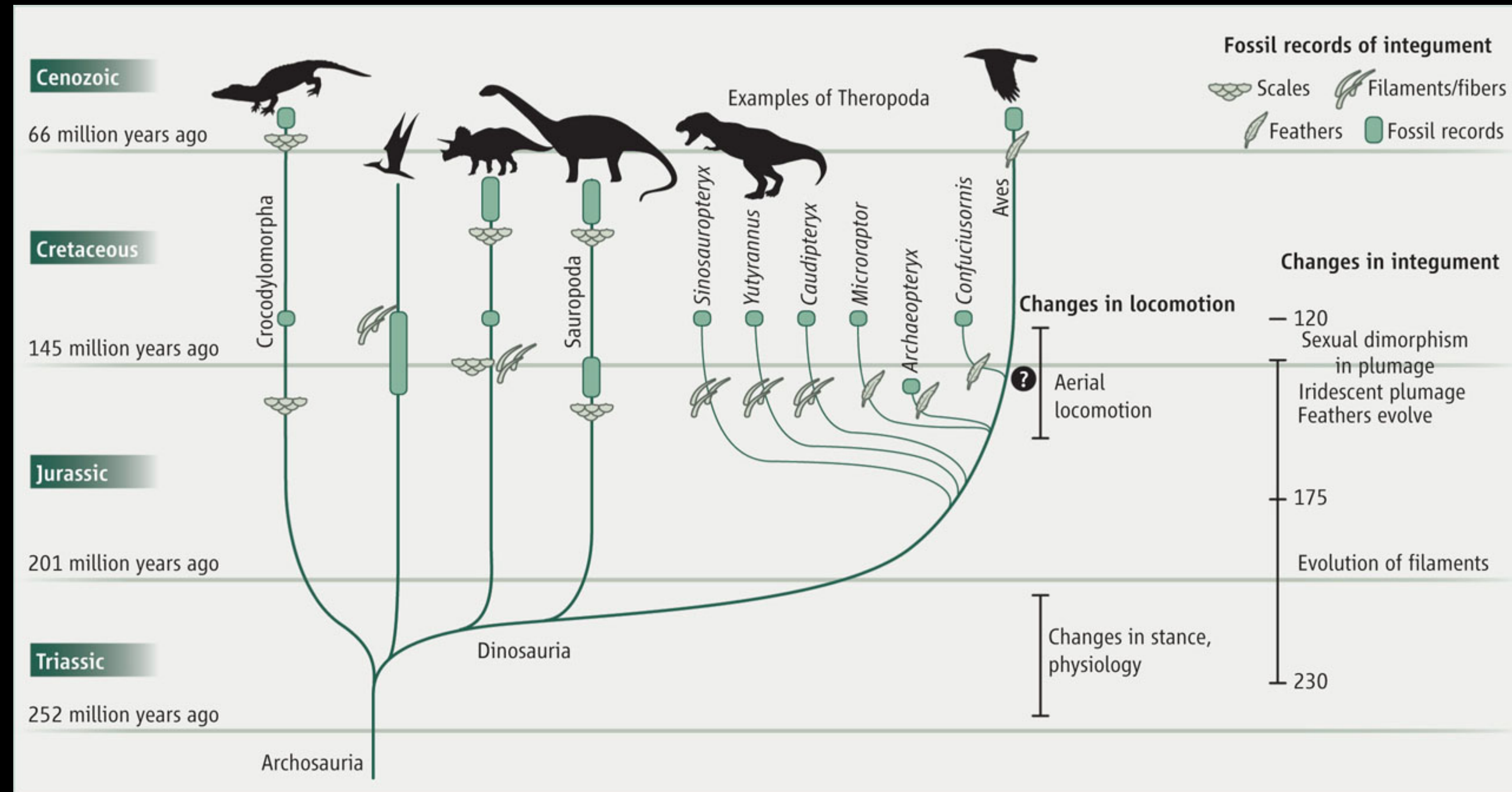
Ancient Feather (Cretaceous)



Exaptation

The adaptive repurposing of biological subsystems to perform alternative functions

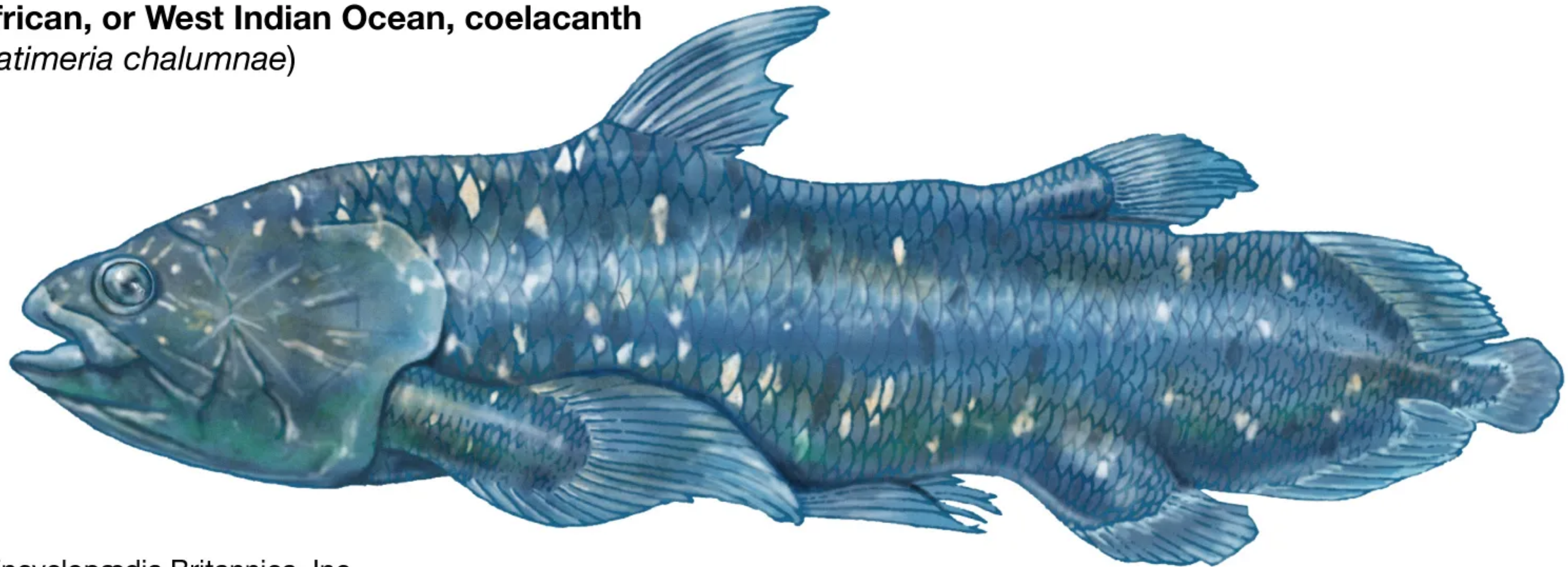
- Feathers likely originally evolved for thermoregulation, then prey capture
- Later coopted and modified in modern birds for flight



Exaptation

The adaptive repurposing of biological subsystems to perform alternative functions

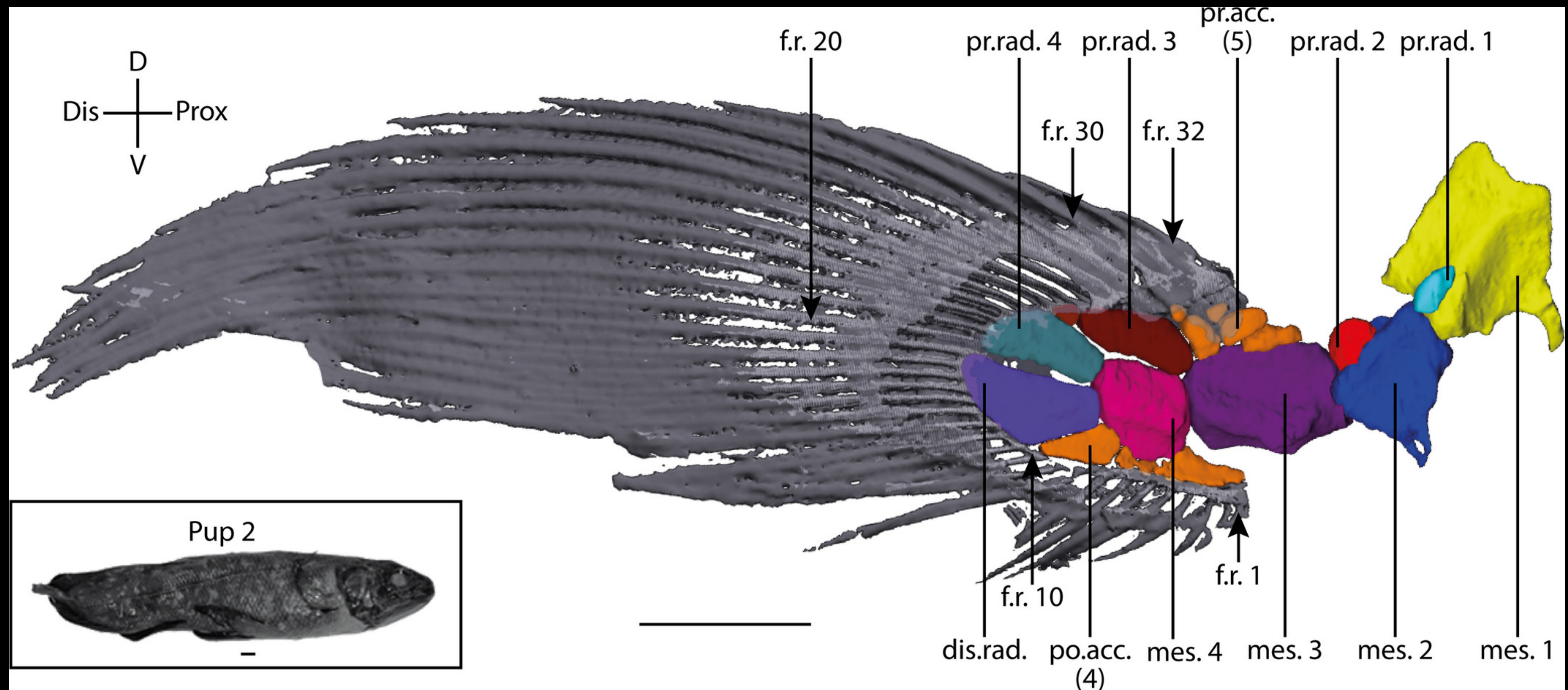
African, or West Indian Ocean, coelacanth
(*Latimeria chalumnae*)



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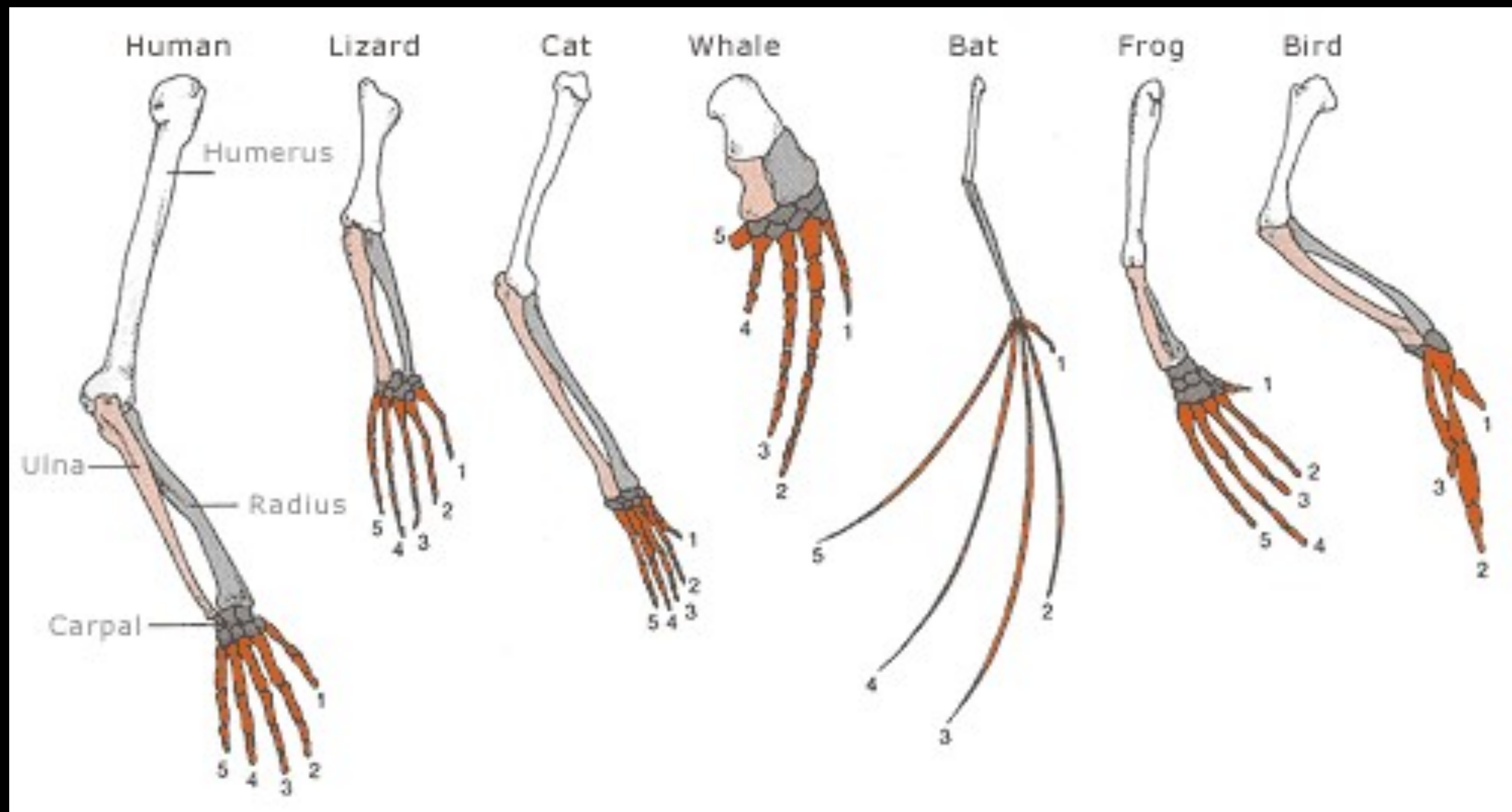
Exaptation

The adaptive repurposing of biological subsystems to perform alternative functions

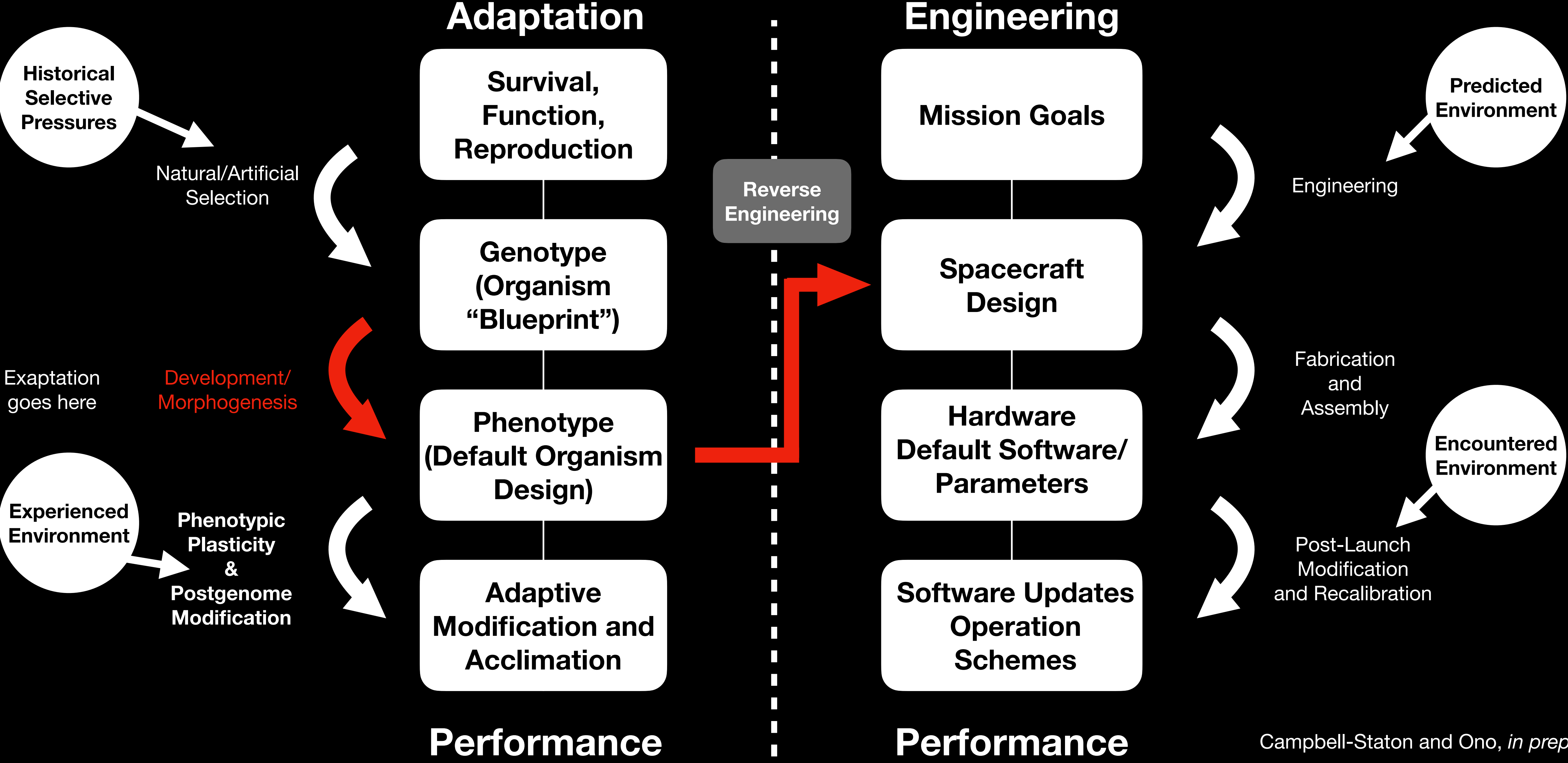


Exaptation

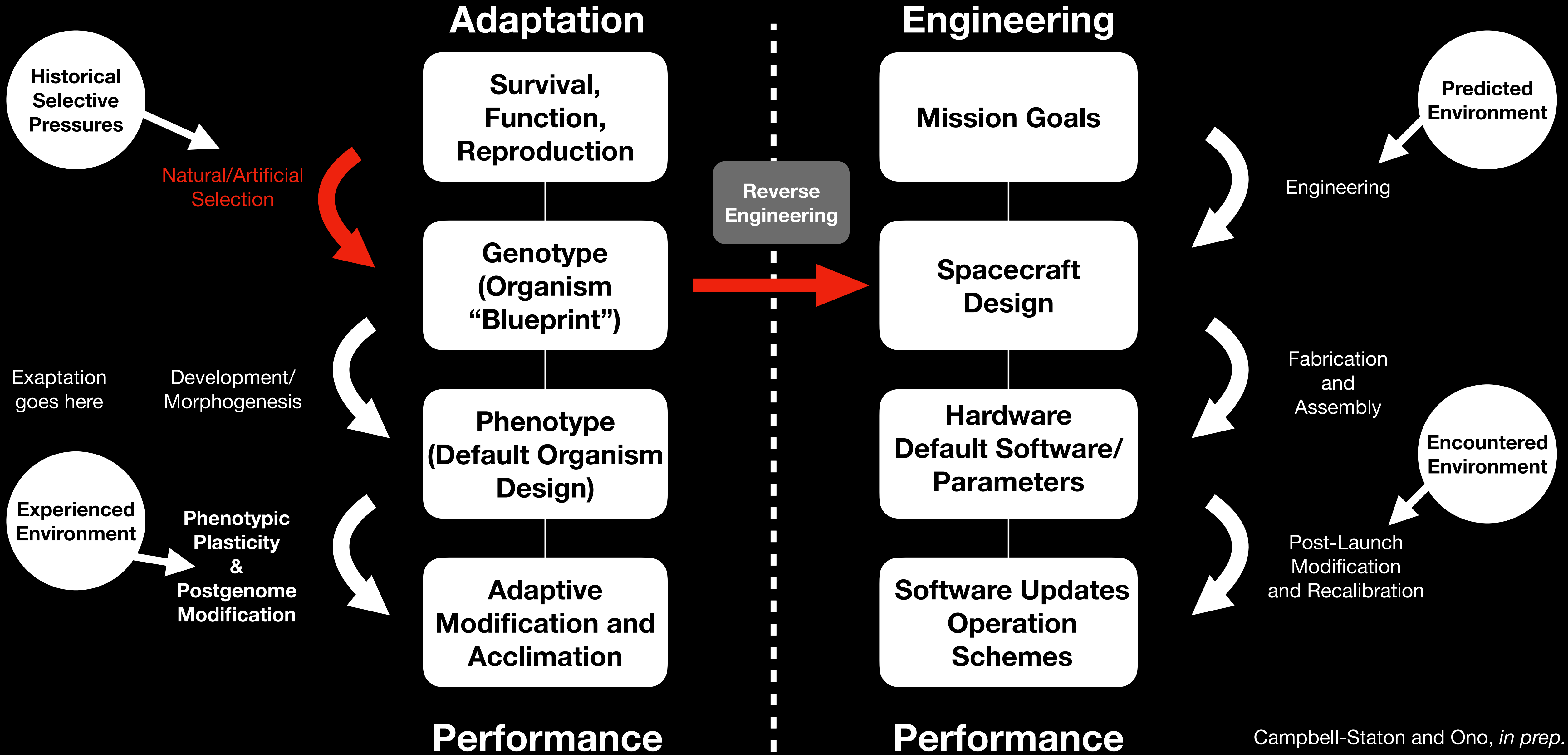
The adaptive repurposing of biological subsystems to perform alternative functions



Beyond Biologically-Inspired Engineering



Beyond Biologically-Inspired Engineering



Exaptation

The adaptive repurposing of biological subsystems to perform alternative functions

TAKE HOME POINT

- Across the tree of life structures and physiological systems are repurposed in the face of novel environmental challenges to perform unintended functions.
- This repurposed system is commonly referred to as an exaptation.

The purposeful engineering hardware/software that can be scavenged/coopted for unrelated functions offers expanded problem-dependent alteration of functionality to complete tasks in the face of unforeseen variables post deployment.

Natural/Artificial Selection

Change in Phenotype/Genotype Frequency within a Generation due to novel stress or resource

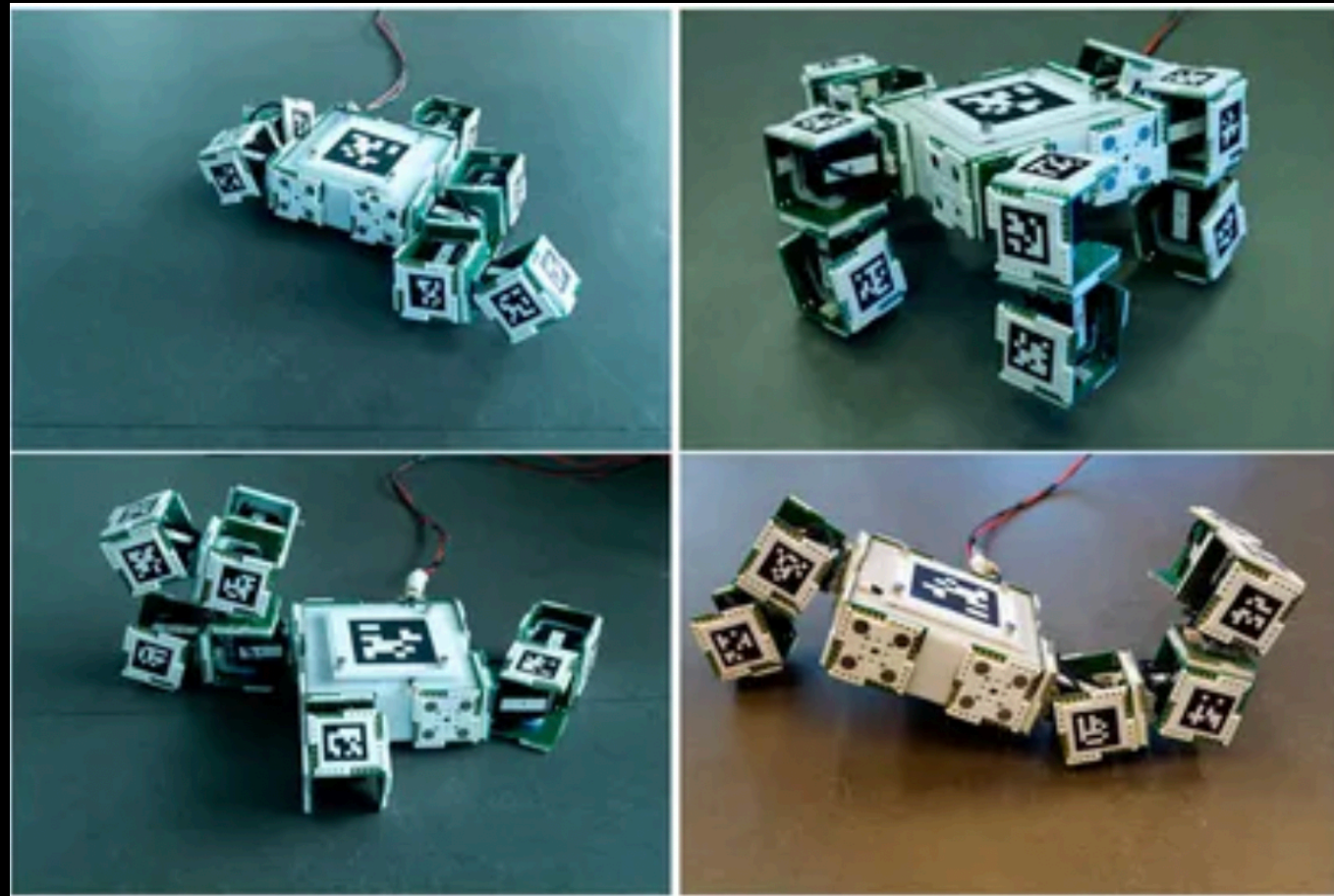
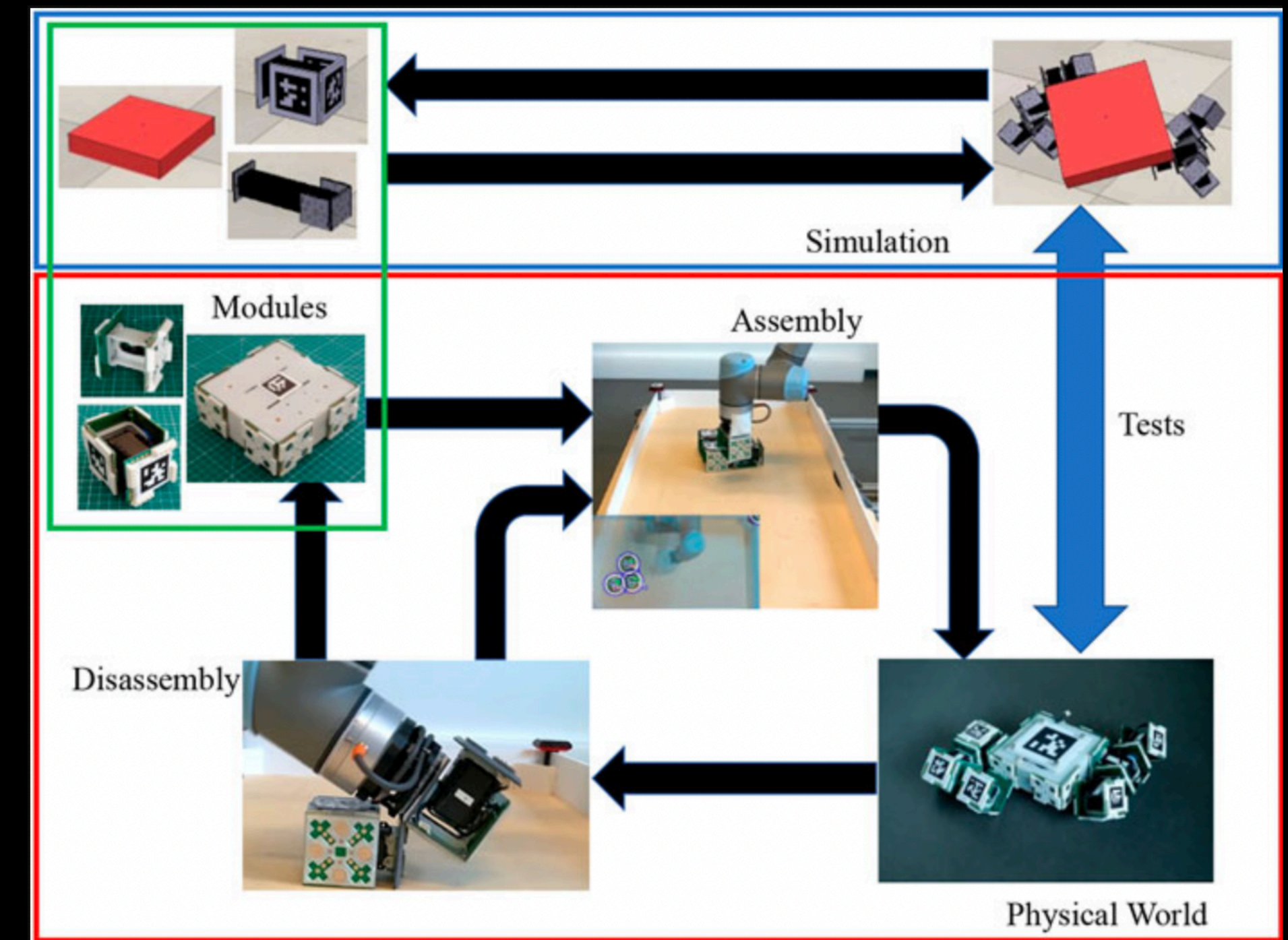
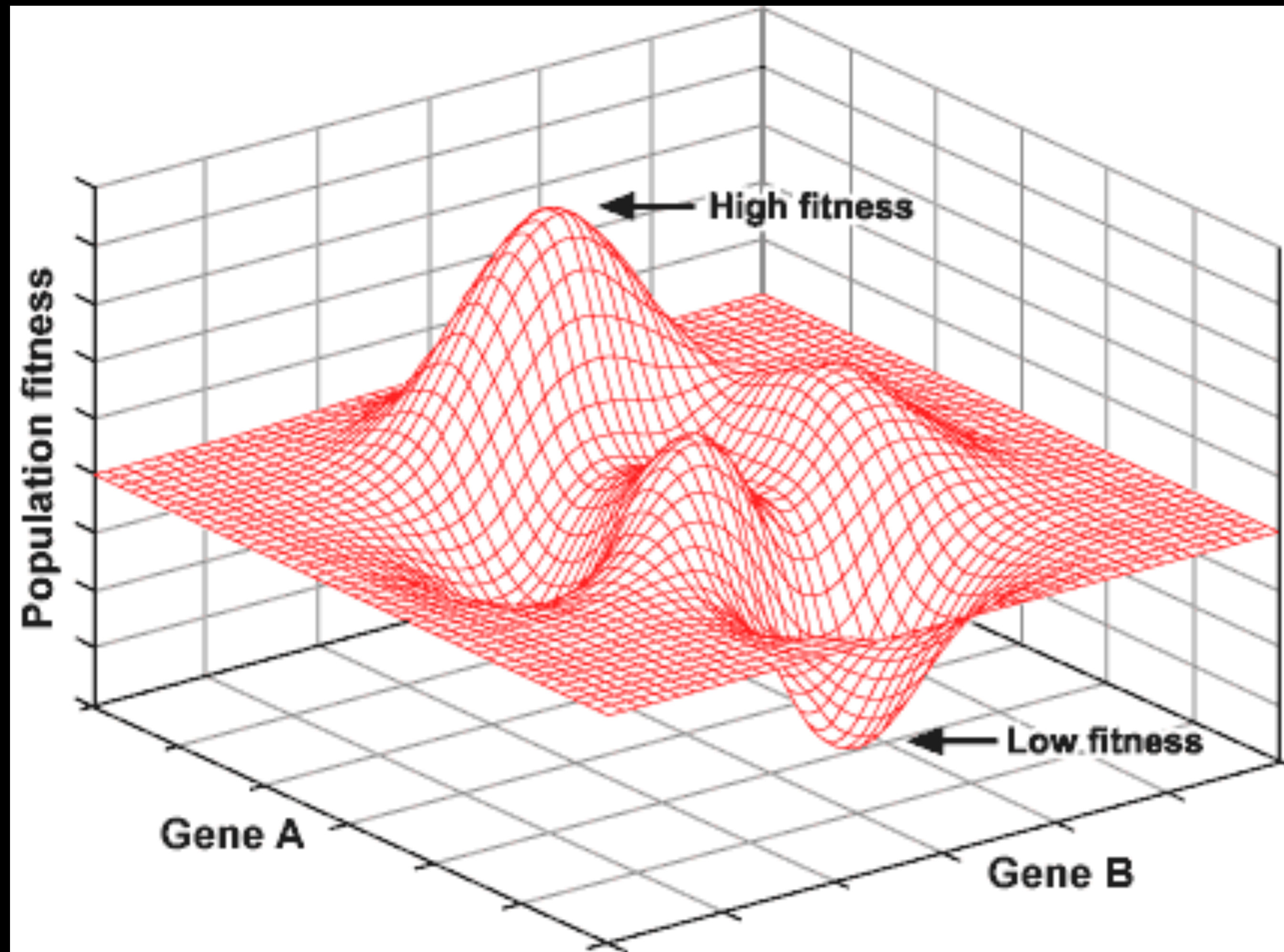


FIGURE 6. Some evolved robots that were manually built with EMERGE modules with the help of the visual guiding tool. The robots are shown with the motor of the modules set at the initial angle in the evaluation, based on the evolved controllers. All robots took under 5 min to assemble.



Adaptive Landscapes

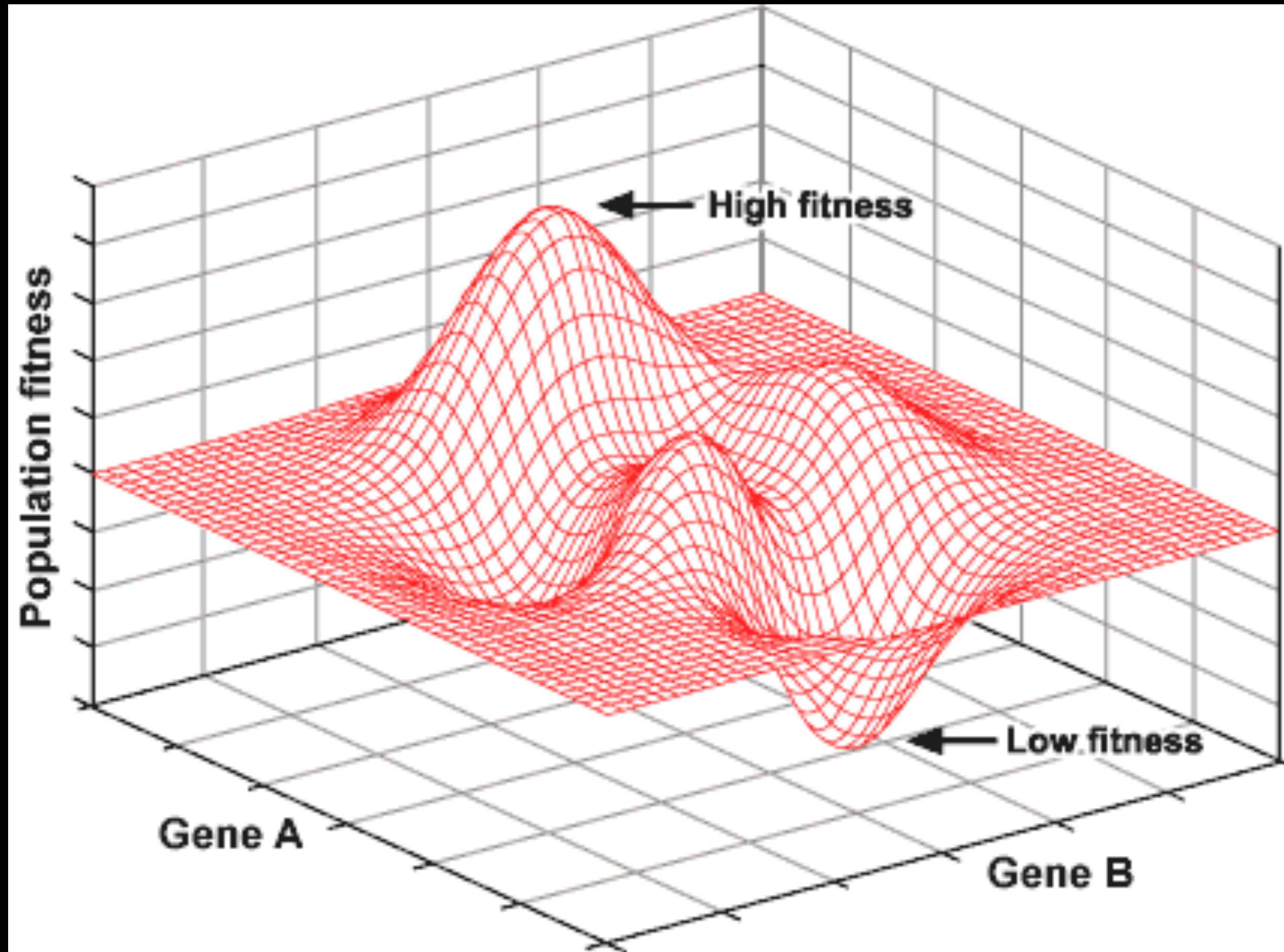
A useful tool for thinking about fate and chance in evolution



- Phenotypic Variation
- Differential Survival Based on Variation
- Heritability

Adaptive Landscapes

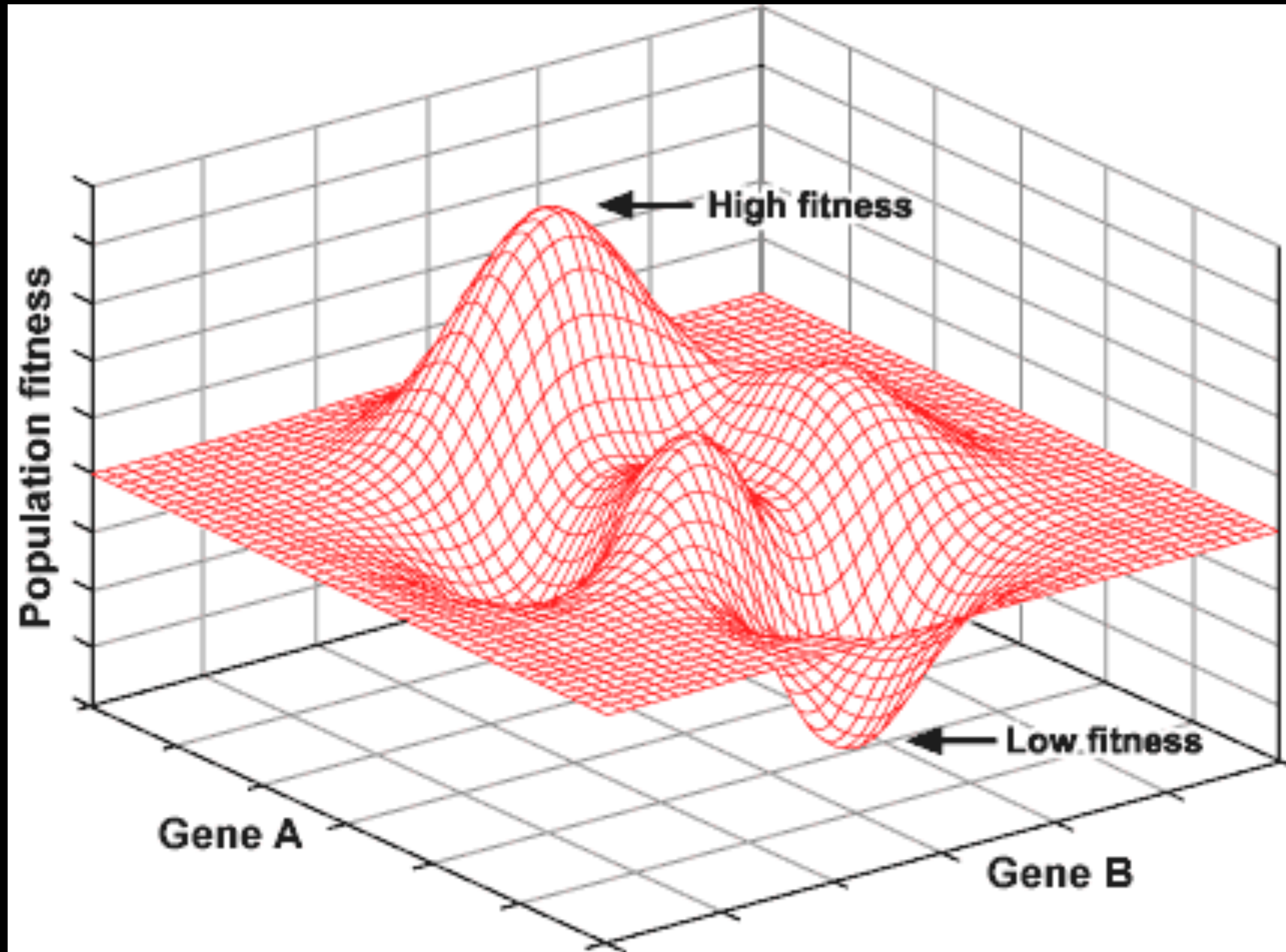
A useful tool for thinking about fate and chance in evolution



- Phenotypic Variation
- Differential Survival Based on Variation
- Heritability
- Modular compositions
- Differential Ability to Successfully Perform a Given Task
- Ability to Quantify Relative Performance
- Ability to recapitulate simulated composition in hardware

Adaptive Landscapes

A useful tool for thinking about fate and chance in evolution



TAKE HOME POINT

Simulations incorporating basic principles of selection can guide modular configuration in a context-specific manner

Ability to gather data on the relevant environmental parameters important for simulation

Beyond Biologically-Inspired Engineering

