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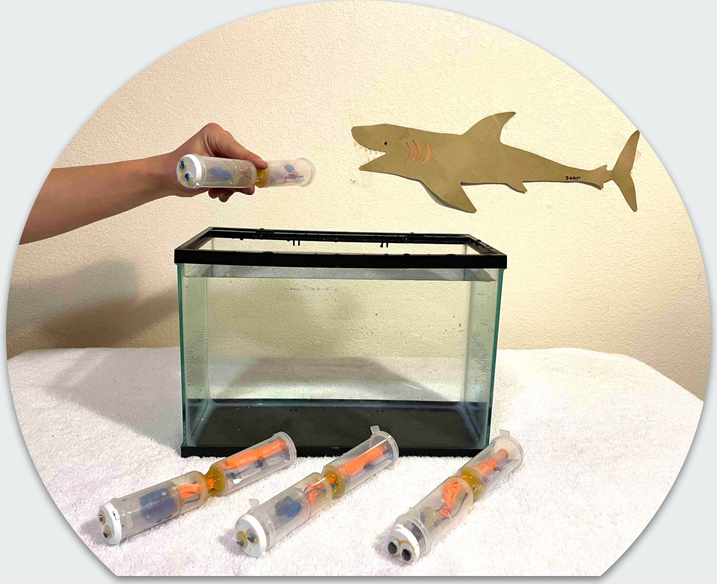


A Comparative Study of Morphological Models from Ancient Marine Worms to the First Fish Inside an Aquarium

Acknowledgements:

This project came together thanks to generous help from my family:

- My brother, for lending me his precision power drill, hack saw, and hot glue gun;
- My dad, for finding me all the vials, tubes and strips from Tap Plastics, and for taking photos of models as I performed experiments underwater;
- My mom, for being the best audience in the world!

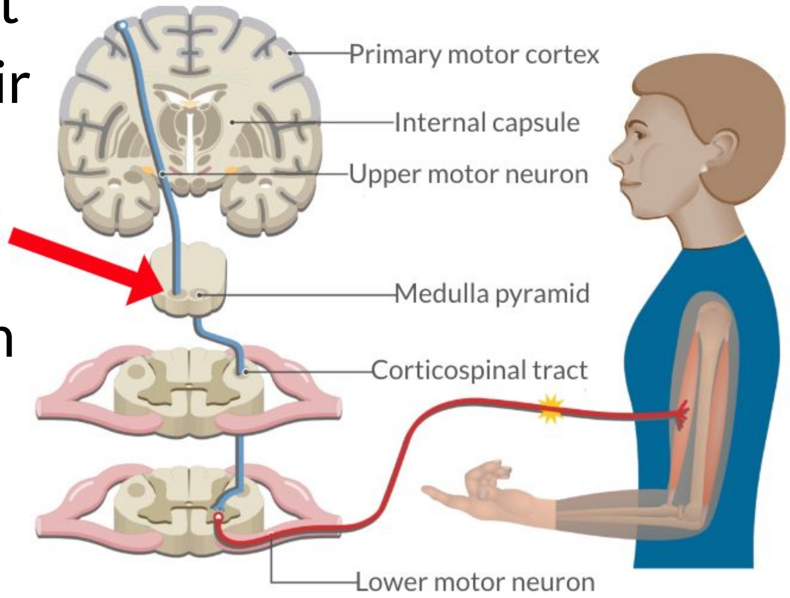
Contralateral Control of the Body by the Brain—*But Why?*

This perennial question has puzzled many who study brain form and function. No one knows *why*.

The **corticospinal tracts** connect the brain to the spinal cord. Their nerve tracts are ***decussated***, or crisscrossed in the form of an ***X***.

All vertebrates have decussation in their corticospinal tracts.

Why is that?



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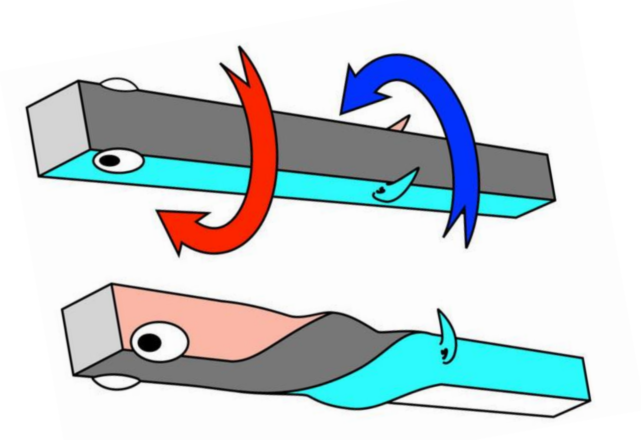
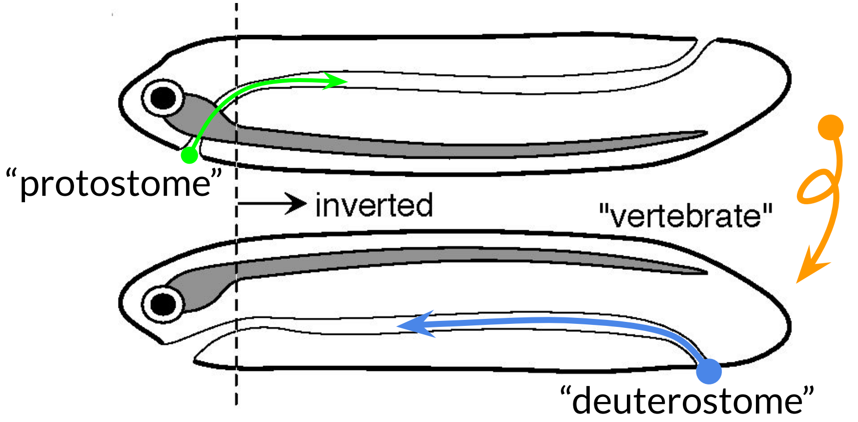
Two Competing Hypotheses

Two leading theories from recent research: **Axial Twist Theory** and **Somatic Twist Theory**, have testable hypotheses for how decussation occurs as a by-product of **dorsoventral inversion**.



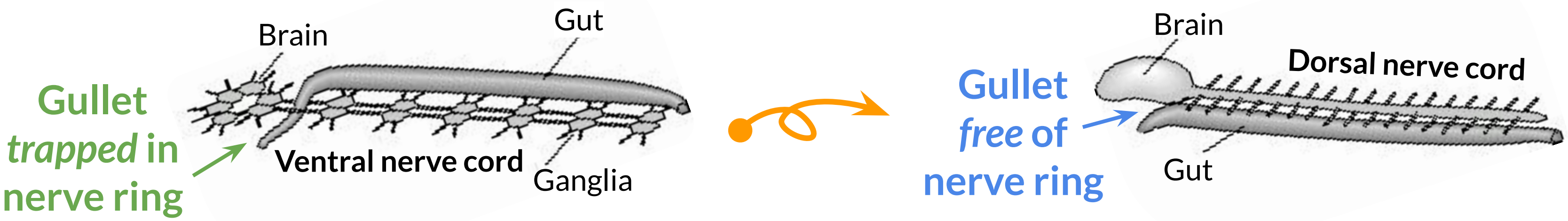
(A) **Axial Twist** (de Lussanet & Osse, 2012): one 90° turn & two 90° twists.



(B) **Somatic Twist** (Kinsbourne, 2013): one 180° twist.

Dorsoventral Inversion

In 1822, a French Zoologist, Geoffroy St. Hilaire, dissected a crayfish and compared it with the vertebrate body plan:



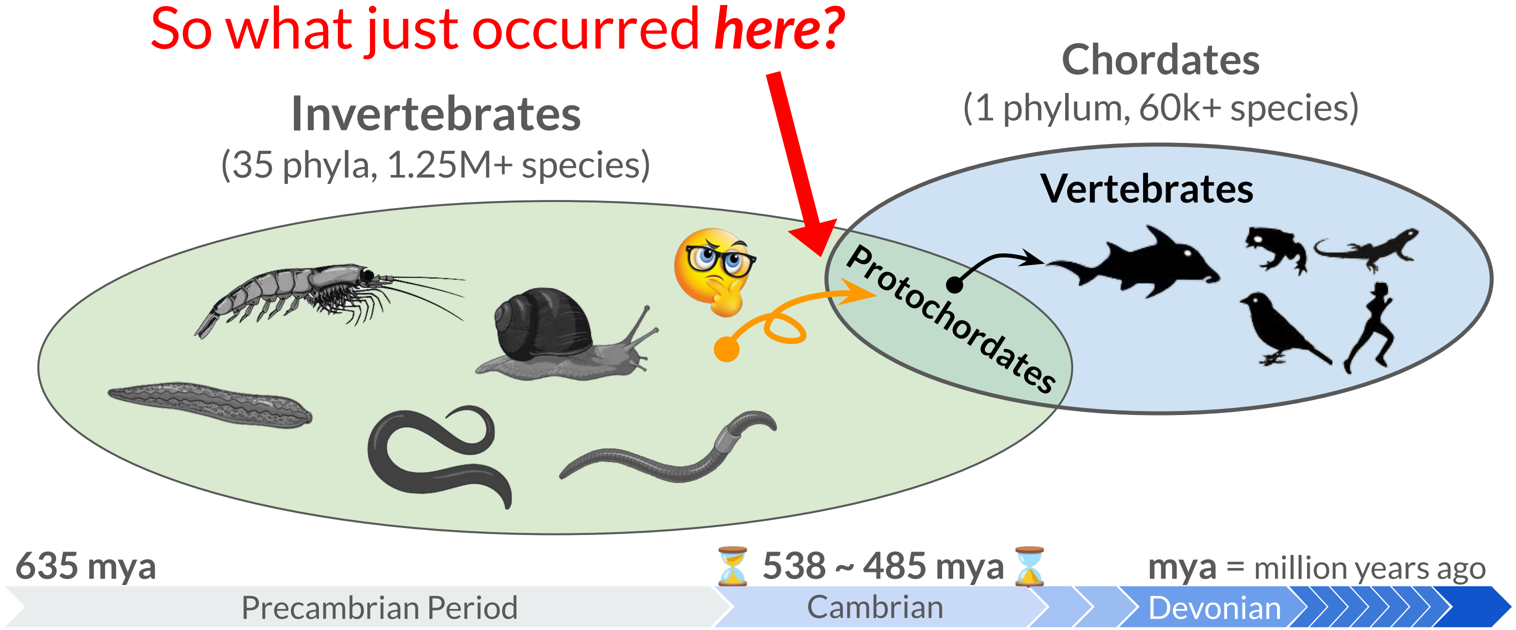
Invertebrate Body Plan

Vertebrate Body Plan

St. Hilaire noted that when the crayfish was turned upside down, its nerve cord is now above the digestive tract, as they are in chordates and vertebrates. In other words, the ventral half of arthropods, which are invertebrates, is *homologous* with the dorsal half of vertebrates.

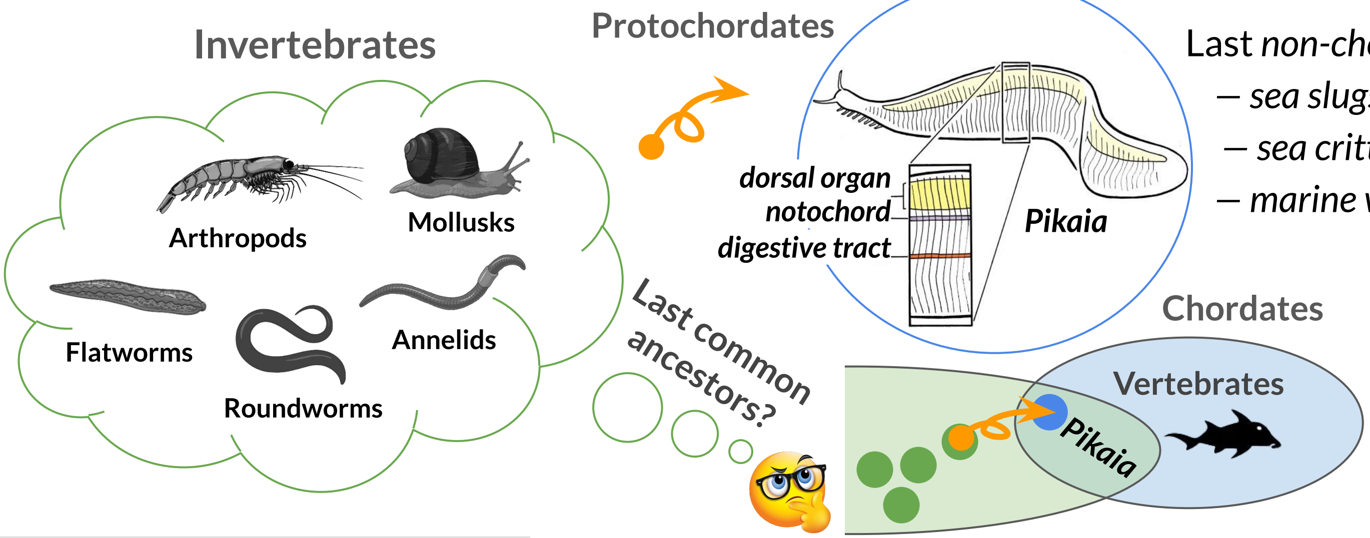
Evolutionary Biology Offers A Clue

All vertebrates have decussation. However, no such contralateral arrangement can be found in any of the other 35 invertebrate phyla.



Scope of Empirical Study

To evaluate ***two competing hypotheses*** that try to explain decussation in chordates & vertebrates, and explore **twist theories** in the context of ancient marine worms and a protochordate: ***Pikaia***, the *first fish*.



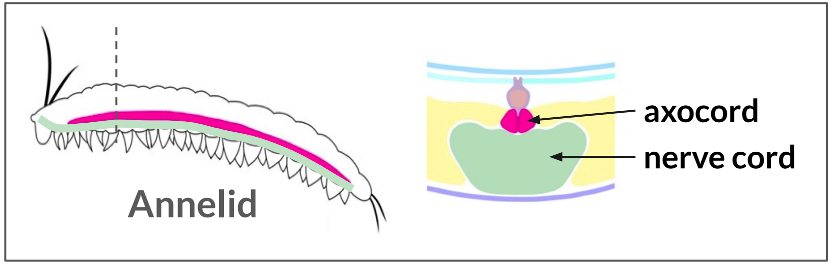
Last *non-chordate* ancestors?

– *sea slugs?*
– *sea critters?*
– *marine worms?*

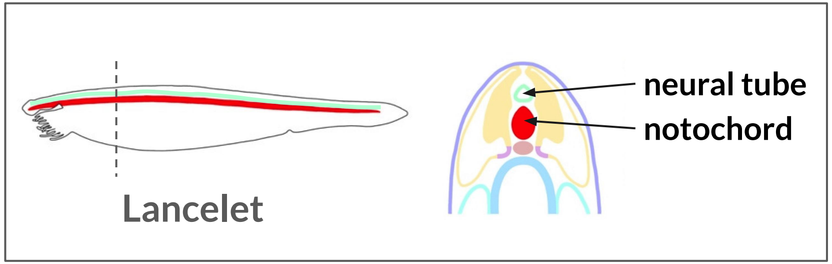
Morphological Models: A Comparative Study

I built morphological models to test competing twist theories within a controlled **aquarium** environment.

I chose the **annelid** as reference model for ancient marine worms, who last shared a common ancestor with the **lancelet**, the closest living proxy of *Pikaia*.



(a) **Annelid** Reference Model & Body Plan.

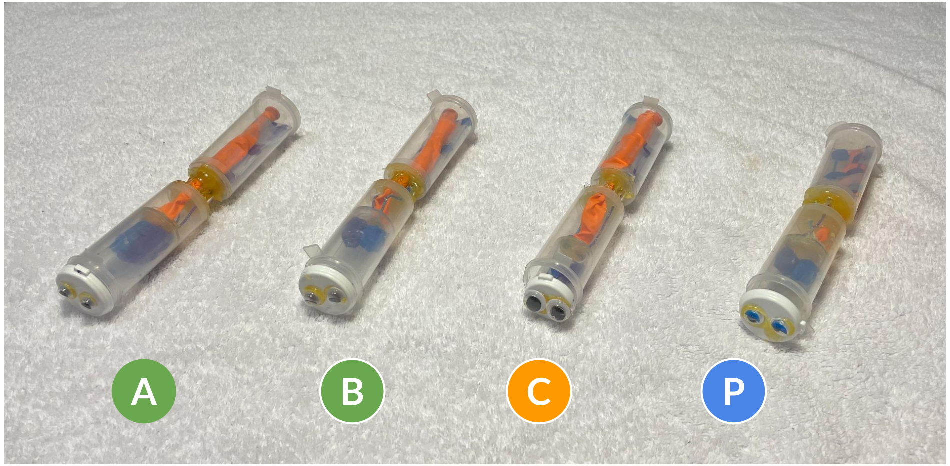


(b) **Lancelet** Reference Model & Body Plan.

Constructing Twistable Body Plan Structures

I assembled plastic tubes & vials, glued together a twistable body plan structure. I made model **P** for Pikaia, and marine worm models: **A**, **B**, and **C**, using different configurations of oropharynx and nerve cords.

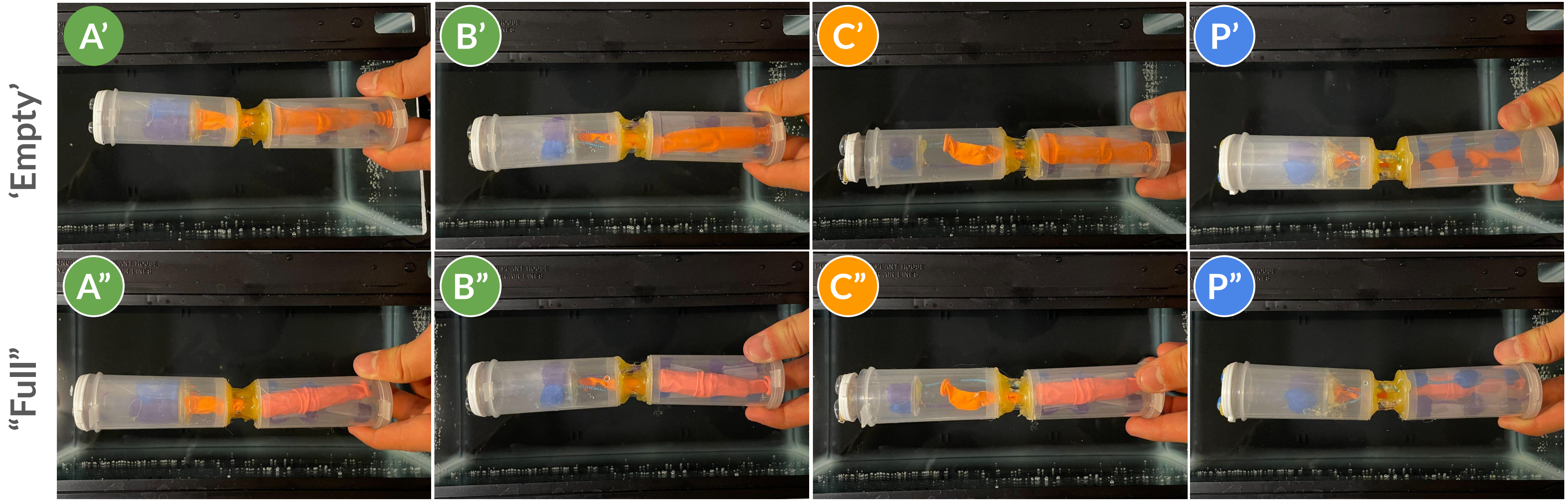
(a) Materials for Model Construction.



(b) Twistable Body Plan Structures: **A**, **B**, **C** & **P**.

Model Testing: Buoyancy Tests Inside an Aquarium

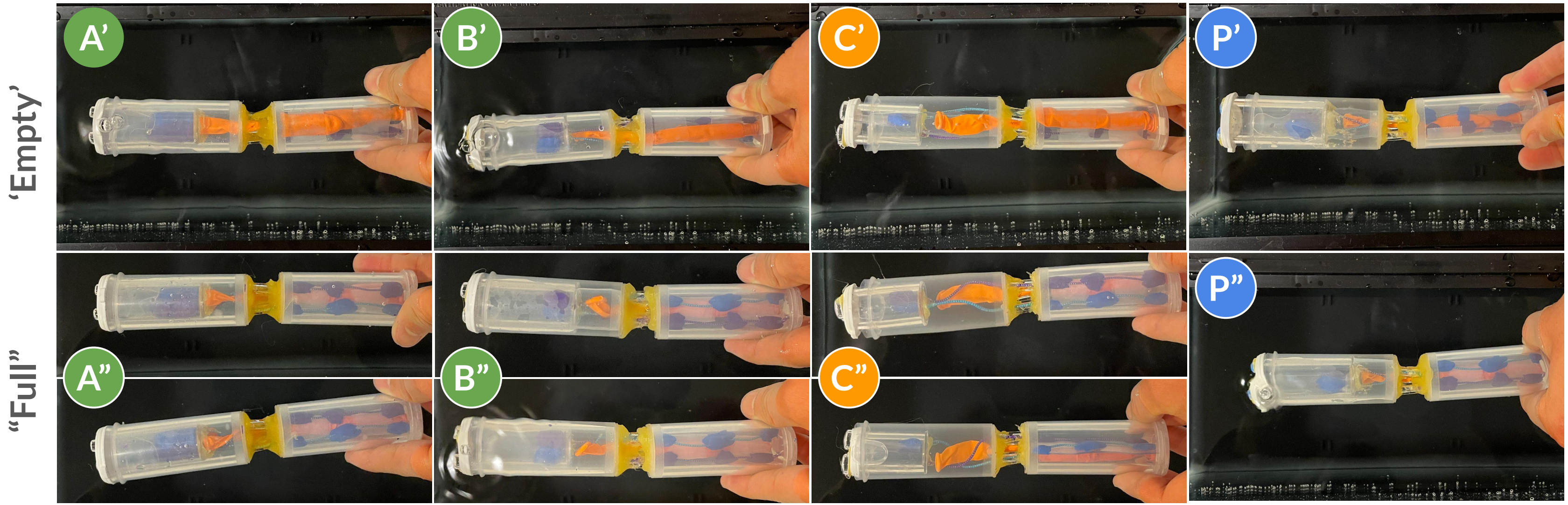
I conducted buoyancy tests by dropping models into a water-filled aquarium. I noted the effects of body density changes underwater as the stomach went from empty to full.



I ran buoyancy tests on 4 models: **A**, **B**, **C**, and **P**—when stomach was empty or full.

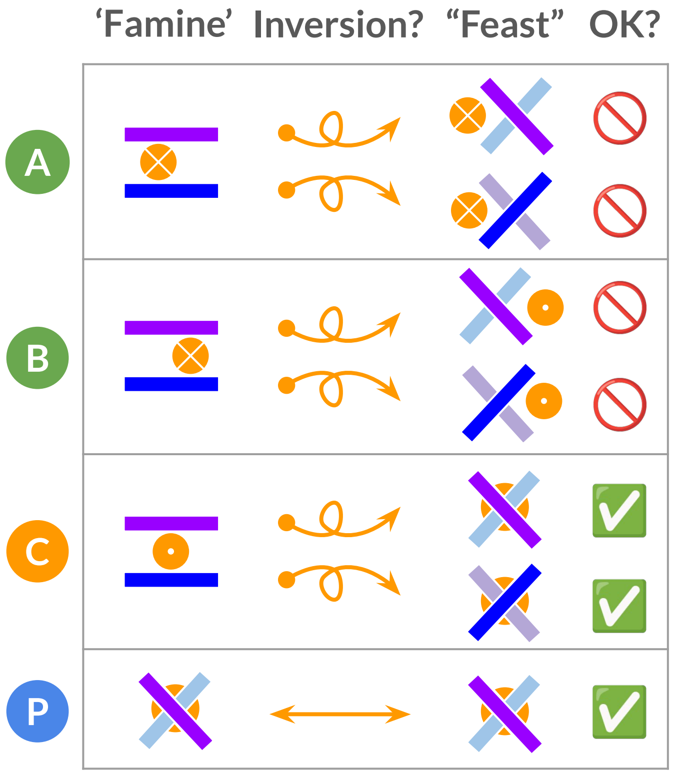
Summary of Test Results

I ran trials for **8 test cases** on **4 models** in an aquarium to generate **11 outcomes** for analysis. Only dorsoventral inversion in **C** on a full stomach resulted in correct decussation topology:



Intermediate *transitory* body plan remains plausible, though not recorded in fossils.

Analysis of Test Results



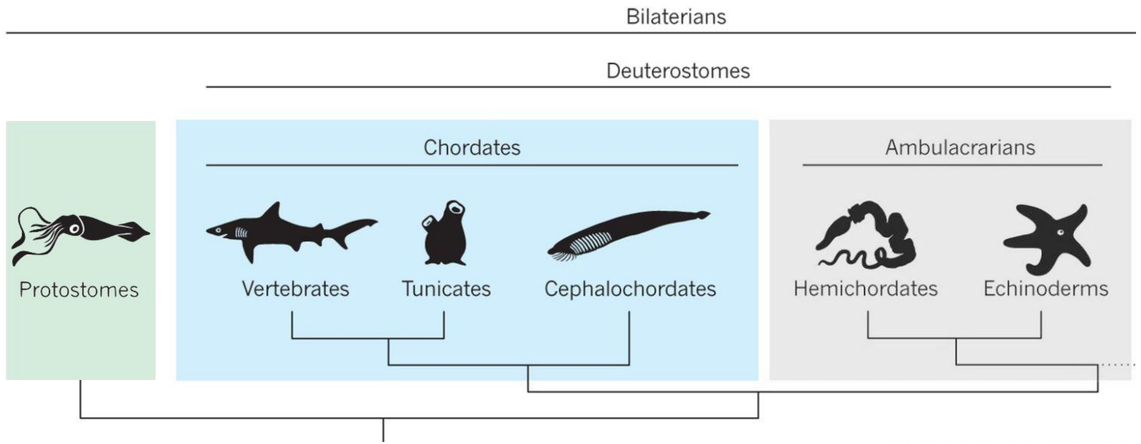
What happens when food sources are bountiful?

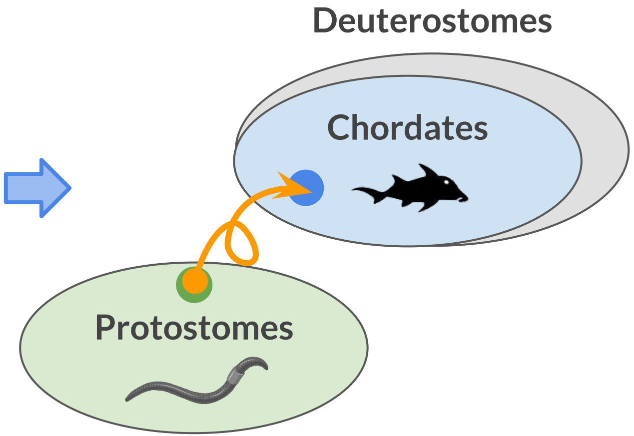
- Model **A** suffers from a decussation that tangles up the gullet when the belly is full. So this marine worm couldn’t eat much—even in times of plenty—on pain of extinction!
- Model **B** results in an unusual body plan. The mouth rotates to the back—like a sea squirt—an evolutionary dead end for bottom feeders as the gullet is also choked by decussation!
- Model **C** has an initially surprising transitory body plan. The gullet develops at the dorsal side—outside of the nerve ring. So dorsoventral inversion rotates the mouth back to its ventral side while the gullet remains free from decussation. This adaptation allows for feasting during bountiful times!
- Model **P** is the one with a stable body plan. Excess fat stored inside a dorsal organ keeps the body on an even keel when food becomes scarce. The gullet steers clear of decussation.

Discussion

Q1: “Why are *all* chordates—and vertebrates—deuterostomes?”

Invertebrates are **protostomes** (“*mouth first*”). Chordates, however, are bilateral **deuterostomes** (“*mouth second*”), as the mouth develops last, after the anus. ***Why is that?*** What can developmental biology tell us about the early chordates?

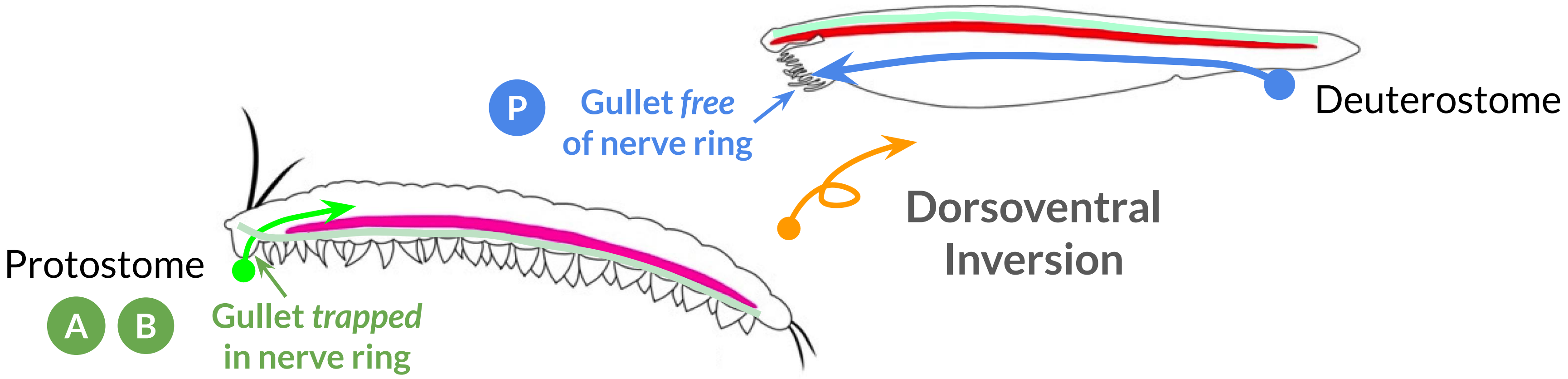




Discussion (cont'd)

Q2: "How did the gullet manage to escape the nerve ring?"

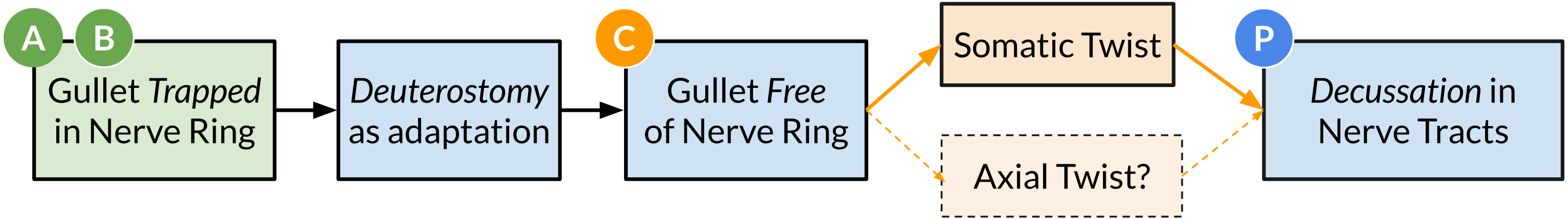
Ancient marine worms evolved **deuterostomy** as a necessary adaptation to prevent the gullet from developing *early*—starting near the mouth—and then running straight into the nerve ring of an embryo:



So it develops *later* from the other direction—staying *far away* from decussated nerve tracts!

Conclusion

My study reveals what's missing from twist theories: how the gullet escaped the invertebrate nerve ring — via a transitory body plan that adapted to bountiful food sources. That made an underwater somatic twist possible 550 million years ago. So that's why the corticospinal tracts of *all* vertebrates today have decussation!



An Evolutionary Pathway for Pikaia: From *Deuterostomy* to *Somatic Twist*.

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