Evolving optimal swimming in different fluids: a study inspired by *batoid* fishes

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Goals

- Investigate how different environments can lead to the evolution of different morphologies and behaviors
- Offer an additional example of *morphological computation* and *embodied intelligence*

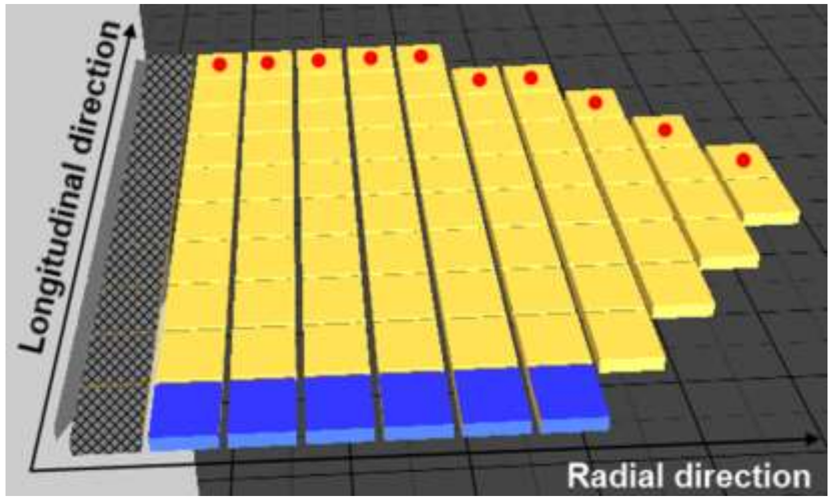
- **Case study: *batoid* fishes**
  - Elastic *soft* bodies
  - Under-actuated fins (pectoral muscles)
  - Locomotion emerges from the interaction with the environment
  - Combination of *waving* (undulation) and *flapping* (oscillation)

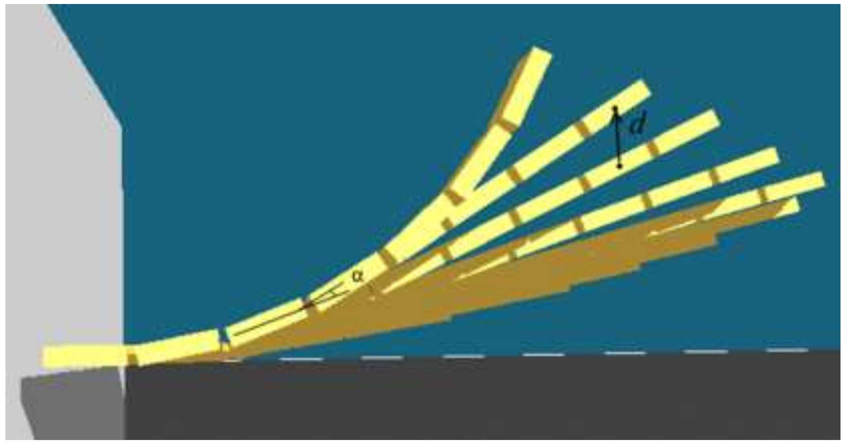
Model-based synthetic methodology

- Lumped parameters discretization of the compliant structure (rigid elements connected by springs)
- Single chain actuation
- Fluid dynamics synthesized by dimensional analysis (*Strouhal*, *Reynolds* numbers)

$$St = \frac{fA}{u} \qquad Re = \frac{\rho \cdot u \cdot \bar{c}}{\mu}$$

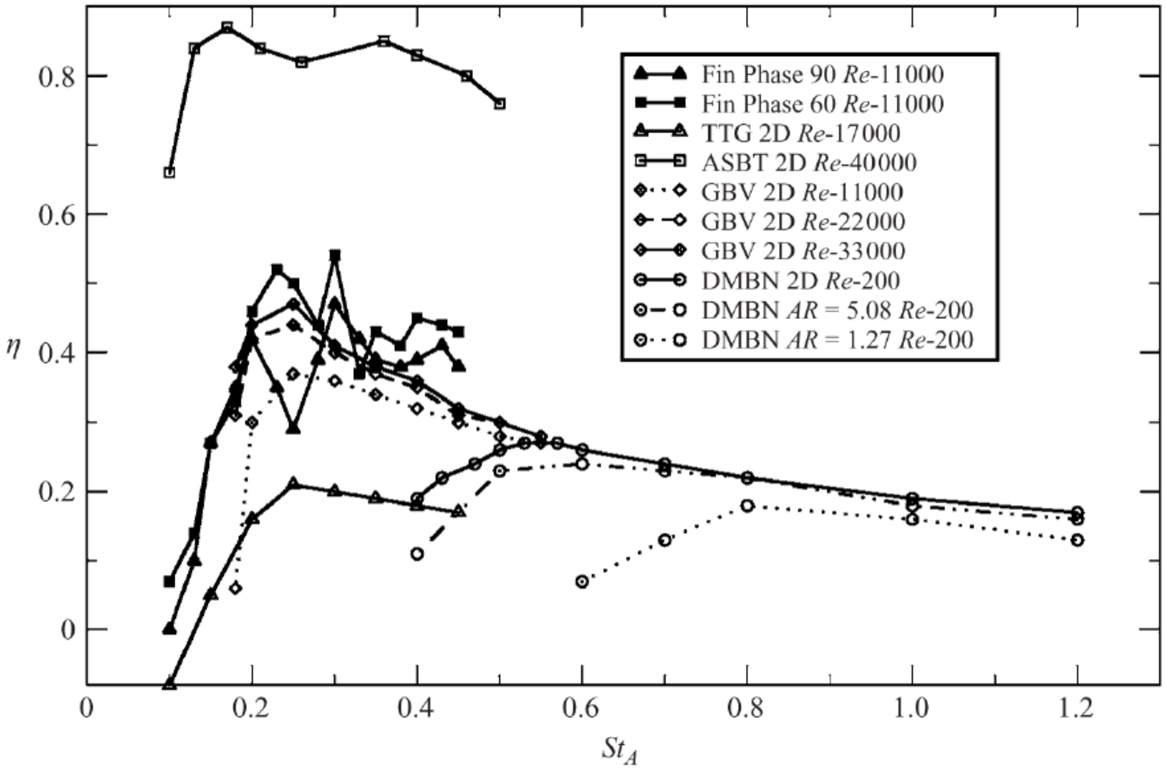
- Fluid-structure interaction modeled through local drag forces





Co-evolution of morphology and control in different fluids

- Morphology: spring constants
- Control: actuation frequency and amplitude
- Fluids: water ($\rho = 1000\ Kg/m^3,\ \mu = 1.15 \cdot 10^{-3}\ Pa \cdot s$), tetrachloroethylene ($\rho = 1622\ Kg/m^3,\ \mu = 0.89 \cdot 10^{-3} Pa \cdot s$)
- Optimization: Genetic algorithms

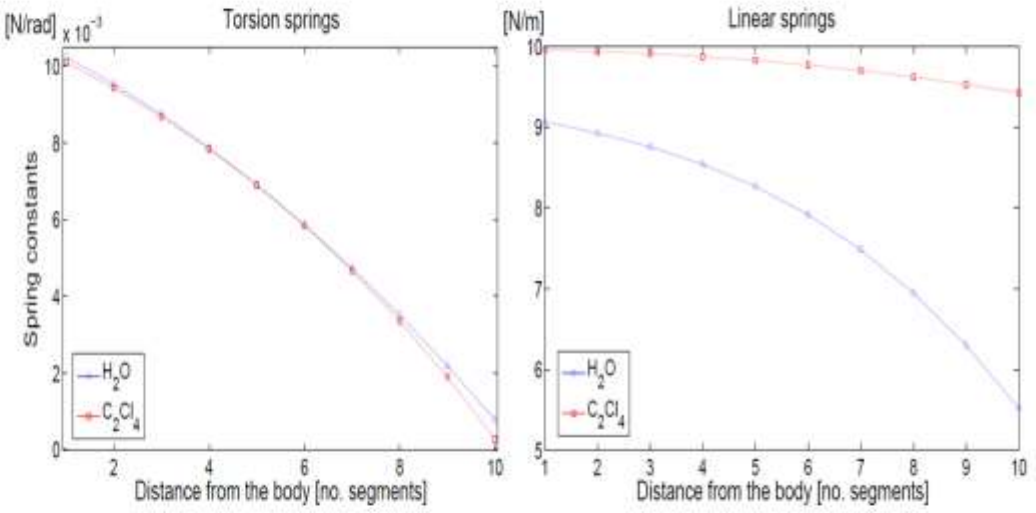


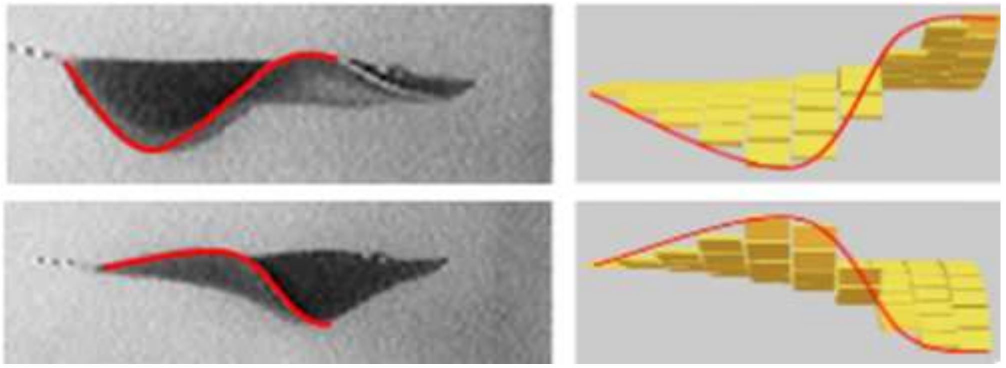
- Optimization target: $St = 0.3$ (maximum swimming efficiency for most of fishes)

Results

- Very good convergence at the target *Strouhal* number in both fluid environments
- Emergence of waving and flapping in the evolved fins, with profiles fitting the shapes of biological ones
- Actuation frequency and amplitude consistent with some species of *batoids*

Fluid	f $[Hz]$	a $[rad]$	A $[m]$	St
Water	0.737	0.261	0.0448	0.300
Tetra chloro ethylene	1.06	0.262	0.0311	0.300

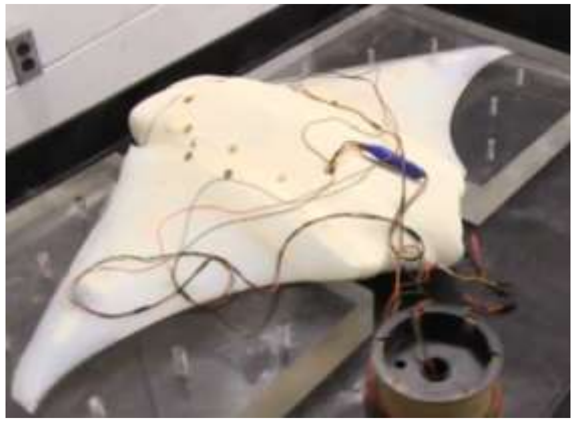


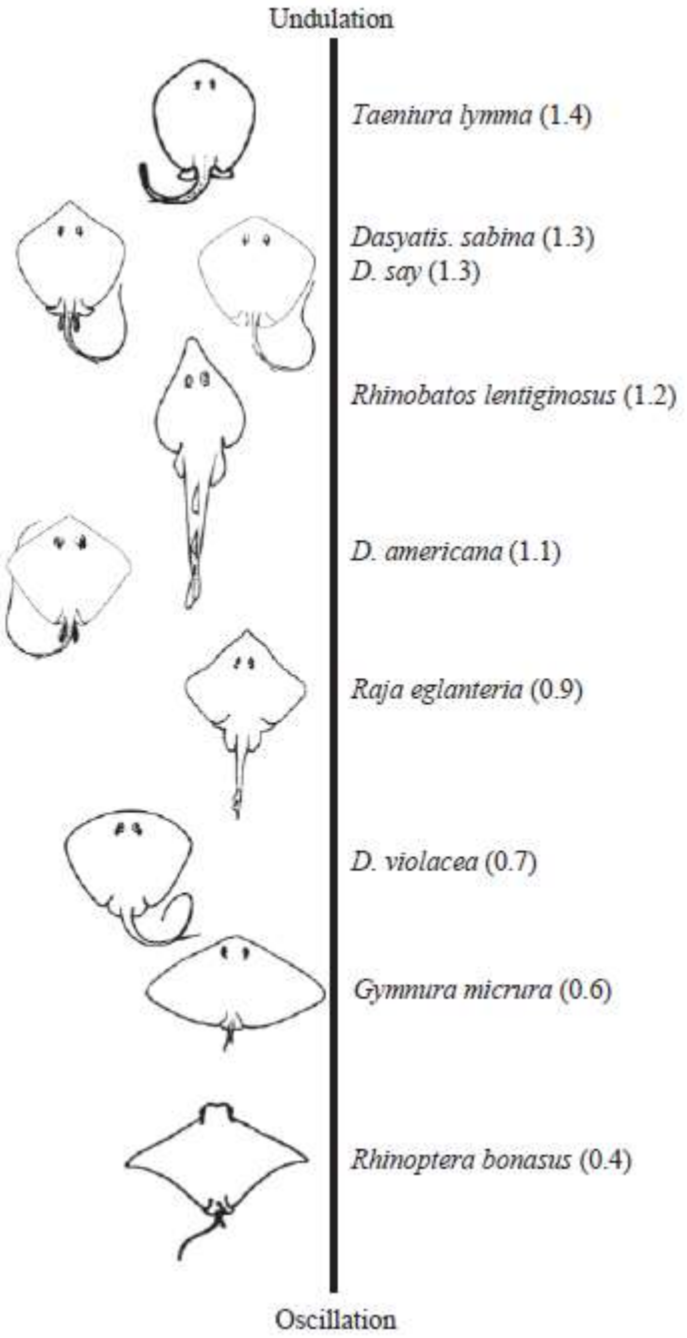


Future work

- <u>Biology</u>: investigation of *batoid* fishes speciation as a result of adaptation to different environments

- <u>Robotics</u>: design of a bio-mimetic *soft* robot able to adapt to different fluids and flow conditions





Thank you for your attention

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