Balancing Performance and Efficiency in a Robotic Fish with Evolutionary Multiobjective Optimization

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Motivations

Optimize Robotic Fish with Flexible Fins

Optimize for
- performance AND
- efficiency

While matching flexibility with control settings

Robotic Fish

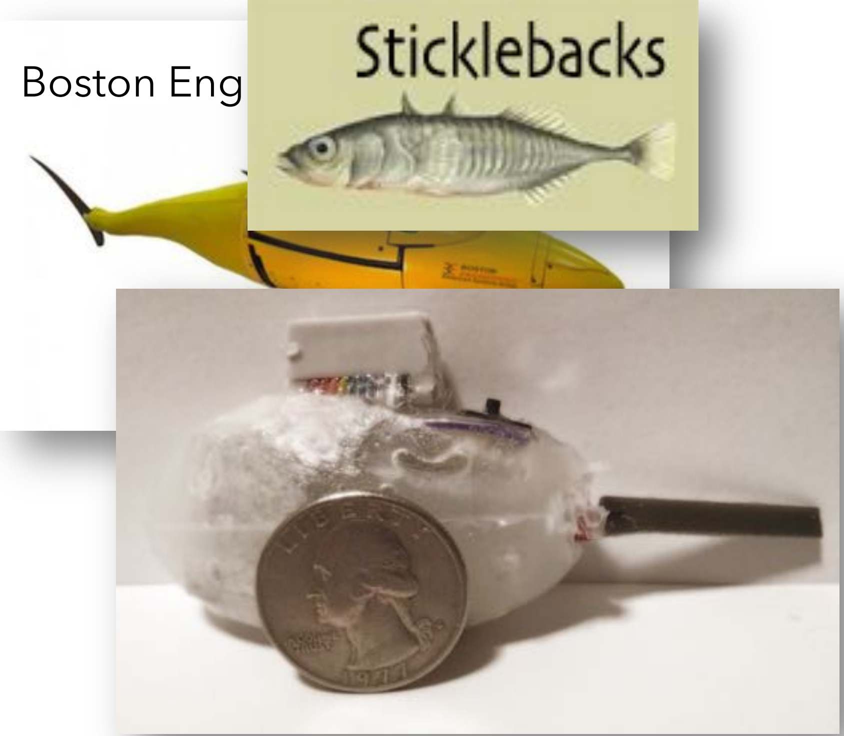
Biomimetic Robots

Compared with other aquatic robots

- Smaller in size
- More maneuverable

Actuation

- less complex
- fewer moving parts



Robotic Fish

Biomimetic Robots

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Challenges

Complexenvironment

- turbulence

Flexible components

- changing performance

Limited supervision

- poor communication

Applications

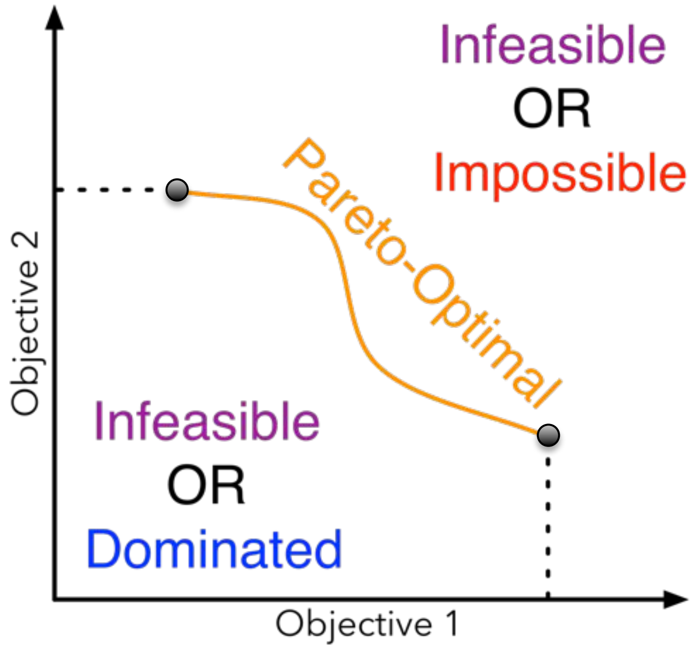
This Paper

- Maximize efficiency
  - focus of several recent studies [Low 2010, Park 2012]
  - important due to lack of supervision
  - remain operational as long as possible

- Maximize average velocity

- Constraints
  - maximum power exerted by the motor
  - ratio of length to width for the caudal fin

Search Space



Pareto-optimal
- best solutions

Dominated
- sub-optimal solutions

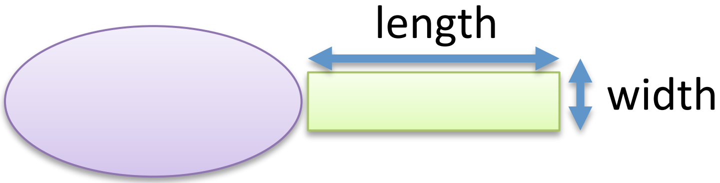
Infeasible
- violate constraints

Impossible
- unachievable

This study: NSGA-II [Deb 2000]

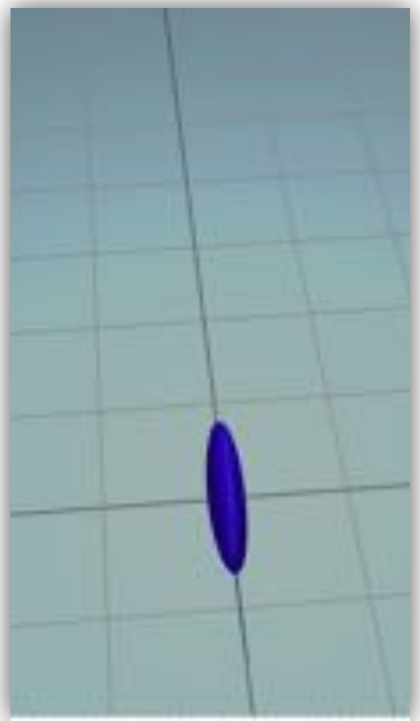
Computational Evolution

- Fin characteristics
  - flexibility
  - length
  - height
- Control parameters
  - sinusoidal amplitude
  - sinusoidal frequency

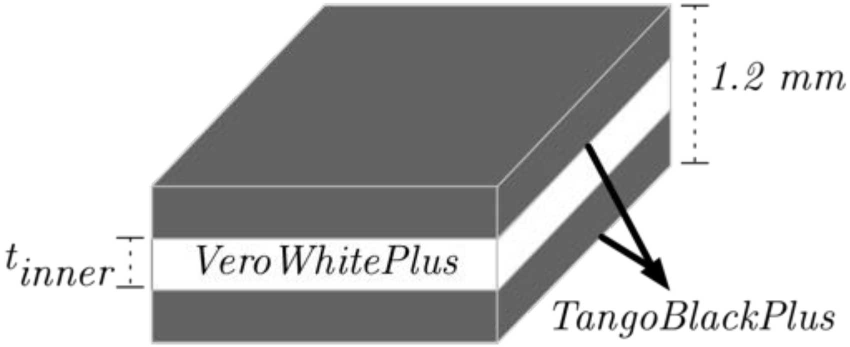


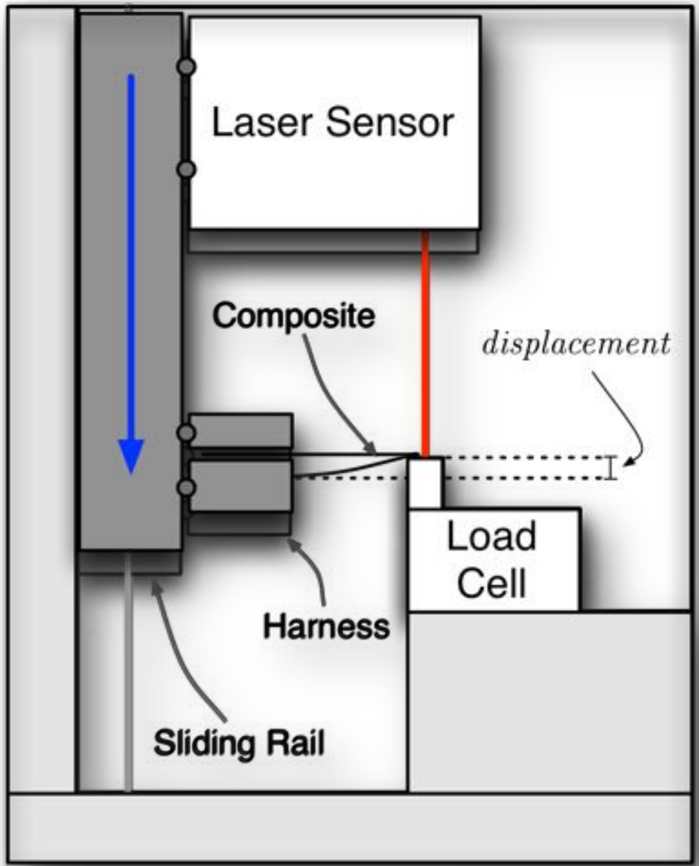
- Why evolutionary multiobjective optimization?
  - fewer evaluations and more effective than parameter sweep
  - avoid local optima

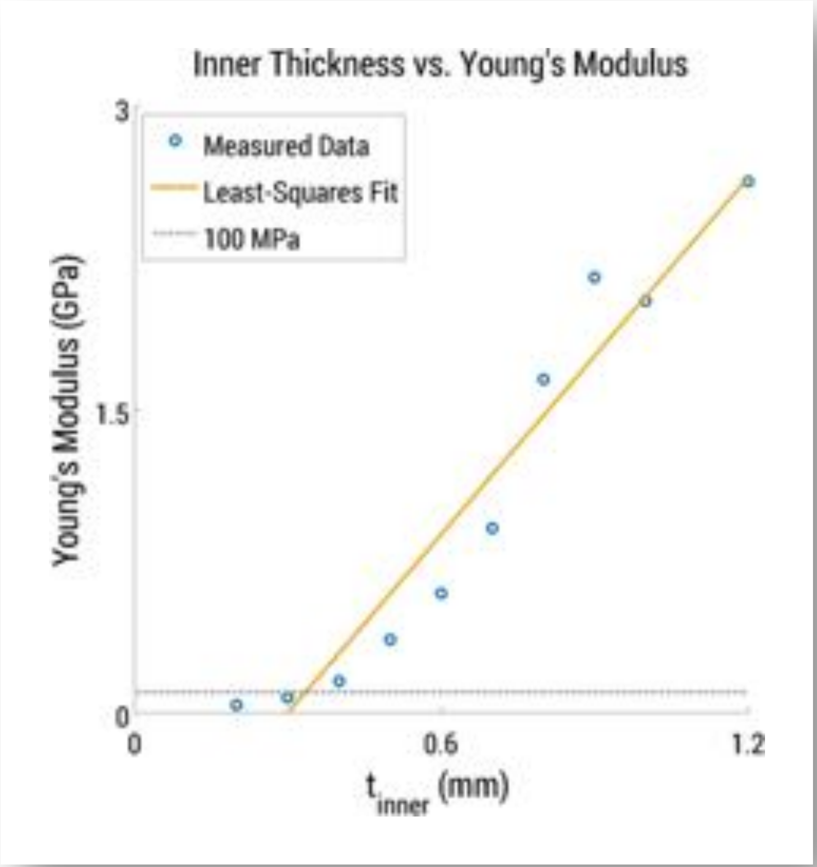
Flexible Fins



3D Printing Composite Fins




Laser Sensor
Composite
displacement
Load Cell
Harness
Sliding Rail



Inner Thickness vs. Young's Modulus
Measured Data
Least-Squares Fit
100 MPa
Young's Modulus (GPa)
3
1.5
0
0
0.6
1.2
t inner (mm)

Efficient Simulation

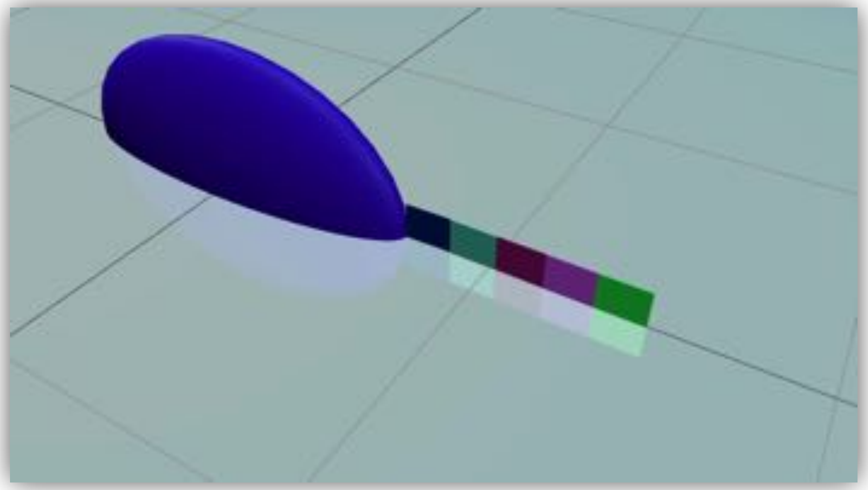
MATLAB / Simulink

Hydrodynamics

- developed by Wang et al. [Wang 2012, Clark 2012]
- faster and less accurate compared to CFD

Flexibility

- rigid bodies
- torsion springs (can be converted to Young's modulus values)



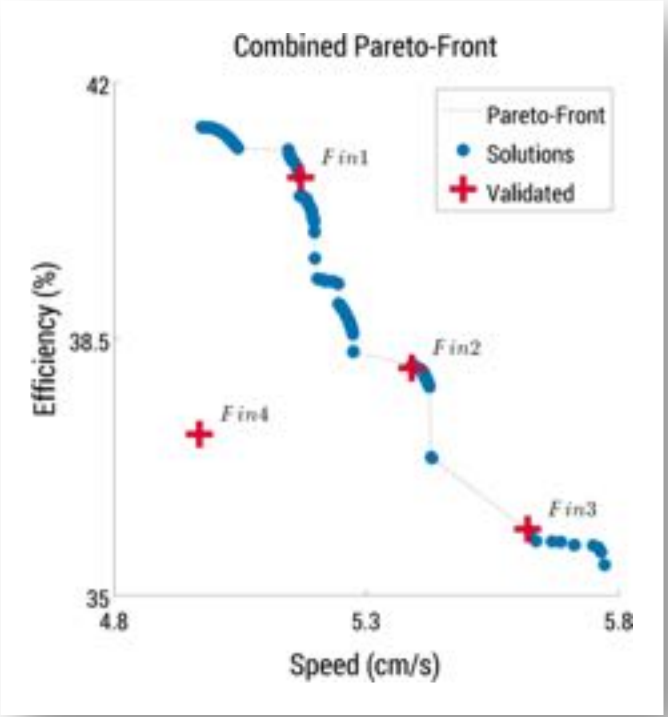
Evolutionary Optimization

Task : quick and efficiently forward swimming

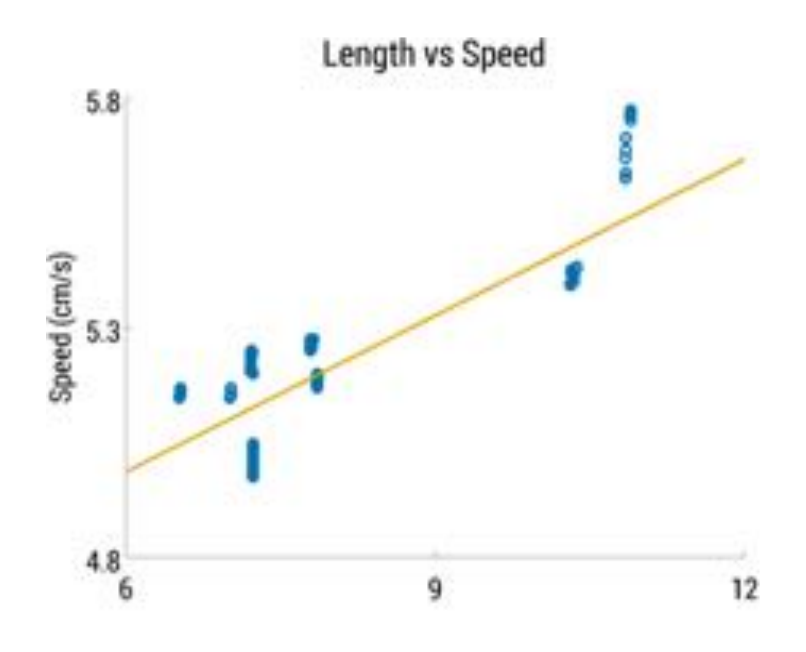
- Evolve
  - fin flexibility
  - fin dimensions
  - sinusoidal control parameters
- NSGA-II parameters
  - 200 individuals in the population
  - 500 generations for convergence
  - 20 replicate experiments

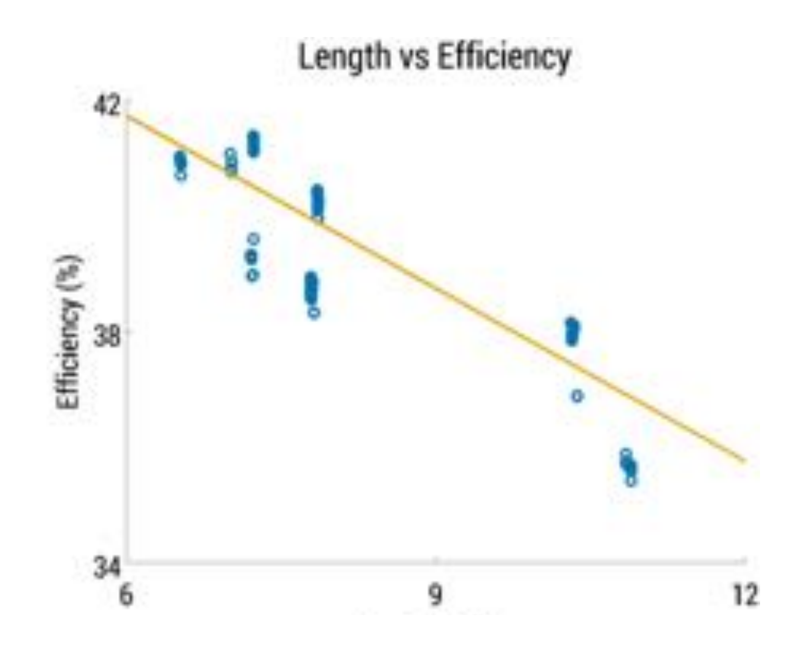
Final Combined Pareto-Front

- Efficiency
  - 35 to 40 percent
  - similar to values found in other studies
- Velocity
  - 4.8 to 5.8 cm/s



Caudal Fin Length





Discussion

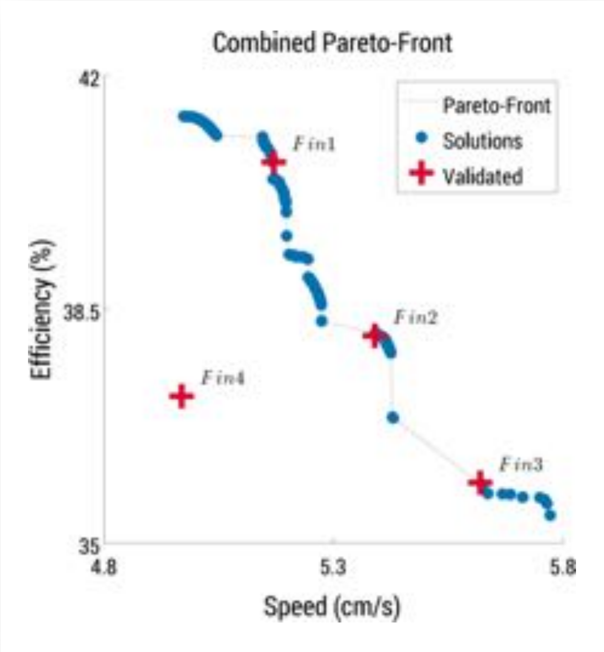
Guidelines

1. Flexible fins are more efficient
2. Length-height ratio of 3-to-1
3. Fin length ½ the length of the body
4. Increase speed by increasing amplitude

Choosing a single Pareto-optimal value is specific to the task given to the robotic fish.

- example : robotic fish needs to operate for 1 hour
- choose the fastest solution that is within the bounds for efficiency

Physical Trials

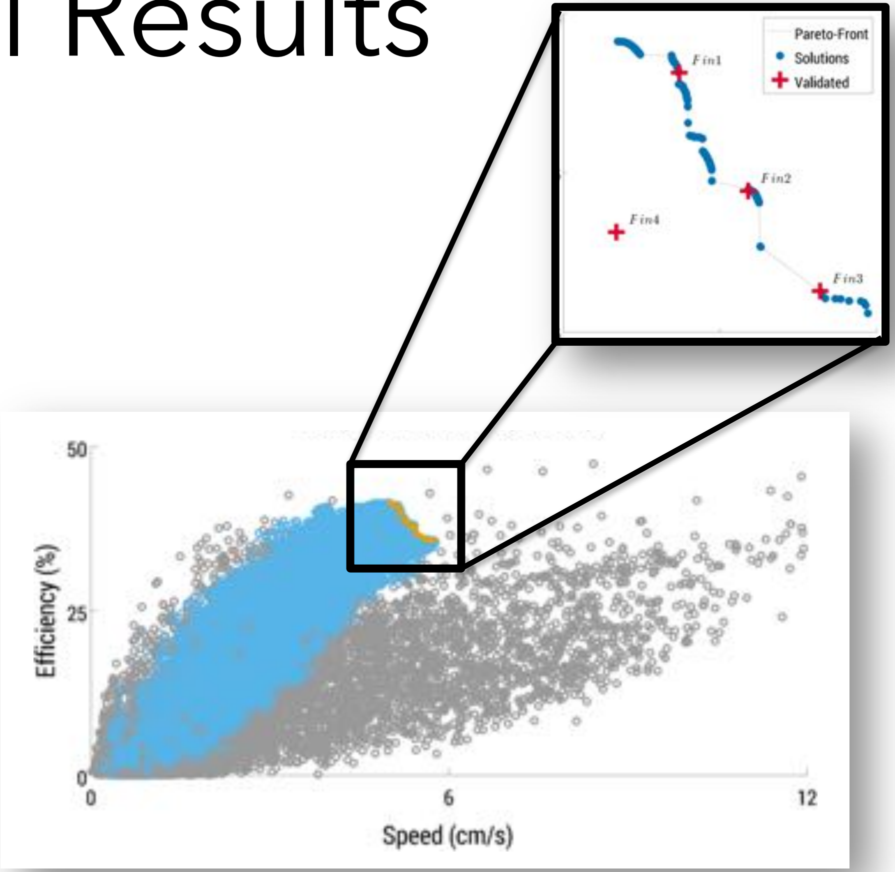


Label	Simulation (cm/s)	Reality (cm/s)
*Fin*1	5.17	7.43
*Fin*2	5.39	4.00
*Fin*3	5.62	5.00
*Fin*4	4.97	4.90

Physical Results

Reality gap
- different dynamics
- printing fins
- noisier control

Pareto-front clustering
- all are good solutions
- tight clustering between solutions



Summary

In this study we,

- optimized a robotic fish for two objectives
  - objectives: speed and efficiency
  - evolved parameters: fin morphology and control
- we found a set of guidelines for designing robotic fish of similar builds
- however, physical results are somewhat inconclusive and will need to be expanded

Ongoing Research

How can we improve the transferability of evolved individuals?

- cross the reality gap through adaptive control

How can we get better generality during evolution?

- operate under different control conditions
- more complex tasks

How advantageous are more complex fins?

- include non-rectangular fins
- include non-uniform flexibility fins

Thank You

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