Non-invasive studies of animal propulsion and sensing

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Background

- Swimming animals move and sense the environment by interacting with surrounding fluid;
- The flow generated by animal/fluid interaction can be treated as a unsteady dynamic system.

Project Problems:

1. How to quantify these unsteady flows non-invasively?
2. What knowledge can be learned by studying the unsteady flow geometry?

Project Goals

1. ***Identify the unsteady flow geometry*** **generated by a free-swimming jellyfish, using Langranian Coherent Structure (LCS) analysis;**

2. **Combine the LCS calculations with existing measurements and dynamical systems theory (e.g. transport in Poincare maps) to *compute transport rates* in a free-swimming jellyfish*;***

3. ***Manipulate live jellyfish*** **to determine dependence of flow geometry on animal behaviors (e.g. swimming frequency).**

How to identify flow geometry?

Lagrangian solution:

Finite-time Lyapunov exponent field (FTLE)

For a time interval T, nearby particles $x(t)$ and $y(t)$ in the flow will separate as

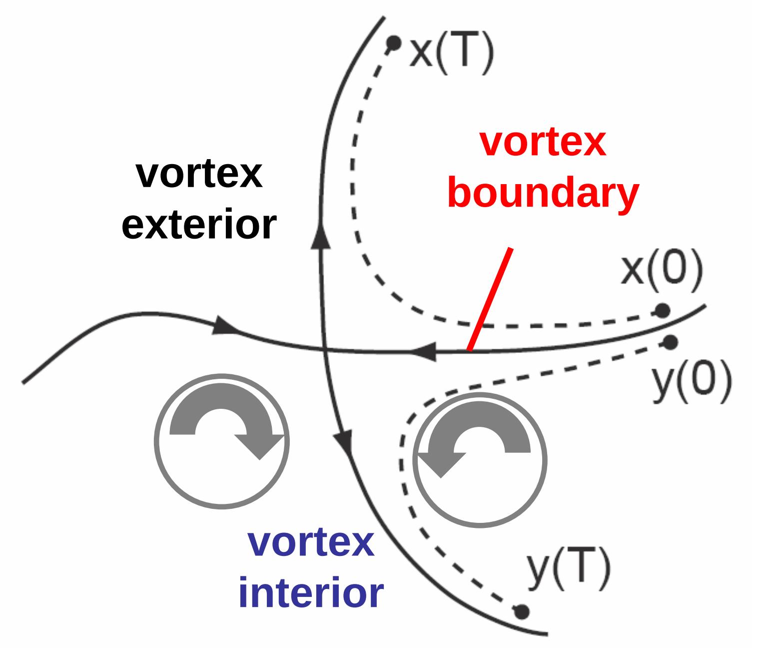
$$\delta(T) = \|x(T) - y(T)\| \sim e^{\sigma T}\delta(0) = e^{\sigma T}\|x(0) - y(0)\|$$

where $\sigma = \sigma(x)$ is the finite-time Lyapunov exponent

Key observation:

Level sets of large $\|\sigma\|$ in $\sigma(\mathbf{x})$ indicate boundaries of flow regions with distinct behavior, including free vortices

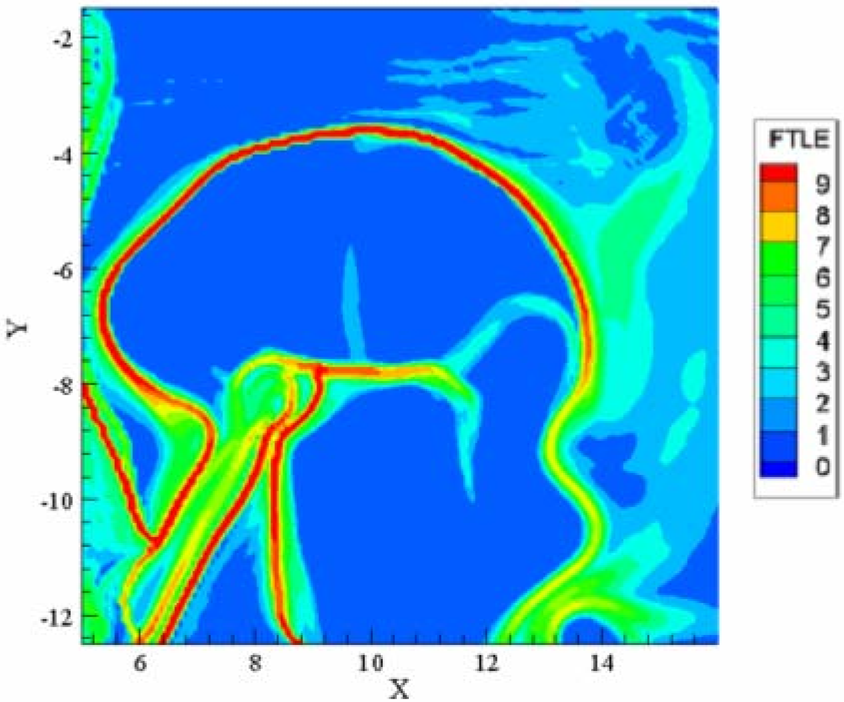
"Lagrangian Coherent Structures (LCS)"



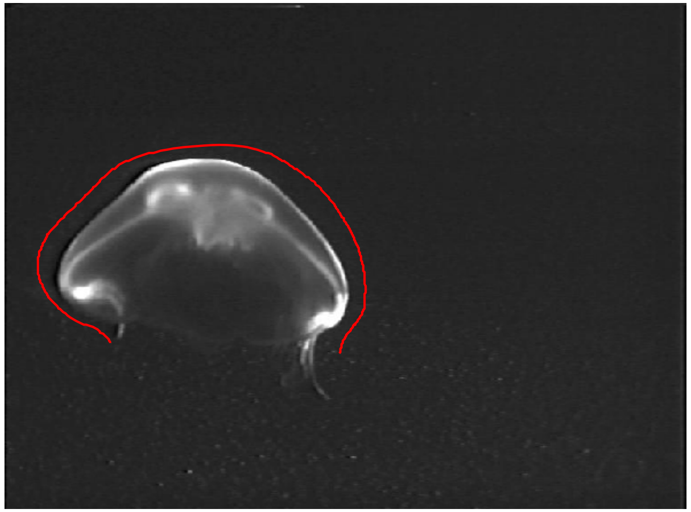
Ref: Haller (2000 – 2005); Shadden et al. (2005, 2006)

LCS analysis on a free-swimming jellyfish:

Backward-time FTLE and LCS



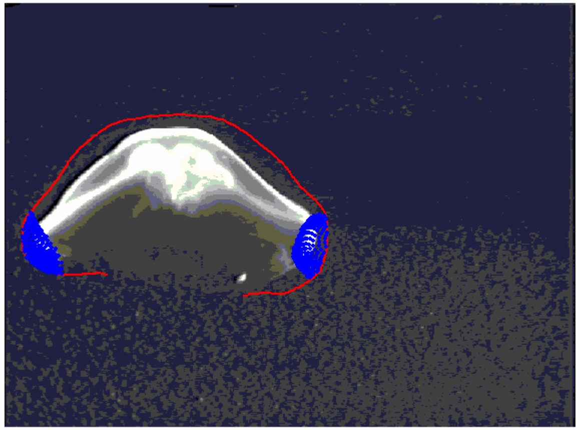
FTLE



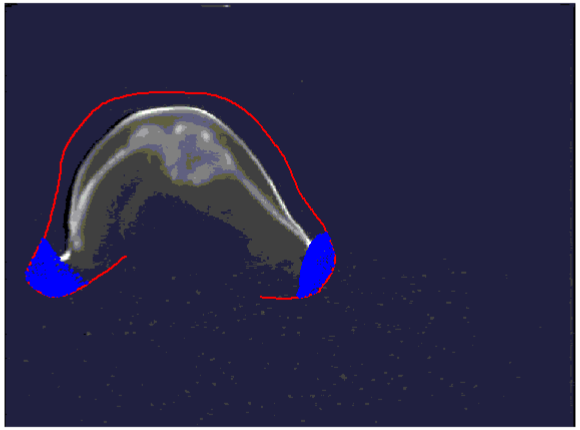
LCS

LCS analysis on a free-swimming jellyfish:

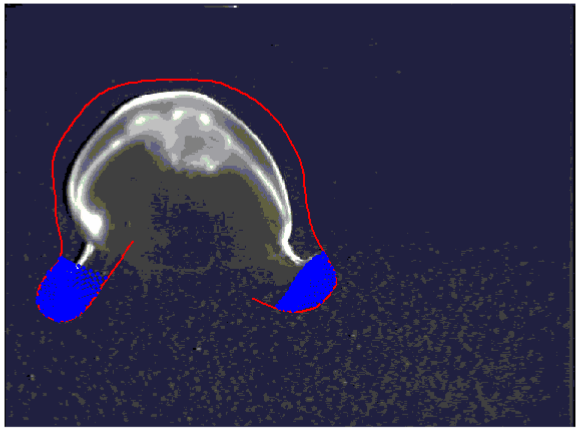
Flow geometry dictates transport and propulsion



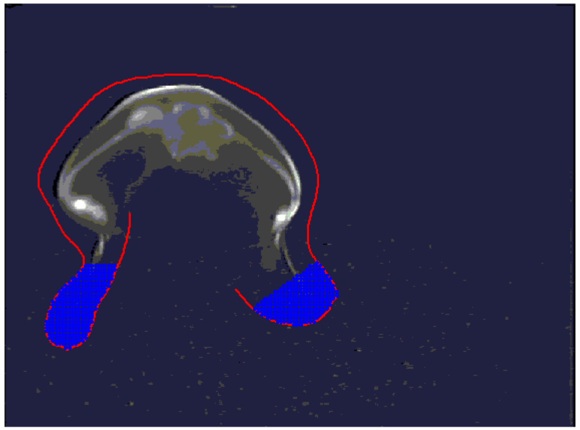
$t = 0$



$t = 0.67\ s$



$t = 1.33\ s$

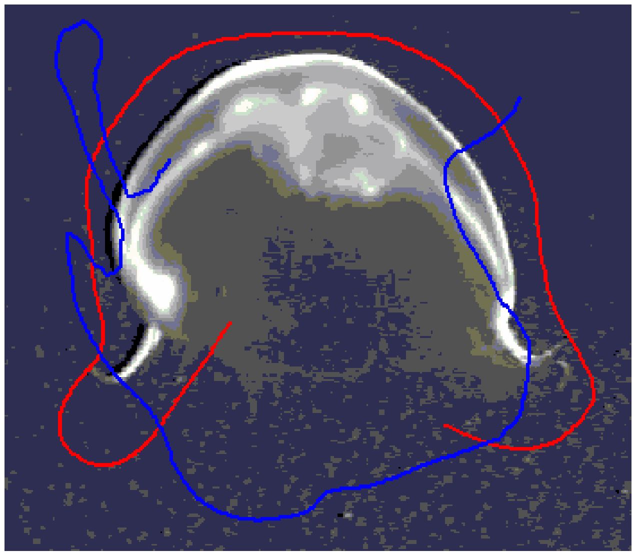


$t = 2\ s$

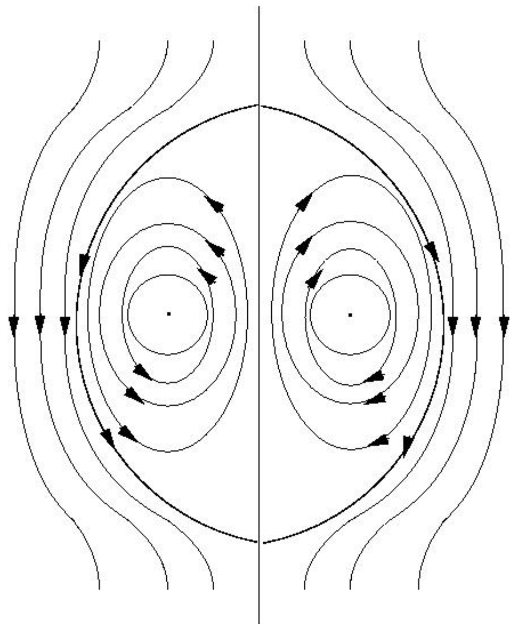
LCS based fluid transport rate computation

Theoretical background: Rom-Kedar et al. - J. Fluid Mechanics (1990), vol.214, pp347-394)

Flow generated by the jelly fish



Oscillating vortex pair



+ perturbation !

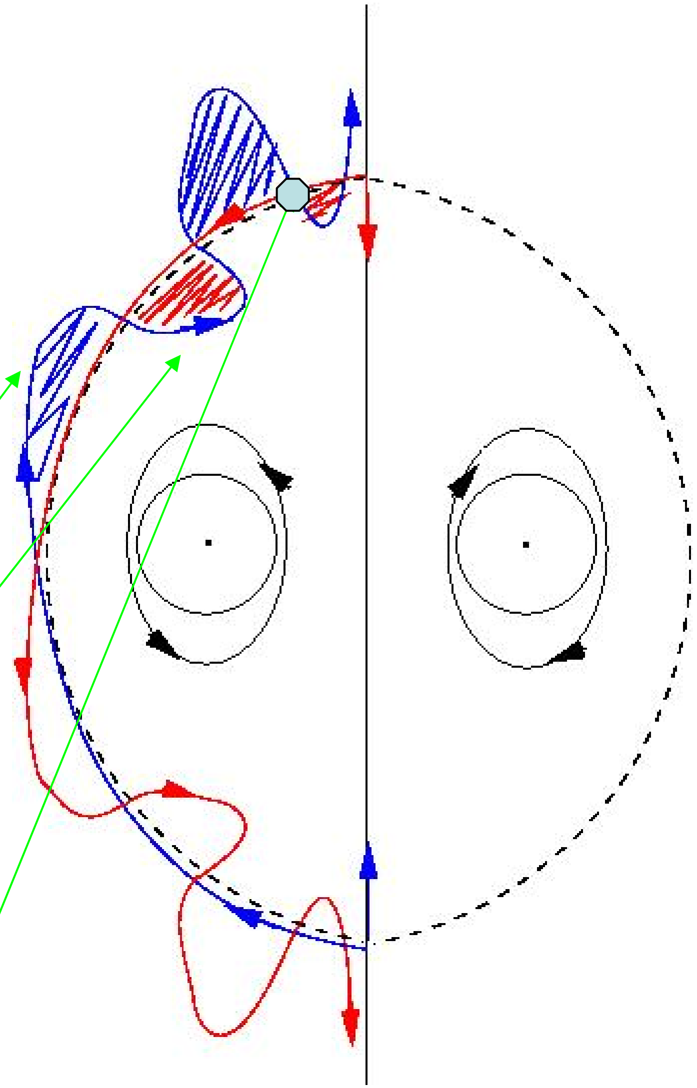
LCS based fluid transport rate computation

The perturbations in the stream generate lobes in the invariant manifolds, entraining and detraining fluids in/out of the core region!

Poincare’ methods (periodic flow)

blue areas will be entrained

red areas will be detrained



Intersection points

LCS based fluid transport rate computation

Our flow is aperiodic, BUT:

LCS knowledge gives us more info than Poincare map!

It is a “movie” of how the manifolds are deformed in one motion cycle of the jelly fish.

⇒ By monitoring the area variations of the lobes, we can compute the transport rate of fluid in/out the jelly fish.

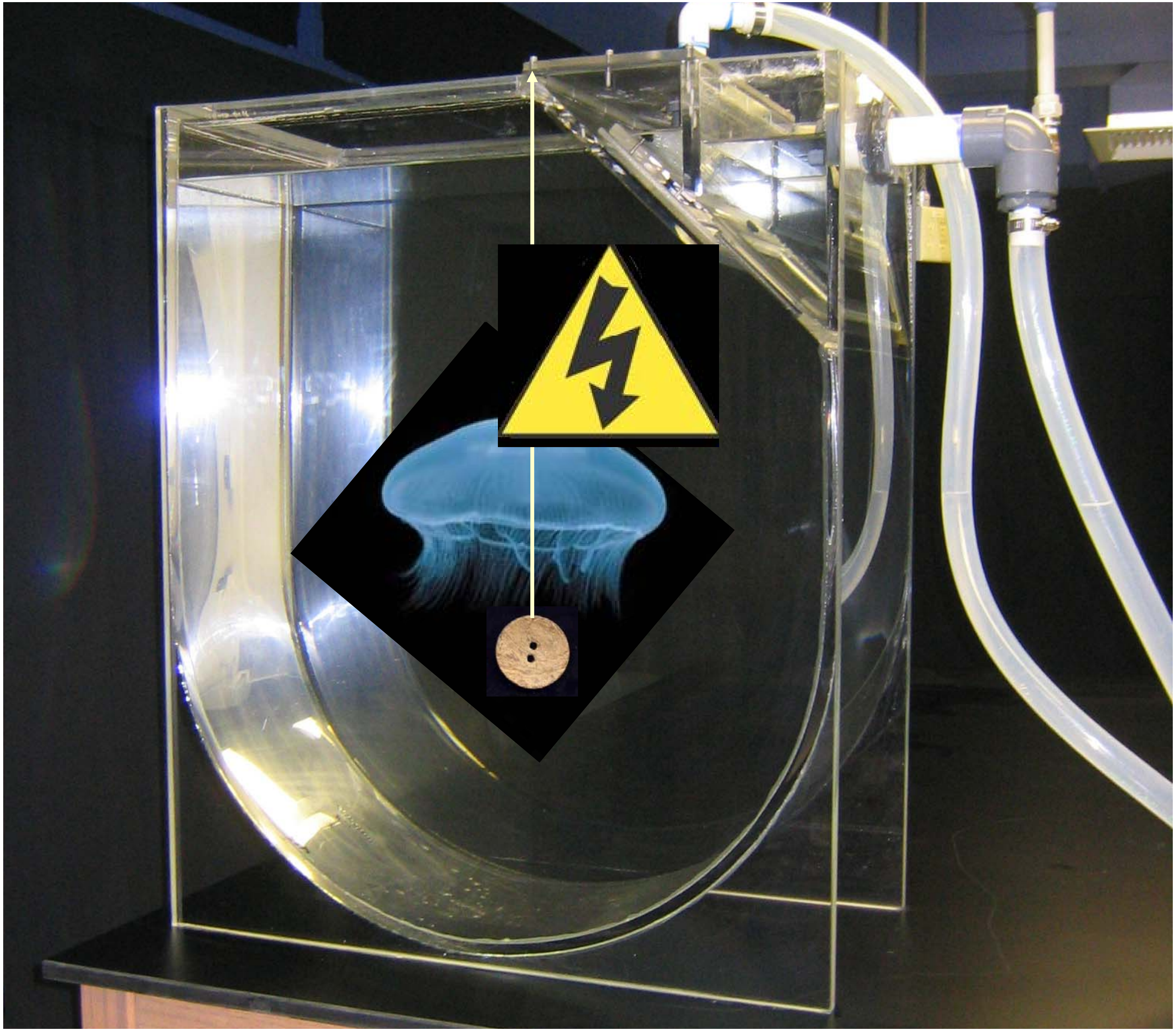
Stage of the project:

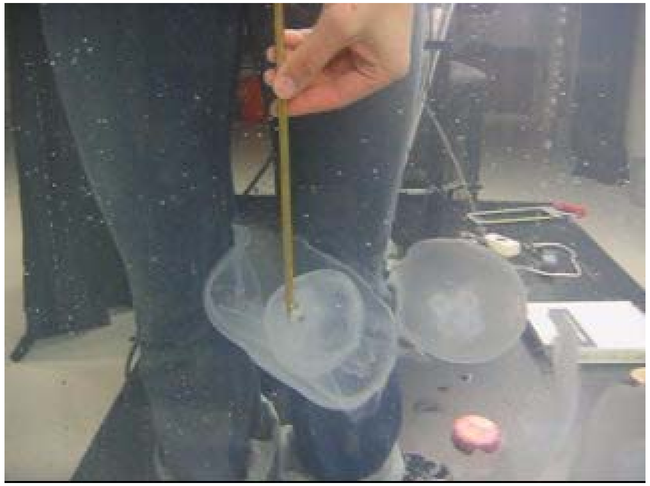
- ✓ FLCS & RLCS known for one frame
- ✓ Computation of intersection points
- ➢ Area of the lobes
- ➢ Rate of variation of the areas

Jellyfish Experiment

- Specimens: moon jellyfish
- Visualize the flow generated by jellyfish
  - Digital Particle Image Velocimetry
    - Add particles to flow
    - Two pulsed lasers
    - Image capture

- ***Need to fix the jellyfish position***





Methods to be used

- Suction mount
  - Water pump
  - Flexible hoses
  - Acrylic rod
- Mechanical mount
  - Aluminum rod and screw