



*FREE<sub>sub</sub>NET*

*Phase I, Work package 1*

# New Methodologies: AUV Concepts

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# Path planning and following for AUVs

- PP and PF motivated by challenging scenarios
- Mission planning and path generation
- Path following
- Conclusions and future work



# Mission Scenarios

- Seismic Exploration
  - Form an “*active hydrophone array*” (adaptable structure)
  - *Collision avoidance* (towed hydrophonic streamers)
- Deepwater Archeology
  - *Deep sea seafloor surveying of large unstructured areas + obstacle avoidance for extended periods of time*
  - Multiple-vehicle missions to *reduce survey time*

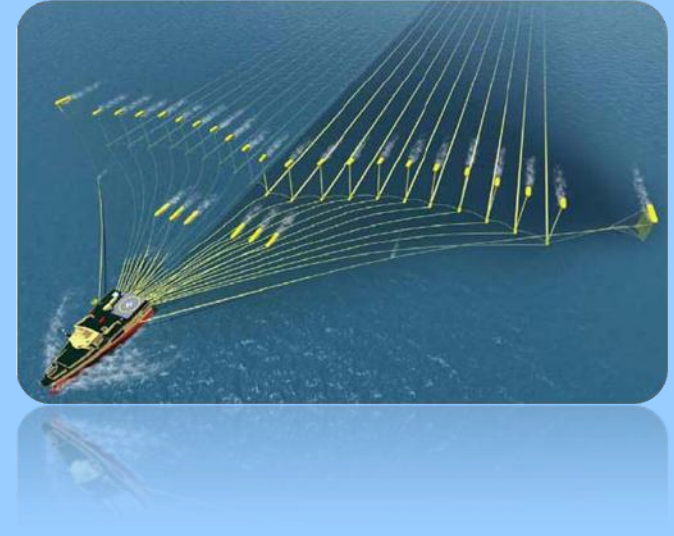


Image property of Centre for Ships and Ocean Structures, NTNU

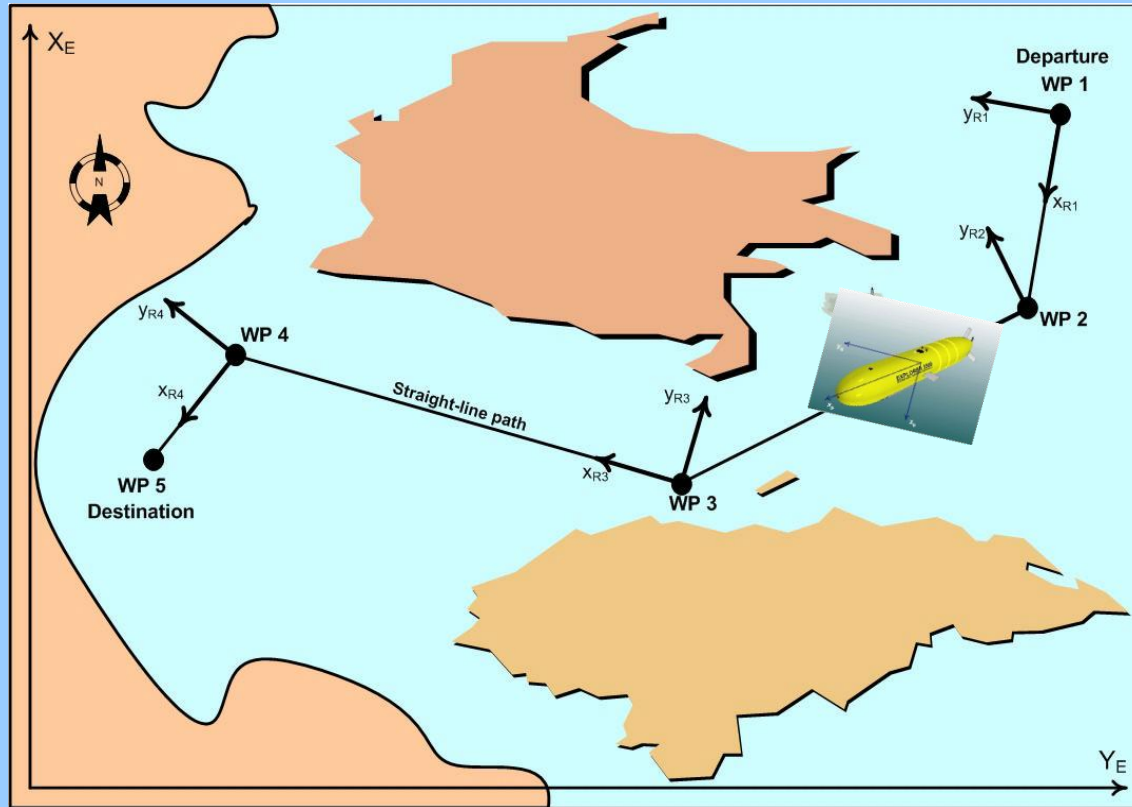


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# Mission Planning

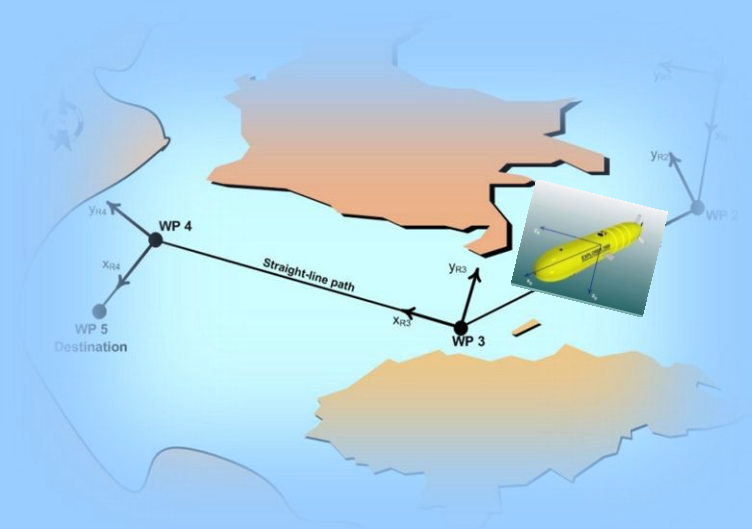


How is the mission described “geometrically”?

# Path Planning

- **Problem description**

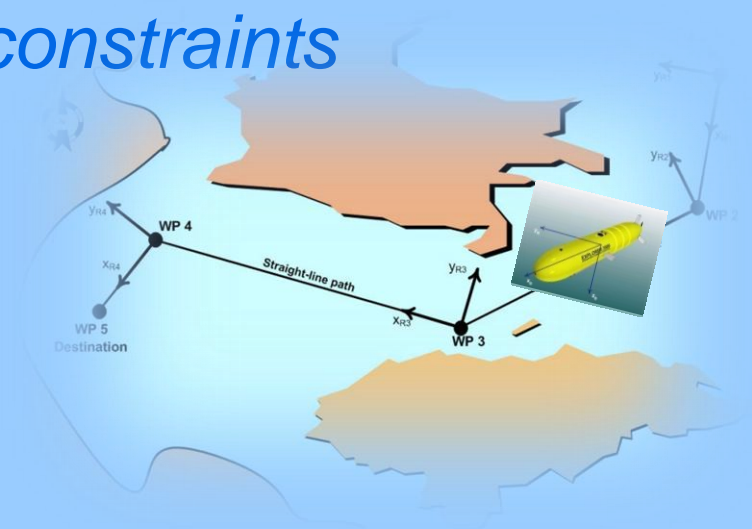
- Desired *waypoints* or *maneuvers*
- Desired AUV *formation*
- Optimal *energy expenditure* or *maneuvering time*



# Path Generation

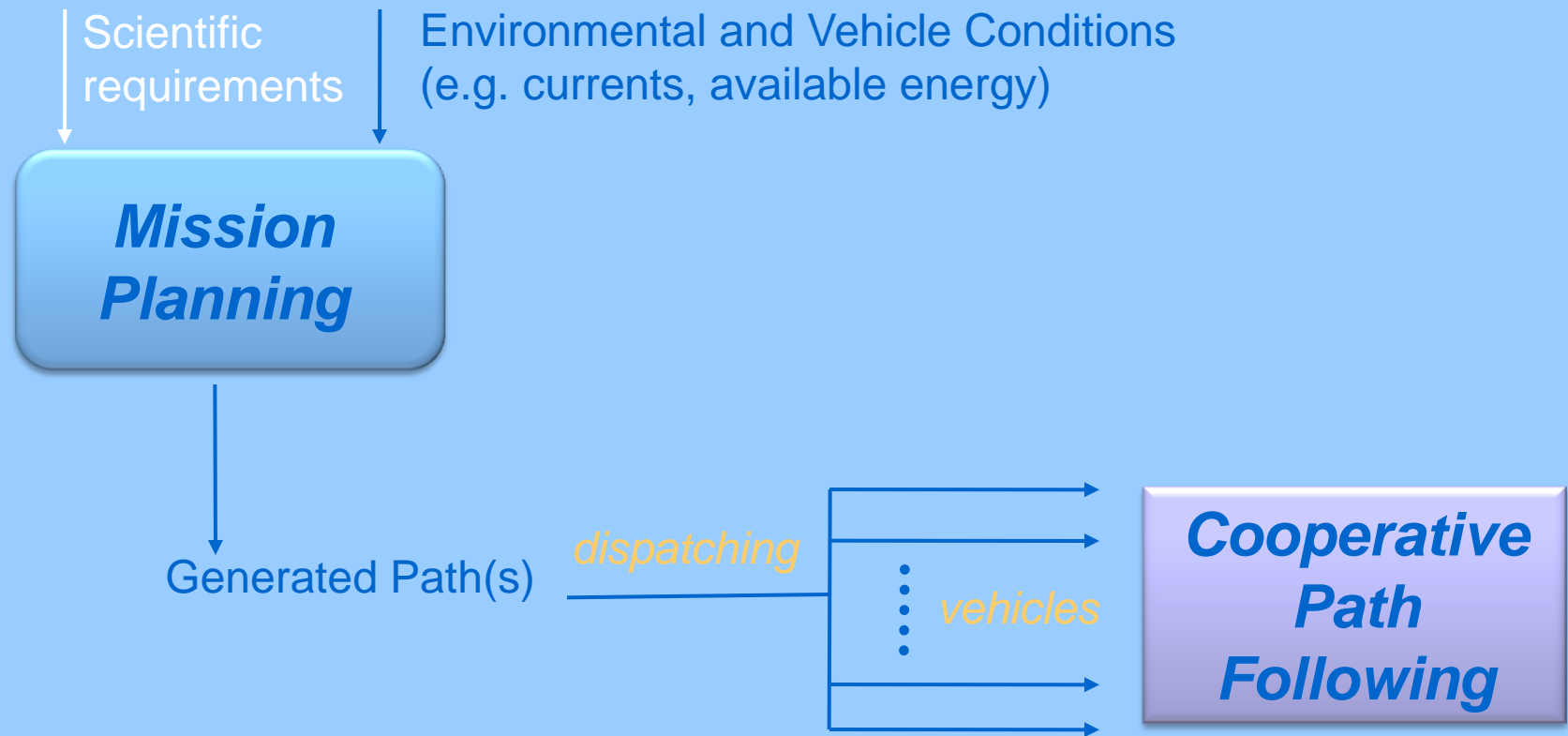
- **Difficulties**

- Go-to-formation maneuver (*deconflicted paths*)
- Avoid (concave) *obstacles*
- Generate *collision-free paths*
- Generate *synchronized trajectories*
- Meet energy and *trajectory constraints*



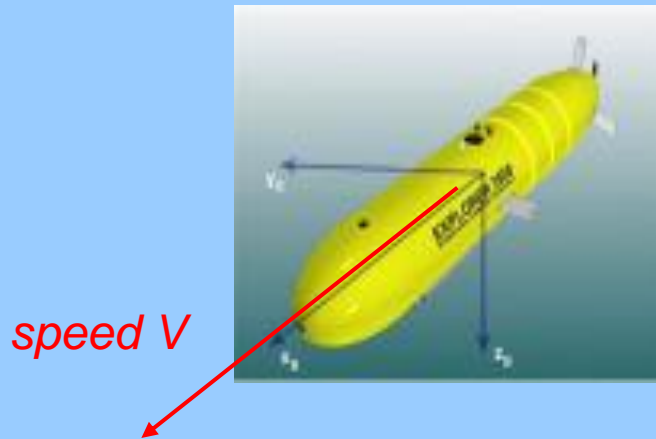


# Mission Planning and Execution

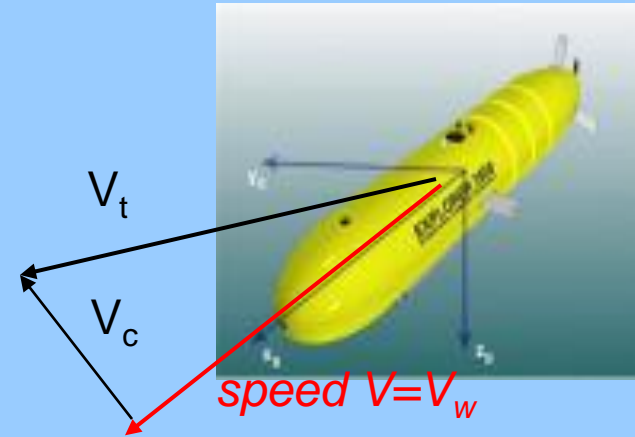


# Energy: Ocean Current Influence

Energy spent  
(without current)



Energy spent  
(with current)

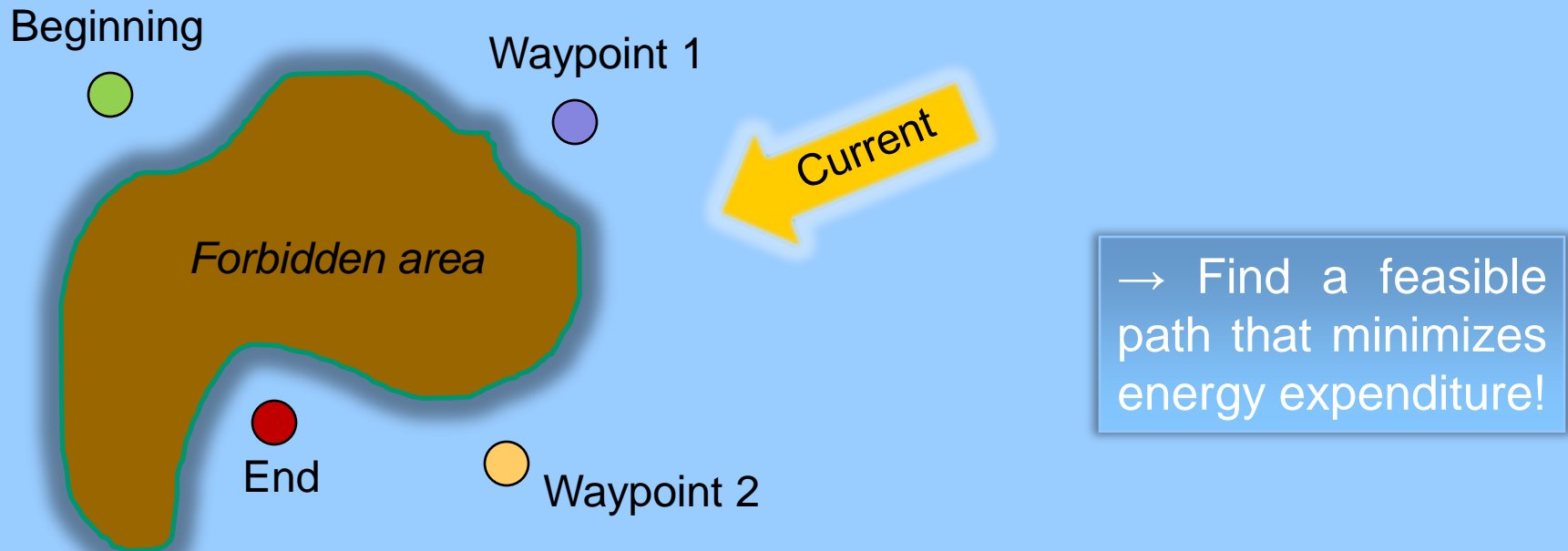


- Thrust Force  $F = \text{Drag} = kV^2$
- Power =  $F \cdot V = kV^3$
- Energy =  $\int \text{Power}$

- $V_t$  = desired inertial speed, requires
- $V_w$  = speed w/respect to water
- Power =  $kV_w^3$
- Energy =  $\int \text{Power}$



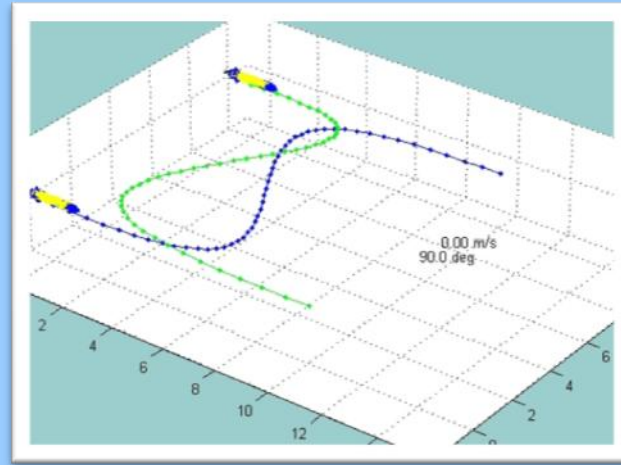
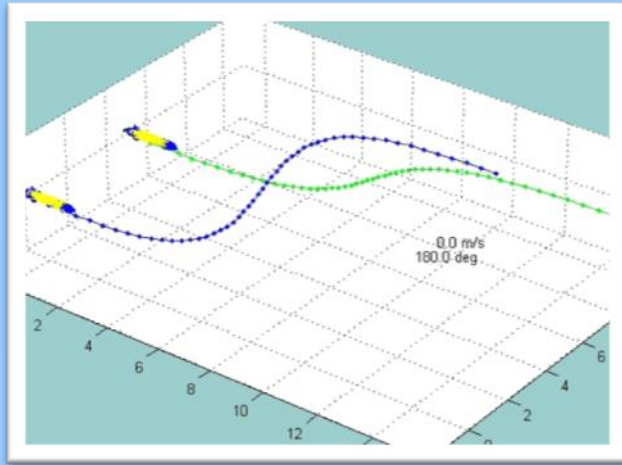
# Single Path Generation



- Parameterize the paths by  $\tau$  (not necessarily length!)
- Adopt a polynomial description in  $\tau$
- Incorporate spatial and temporal constraints

*Path Generation inspired by the work of O. Yakimenko and I. Kaminer, NPS, and R. Ghabcheloo, IST*

# Multiple Path Generation



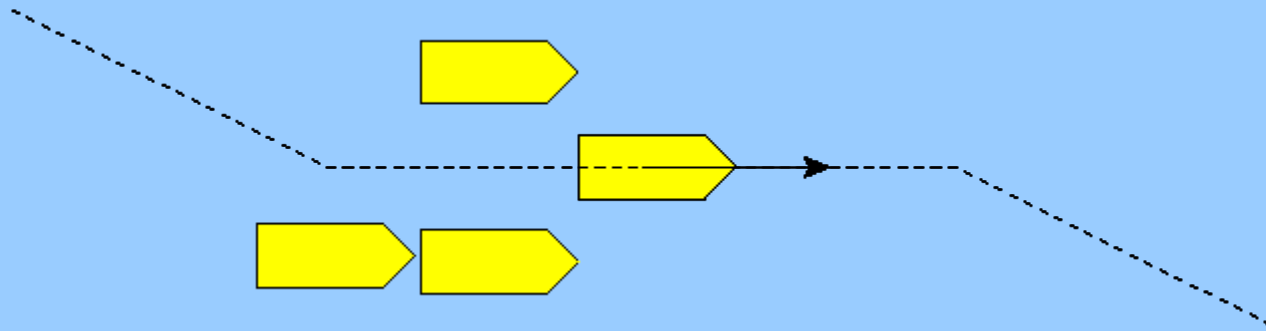
→ Spatial and Temporal Deconfliction!

Transitioning from initial positions to single line

Transitioning from initial positions to side-by-side pattern

# Path Following

- **Problem description**
  - Desired path
  - Desired along-path speed
  - Desired AUV formation



# Path Following

- **Difficulties**

- Guidance law with guaranteed convergence
- Robustness
  - Environmental disturbances (ocean currents)
  - Modelling errors
- Possible collisions
  - With surrounding (obstacle avoidance)
  - Other AUVs (collision avoidance)
- Desired formation
- Limited communication and measurements



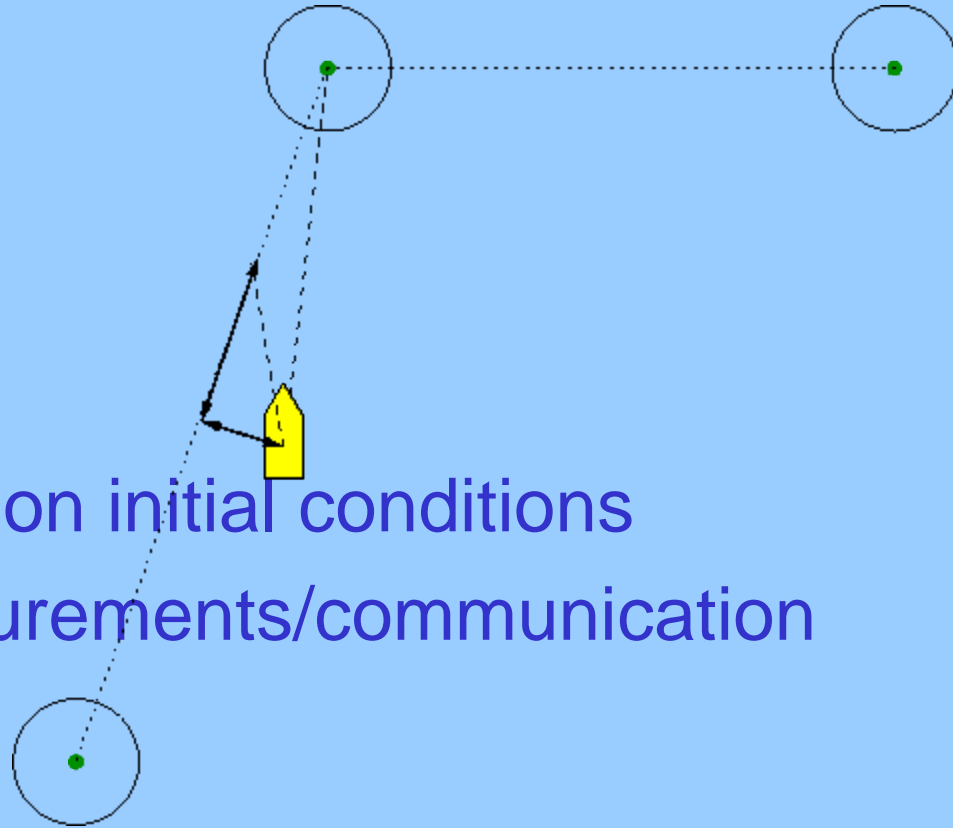
# Path Following

- **State-of-the-art:** *Guidance Methods*

- Way-Point tracking
- Line-of-Sight guidance

- **Open Problems:**

- Applicability dependant on initial conditions
- Minimise needed measurements/communication



# Path Following

- **State-of-the-art:** *Disturbance rejection*
  - Ocean currents
  - Modelling errors
  
- **Open Problems:**
  - Methods exist, but should be used in all situations
  - Cooperation might improve quality of estimates





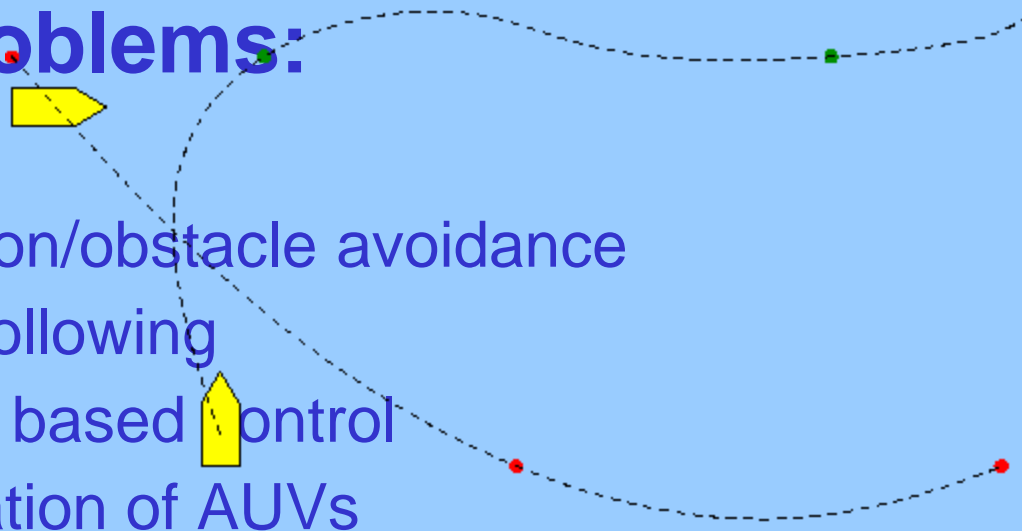
# Path Following

- **State-of-the-art:** *Collision Avoidance*
  - Single vessel
  - Vessel modelled as a mass point
  - Distinct collision/obstacle avoidance

- **Open Problems:**

Combine:

- Collision/obstacle avoidance
- Path following
- Model based control
- Formation of AUVs



# Conclusions and Future Work

**Conclusion:** Many problems have been solved separately, but need to be combined to obtain *robust cooperative control of multiple AUVs*

## Future work:

- Inter-vehicle communication, coordination and cooperation
- Path planning with collision and obstacle avoidance
- Path following with collision and obstacle avoidance
- Collaborative behaviour of AUV formations
- Robustness against currents and modelling errors



# Thank you for your attention!



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